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Effects of Electrical Muscle Stimulation on Body Composition, Muscle Strength, and Physical Appearance

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ABSTRACT

Electrical muscle stimulation devices (EMS) have been advertised to increase muscle strength, to decrease body weight and body fat, and to improve muscle firmness and tone in healthy individuals. This study sought to test those claims. Twenty-seven college-aged volunteers were assigned to either an EMS (n = 16) or control group (n = 11). The EMS group underwent stimulation 3 times per week following the manufacturer's recommendations, whereas the control group underwent concurrent sham stimulation sessions. Bilaterally, the muscles stimulated included the biceps femoris, quadriceps, biceps, triceps, and abdominals (rectus abdominus and obliques). An identical pre- and posttesting battery included measurements of body weight, body fat (via skinfolds), girths, isometric and isokinetic strength (biceps, triceps, quadriceps, hamstrings), and appearance (via photographs from the front, side, and back). EMS had no significant effect on the any of the measured parameters. Thus, claims relative to the effectiveness of EMS for the apparently healthy individual are not supported by the findings of this study.

Key Words: skinfolds, girths, muscle tone, firmness

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Introduction

Electrical muscle stimulation (EMS) has been a mainstay of physical therapy practice for many years as a method to rehabilitate muscles after an injury or surgery. In the early 1960s it was often used in an attempt to prevent the atrophy that occurs when skeletal muscle is denervated. As more sophisticated stimulation devices were developed, it became a popular treatment technique for patients that had sustained central nervous system impairment secondary to a stroke or spinal cord injury. Over the past 20 years, manufacturers have developed units with an improved ability to modulate a variety of electrical wave forms resulting in an electrical current that can be comfortably used to stimulate innervated muscles. Because of these developments, EMS has been more commonly used to promote strength gains in the lower extremity of patients who have had orthopedic surgery, particularly anterior cruciate ligament reconstructive surgery.

The improved ability of EMS units to stimulate innervated muscle has ignited interest in its use as a training technique for healthy individuals without neuromuscular pathology. The early work of Kots in the former Soviet Union suggested that EMS was more effective than exercise alone in strengthening skeletal muscle in elite athletes (5). The proposed advantage of using EMS is that the recruitment order is reversed relative to volitional exercise. During volitional activity, the central nervous system first activates the smallest alpha motoneurons. With increasing levels of required force, progressively larger motoneurons are activated. This recruitment order, dependent on the size of the alpha motoneuron, has been termed the ''size principle'' of motor unit recruitment. The size of alpha motoneurons is related to the type of muscle fiber innervated by the motoneuron. Slow oxidative (SO) muscle fiber types are typically recruited first, whereas fast glycolitic (FG) are the most difficult to recruit during volitional activation. The order of muscle fiber recruitment is reversed when the muscle is activated via electrical stimulation, with the largest-diameter muscle fibers (FG) being recruited first and the smaller-diameter (SO) muscle fibers being recruited later.

Recently, the potential benefits of EMS have been marketed to the general public as another ''get-fit-quick'' gimmick. ''Building rock-hard abs'' or ''firming the flab on your buttocks and thighs'' while working

at your computer or watching TV, without having to exercise, is an attractive lure for many people. Although several over-the-counter electrical stimulation units are being marketed to the general public, the claims supporting the benefit of EMS in the general population have never been verified. Previous investigators who have examined the benefits of EMS have typically stimulated 1 or 2 isolated muscle groups, i.e., the quadriceps femoris or the hamstrings or both. The benefits of applying EMS to the entire body to achieve a full body conditioning program have not been examined. Thus, the purpose of the current study was to determine if EMS can increase muscle strength, decrease body weight and body fat, and increase muscle firmness and tone (as the manufacturers claim) in healthy individuals using an over-the-counter EMS device marketed to the general public.

Methods

Subjects

Twenty-nine apparently healthy, college-aged volunteers served as subjects for this study. Subjects engaged in a formal exercise program during the previous 6 months were excluded from the study. Subjects were randomly assigned to either a control or EMS group. Initially, 17 subjects were in the EMS group and 12 were in the control group. More subjects were placed in the EMS group at the start of the study because we anticipated a higher drop-out rate in that group (because of the potentially uncomfortable nature of the stimulation). Over the course of the study, 1 subject dropped out of the control group (due to an injury unrelated to the study) and 1 subject dropped out of the EMS group (because of time constraints). All subjects who completed the study were paid $100.

Testing

Both groups of subjects underwent an identical battery of tests before and after the 8-week training program. The pre- and posttests included measurement of body weight, skinfolds, girths, muscle strength of the biceps, triceps, quadriceps, and hamstrings at a fixed joint angle (isometric maximal contraction) and at $60°\cdot s^{-1}$ (isokinetic maximal contraction); photographs from the front, side, and back with the subject in a standard position; and Leikert rating scales for muscle strength, firmness, and tone.

Body Weight. Body weight was measured using a standard Health-O-Meter laboratory scale.

Skinfolds and Girths. All skinfolds and girths were measured by the same examiner. Skinfold thicknesses (fat folds) were each measured 3 times at the following 10 sites on the body using Lange calipers; biceps, triceps, subscapular, pectoral, mid-axilla, iliac crest, supraspinale, abdominal, thigh, and calf. The mean of the 3 measurements for each site was used in the calculation. Percentage of body fat was estimated from the sum of 7 skinfolds (chest, mid-axilla, subscapular, triceps, abdominal, iliac crest, and thigh) as described by Pollock et al. (7).

Girth measurements (circumferences) were made at 10 sites using a spring-loaded steel tape measure. Measurement sites included the upper arm (flexed), forearm, wrist, chest, waist, hips, upper thigh, midthigh, and calf. Absolute girth measurements include both the circumference of the muscle as well as the subcutaneous fat layer. ''Corrected'' girths, which represent the circumference of the muscle and bone, were calculated using the O-scale method, whereby the fat layer is subtracted from the circumference of the respective body part (8), allowing calculation of effective lean limb girth.

Isometric and Isokinetic Strength. Isometric strength of the biceps, triceps, quadriceps, and biceps femoris on the subjects' right side was measured on a Cybex-340 dynamometer. For each exercise, 5 repetitions were performed, sampling at 100 Hz at $6°\cdot s^{-1}$. Peak torque data was corrected for gravitation torque for each of the isokinetic testing positions. The strength testing protocol measured the peak torque during concentric contractions for opposing muscle groups (biceps–triceps and quadriceps-hamstrings). The peak torque output for the maximum repetition of the 5 maximal repetitions was used in the statistical analysis.

For the biceps-triceps measurements, subjects were in the supine position with the elbow flexed to 90°. For the measurement of isometric strength, the dynamometer arm was locked in position so that no joint movement could take place. For the measurement of isokinetic maximal strength, subjects stayed in the same position and the dynamometer was set at $60°\cdot s^{-1}$ of joint movement. For the quadriceps–biceps femoris measurements, subjects were in a sitting position, with the hip flexed to 90°. Again, for the isometric and isokinetic measurements the speed on the Cybex were set at $0°\cdot s^{-1}$ and $60°\cdot s^{-1}$, respectively. For all trials, the best of the 3 trials was recorded as the subject's maximal strength.

Photographs. Subjects were photographed from the front, side, and back using a digital camera. Men were clothed in a trunk-style swimming suit and women were clothed in a 2-piece swimsuit. All photographs were reviewed and graded for firmness and tone by 1 of the researchers using a 1–10 Leikert-type scale (with 10 being highly firm and toned and 1 being least firm and toned).

Self-Perception Questionnaire. All subjects completed a 9-item questionnaire to measure their perception of their strength, muscle tone, and muscle firmness at the end of weeks 2, 4, 6, and 8. Subjects rated their agreement with each of the items (Table 1) by marking on a 10-cm line. The far left side of the line represented strong disagreement with the statement and the far right side indicated strong agreement. The distance in centimeters from the left side of the line to the subject's

Table 1. Items included in self-perception questionnaire.

1. My arms feel stronger.
2. My legs feel stronger.
3. My abdomen feels stronger.
4. My arms feel more toned and firm.
5. My legs feel more toned and firm.
6. My abdomen feels more toned and firm.
7. People have commented that my arms look more toned and firm.
8. People have commented that my legs look more toned and firm.
9. People have commented that my abdomen looks more toned and firm.

mark was measured and recorded as the score. Subjects' responses to the 3 items related to strength (arms, legs, and abdomen) were averaged to create a single strength score. The same procedure was followed for the 3 items related to muscle tone and the 3 items related to appearance.

Training

Subjects in both the EMS and control groups underwent electrical stimulation 3 times per week for 8 weeks. Before the initiation of the training program, 5 sets of lead wires, supplied by the manufacturer, were cut and repaired so that they appeared to be fully functioning leads. However, they did not transmit any electrical current. These tampered leads were used by subjects in the control group, whereas subjects in the stimulation group used the standard leads. Both groups of subjects used identical electrical stimulators, electrodes, and stimulation parameters. The only difference between the 2 groups was the type of lead used. The subjects in the control group were told that we were using an electrical current with a lower amplitude that should be less noticeable than the standard stimlation protocol.

The stimulation unit used was the Bodyshapers model BM1012BI. This unit was selected because it was representative of the quality and price of over-the-counter units typically marketed to consumers. It was also a unit that was readily available for purchase over the Internet.

The electrical stimulation unit comes equipped with reusable carbon electrodes and a single small sponge to moisten the electrodes before application. However, this method resulted in a small superficial burn under the electrode when the investigators piloted the stimulation protocol on themselves. The investigators hypothesized that simply moistening the electrode by wiping across it with a sponge resulted in a small amount of water in 1 area of the electrode. The electrical current concentrated in this area and produced the subsequent superficial burn. To minimize any dermal damage and increase the comfort of the stimulation, the investigators elected to place a damp sponge between the electrode and the skin to uniformly transmit the electrical current. Sponges were disinfected after each use. No dermal injury was noted throughout the study using this method.

All subjects attended an orientation session before initiation of the electrical stimulation training program. The proper location and application of the electrodes was demonstrated and subjects also received written instructions on how to apply the stimulation electrodes and operate the stimulator. All electrical stimulation sessions for both groups were conducted in the physical therapy department of the UW-La Crosse Student Health Center. Investigators were present to answer questions during each subject's initial stimulation session and to assure that the electrodes were applied properly and the stimulation unit was adjusted appropriately. Subsequent stimulation sessions were scheduled by the subjects at their convenience, 3 times per week for 8 weeks. All subjects completed a total of 24 stimulation sessions.

The bilateral biceps, triceps, quadriceps, hamstrings, and abdominal muscles were stimulated during each stimulation session. While piloting the stimulation protocol on themselves, the investigators also found that it was very difficult to independently apply the electrodes using the Velcro straps supplied with the stimulation unit, particularly to the biceps-triceps muscle groups and the quadriceps-hamstrings muscle groups. The investigators had Lycra sleeves custom-sewn to fit the subjects' upper arms and thigh areas. Subjects typically wore shorts and tank tops during the stimulation session. They applied the Lycra sleeve to either the upper arm or thigh and then slipped the damp sponge and electrode under the Lycra sleeve to the appropriate position on the muscle.

Because the stimulator had only 6 channels, a single training session required 2 cycles of stimulation. During the first cycle, subjects applied 3 sets of electrodes (using 3 channels) to the abdominal area and 1 set to the biceps and triceps of both arms (1 channel each). Electrode placement at each site is shown in Figures 1 and 2. Subjects then completed 10 maximal electrical contractions using 5 channels simultaneously on the stimulation unit with the following parameters: frequency of 45 pulses·s^{-1}, biphasic waveform, 10 seconds on and 35 seconds off, stimulation (vs. tapping) mode, normal (vs. alternate) mode.

Subjects were instructed to adjust the amplitude of each channel to the maximum that could be comfortably tolerated.

For the second cycle of stimulation, subjects moved the electrodes to the locations illustrated in Figures 3 and 4. One set of electrodes was placed on the quadriceps and 1 set was placed on the hamstrings of each leg (2 channels per leg). Subjects then completed the

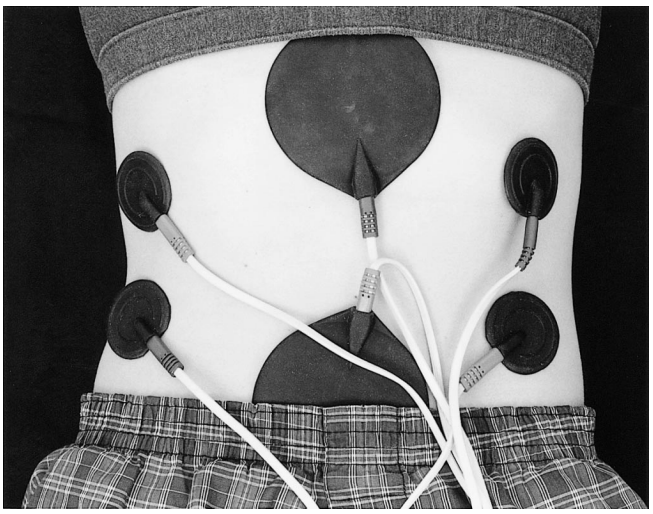

Figure 1. One pair of 1.5-in. circular electrodes was applied over the right internal and external obliques and a second pair was applied over the left internal and external obliques. Two 3.5-in. circular electrodes were applied over the rectus abdominus. These electrodes were secured with elastic straps during the stimulation protocol. The straps have been removed for the photograph.

Figure 2. One pair of 3.5-in. electrodes was used to stimulate the biceps/triceps of each arm by placing the electrode over each muscle belly.

second set of 10 maximal contractions using 4 channels on the stimulation unit simultaneously.

Subjects used the previously outlined stimulation parameters for the first 4 weeks of the study. Following the manufacturer's recommendation for increasing muscle tone, the parameters were adjusted as follows during weeks 5 and 6 of the training program: frequency increased from 45 to 110 pulses·s^{-1}, on time increased from 10 to 30 seconds, and off time decreased from 45 to 30 seconds.

During the final weeks of the training program (weeks 7 and 8), the parameters were readjusted as

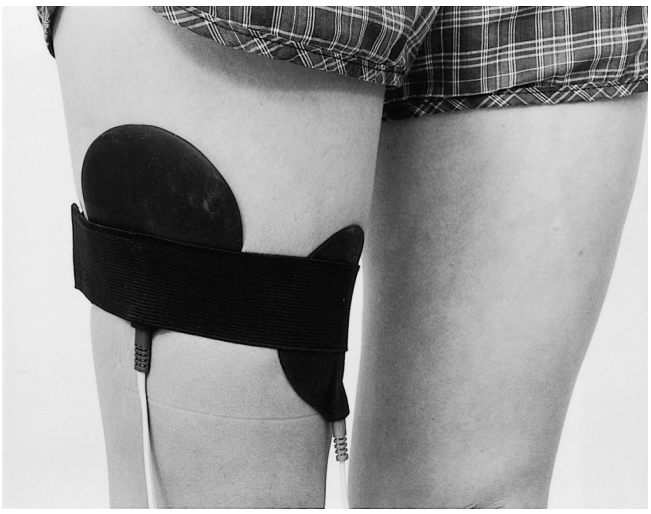

Figure 3. One 3.5-in. electrode was placed over the vastus lateralis and vastus medialis on the anterior side of each leg.

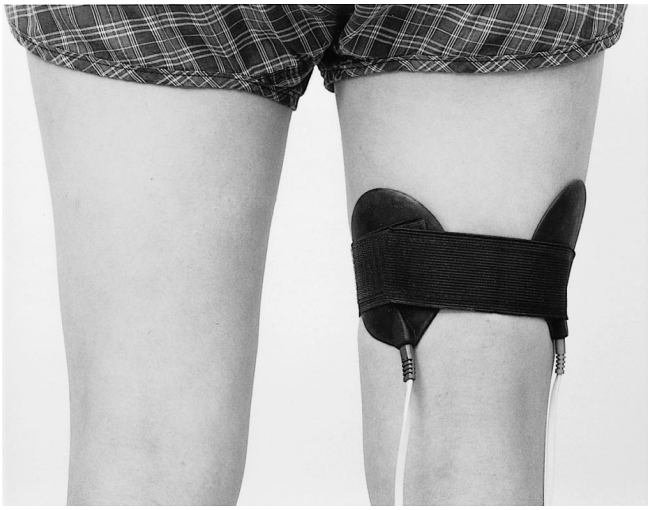

Figure 4. One 3.5-in. electrode was placed over the medial and lateral hamstrings on the posterior side of each leg.

follows: frequency further increased from 110 to 150 pulses·s^{-1}, time increased from 30 to 45 seconds, and off time further decreased from 30 to 15 seconds.

In addition, the electrically elicited maximal isometric contraction tolerated by each subject was compared with the subject's volitional maximal isometric contraction using an Orthotron dynamometer during the first and final weeks of the training program. On each of these occasions, the subjects applied the electrodes and sponges over the right vastus lateralis and medialis and connected the lead wire to the stimulator. The investigator then aligned the axis of the dynamometer with the subject's right knee and stabilized the subject on the unit in a seated position using the thigh, chest, and ankle straps. The knee was flexed to 90° and the speed was set at 0. The subject was asked to try to straighten the knee. Verbal encouragement

Table 2. Descriptive characteristics of the subjects at the beginning of the study.

N	Age (y)	Ht. (cm)	Wt. (kg)	% Body fat
Control				
Women (5)	19.4 ± 0.55	165.8 ± 3.22	60.0 ± 4.67	23.4 ± 3.99
Men (6)	20.6 ± 0.52	181.3 ± 5.25	82.3 ± 14.61	15.1 ± 7.42
Overall (11)	19.8 ± 0.54	173.3 ± 9.39	71.7 ± 15.50	18.8 ± 7.27
EMS*				
Women (9)	19.3 ± 0.71	166.2 ± 2.21	61.7 ± 7.80	22.8 ± 3.54
Men (7)	19.7 ± 1.13	184.8 ± 3.68	85.2 ± 15.97	16.1 ± 8.16
Overall (16)	19.4 ± 0.88	174.3 ± 13.56	72.8 ± 16.30	19.9 ± 6.82

* EMS = electrical muscle stimulation.

Table 3. Changes in body composition over the course of the study.

	Control		EMS*	
	Pre	Post	Pre	Post
Sum of 7 skinfolds (mm)	119.4 ± 45.77	117.6 ± 44.94	122.4 ± 46.46	123.5 ± 44.02
Body weight (kg)	71.7 ± 15.5	71.1 ± 15.90	72.8 ± 16.30	72.8 ± 16.81
% Fat	18.8 ± 7.27	18.7 ± 7.70	19.9 ± 6.69	20.1 ± 6.40
Fat weight (kg)	13.5 ± 6.53	13.3 ± 6.74	14.4 ± 7.05	14.6 ± 6.70
Lean body mass (kg)	58.2 ± 13.06	57.8 ± 13.25	58.4 ± 13.50	58.2 ± 13.39

* EMS = electrical muscle stimulation.

Table 4. Changes in girths (cm) over the course of the study.

	Control		EMS*	
	Pre	Post	Pre	Post
Arm	31.5 ± 4.05	31.2 ± 4.37	31.2 ± 4.43	31.8 ± 4.45
Arm corrected	27.4 ± 4.35	27.2 ± 4.42	26.0 ± 4.44	26.8 ± 4.28
Waist	80.4 ± 11.77	79.3 ± 10.16	78.0 ± 11.01	78.6 ± 10.58
Thigh	56.5 ± 7.05	55.0 ± 6.21	57.1 ± 5.57	56.1 ± 5.06
Thigh corrected	49.5 ± 6.60	48.2 ± 5.94	50.2 ± 6.19	49.2 ± 5.46

* EMS = electrical muscle stimulation.

was given. The best of 3 trials was recorded in newtonmeters of torque. Subjects were also asked to relax and then adjust the amplitude of the stimulation unit to the highest tolerable level. The highest torque generated during 3 electrically elicited contractions was recorded. Test order (volitional or electrically elicited) was randomized. The Orthotron could not accurately record torque output less than 40.7 n·m. Thus, values less than this level were recorded as 0.

Statistical Analyses

Comparisons between groups and from pre- to posttesting were analyzed using a 2-way analysis of variance with repeated measures. Tukey's post hoc tests were used to isolate pairwise differences when there was a significant F ratio. α was set at $p \leq 0.05$.

Results

The physical characteristics of the 11 subjects in the control group (5 women and 6 men) and the 16 subjects in the EMS group (9 women and 7 men) who completed the study are presented in Table 2. The groups were not different ($p > 0.05$) in terms of age, height, weight, or percentage of body fat at the beginning of the study.

Changes in body composition over the course of the study are summarized in Table 3. There were no significant ($p > 0.05$) changes in the sum of 7 skinfolds, body weight, percentage of body fat, fat weight, or lean body weight from pre- to posttesting in either group.

Girth data are presented in Table 4. Only girths over the muscles that were stimulated are presented, since

Table 5. Changes in skinfolds (mm) over the course of the study.

	Control		EMS*	
	Pre	Post	Pre	Post
Biceps	8.6 ± 3.65	9.1 ± 3.63	9.7 ± 4.16	10.1 ± 4.87
Triceps	16.5 ± 6.29	16.5 ± 6.99	18.3 ± 5.54	18.8 ± 6.29
Abdomen	25.2 ± 11.50	24.9 ± 10.08	24.3 ± 12.85	24.9 ± 11.88
Thigh	23.4 ± 10.08	22.5 ± 9.29	22.3 ± 7.71	22.6 ± 8.50

* EMS = electrical muscle stimulation.

no change would be expected in the nonstimulated areas. There were no statistically significant ($p > 0.05$) changes in arm, waist, or thigh girths in either group over the course of the study. The corrected arm and thigh girths purportedly estimate the circumference of the muscle and bone in those areas. There were no significant ($p > 0.05$) changes in corrected arm or thigh girths over the course of the study in either group.

Changes in the skinfold data are summarized in Table 5. Again, only the skinfolds over the stimulated muscles are presented. There were no significant ($p > 0.05$) differences in the biceps, triceps, abdominal, or thigh skinfolds over the course of the study in either group.

Changes in isometric and isokinetic strength over the course of the study are presented in Table 6. There were significant ($p < 0.05$) changes from pre- to posttesting in both groups for several of the measures; however, there were no significant ($p > 0.05$) differences between groups. For instance, the isometric strength of the biceps decreased in both groups from pre- to posttesting, whereas there was a slight increase in biceps and triceps isokinetic strength measured at $60°{\cdot}s^{-1}$ in both groups over the course of the study. The clinical significance of these changes is negligible and is probably unrelated to the stimulation, since both groups (EMS and control) changed in the same direction.

The photograph evaluation data are presented in Table 7. On a scale of 1 to 10, subjects were generally in the range of 6, indicating that they were not very toned or firm and had room for improvement. However, there were no significant ($p > 0.05$) changes in the appearance of firmness or tone in either group from pre- to posttesting.

The results of the questionnaires completed by the subjects at the end of the second, fourth, sixth, and eighth week of the study are presented in Table 8. All of the scores for the EMS group were significantly ($p < 0.05$) higher than for the control group. There were no significant ($p > 0.05$) changes for either group over the course of the study.

Discussion

There were no significant changes in any of the measured parameters after 8 weeks of EMS. There are

Table 6. Changes in isometric and isokinetic strength (N·m) over the course of the study.

	Control		EMS†	
	Pre	Post	Pre	Post
Biceps				
Isometric	67.1 ± 23.65	62.9 ± 22.67*	61.8 ± 23.88	58.0 ± 20.26*
$60\%{\cdot}s^{-1}$	45.2 ± 16.73	46.9 ± 15.59*	46.6 ± 19.16	49.4 ± 19.63*
Triceps				
Isometric	50.3 ± 20.07	49.2 ± 14.22	51.4 ± 23.50	49.9 ± 28.34
$60\%{\cdot}s^{-1}$	40.8 ± 12.80	44.2 ± 12.26*	42.6 ± 16.49	46.6 ± 21.04*
Quadriceps				
Isometric	202.2 ± 62.08	209.8 ± 55.11	193.9 ± 51.86	191.2 ± 66.18
$60\%{\cdot}s^{-1}$	186.4 ± 50.80	190.9 ± 37.79	176.1 ± 60.78	182.4 ± 60.51
Hamstrings				
Isometric	117.0 ± 34.51	116.5 ± 31.96	120.3 ± 45.73	117.6 ± 42.64
$60\%{\cdot}s^{-1}$	111.7 ± 45.95	112.0 ± 41.54	109.6 ± 44.99	117.1 ± 40.57

† EMS = electrical muscle stimulation.
* Significantly different from Pre ($p < 0.05$).

Table 7. Changes in appearance (via photographs) over the course of the study.

	Control		EMS*	
	Pre	Post	Pre	Post
Front	6.0 ± 0.94	6.0 ± 0.82	6.5 ± 0.97	6.1 ± 0.93
Side	6.8 ± 0.92	6.6 ± 0.84	6.8 ± 1.18	6.9 ± 1.09
Back	6.4 ± 0.84	5.9 ± 0.57	6.8 ± 1.57	6.5 ± 1.32
Composite	6.4 ± 0.81	6.2 ± 0.61	6.7 ± 1.19	6.5 ± 1.00

* EMS = electrical muscle stimulation.

probably several reasons for this finding. First, to achieve an increase in contractile strength, a muscle needs to be stimulated above a critical threshold. This threshold can be as low as 30% of maximal voluntary contraction (MVC) in deconditioned individuals, but must be in the range of 60–80% of MVC in highly conditioned athletes (6). After a series of studies to determine the minimum threshold required to achieve improvements in strength, Currier and colleagues concluded that the electrically induced contraction must be least 60% MVC (2, 3, 9). When the strength of the electrically elicited contraction in the current study was measured on the Orthotron, the resultant force was less than 20% of the volitional MVC. This level of contraction is well below the critical threshold necessary to increase the strength of the muscle in an apparently healthy population.

A second factor was the poor quality of the stimulators used. The units did not have the ability to alter the phase duration of the pulsed waveform. They delivered a stimulus with a relatively long pulse duration, making the stimulation quite uncomfortable. In addition, most commercially available medical-grade stimulators have a ramp function that allows the amplitude to gradually increase each time the unit cycles on, thus increasing the comfort of the electrical stimulation. The long phase duration coupled with the lack of a ramp function may not have allowed the subjects to increase the amplitude of the stimulation to the critical threshold required to achieve a strong motor contraction.

The order of muscle fiber recruitment is reversed during EMS relative to volitional contraction; thus, the very fatigable FG fibers are preferentially recruited (10). In addition, there is synchronous activation of all axons of the same size and relative distance from the electrode (1). Relative to volitional contractions, electrically induced contractions lead to much greater muscle fiber fatigue due to the selective recruitment of fatigable muscle fibers in combination with the synchronous activation of the same muscle fibers over and over again. Thus, muscle strengthening protocols utilizing EMS are typically designed to minimize fatigue. The first way of minimizing fatigue is to allow a sufficient period for the muscle fibers to recover after each contraction. This is frequently accomplished by using on:off ratios of about 1:5. (1). However, the stimulators used in the current study only allowed for relatively short off periods. The on:off ratio utilized at the beginning of the study was only 1:3.5. The short off period most likely did not give the muscle sufficient time to recover between contractions, therefore contributing to a quick fatigue of the muscle.

The other factor to consider when attempting to minimize the muscle fatigue during EMS strengthening protocols is stimulation frequency. Muscle fatigue increases as the stimulation frequency increases (4). Most strengthening protocols suggest using a frequency high enough to achieve a tetanic contraction but low enough to minimize muscle fatigue (1). Typically this is achieved using frequencies between 50 and 75 pulses·s^{-1}. Although the rate control knob indicated that the stimulators were capable of delivering electrical pulses at frequencies varying from 40 to 150 pulses·s^{-1}, data from an oscilloscope indicated that these units could only deliver electrical pulses at frequencies ranging from 90 to 151 pulses·s^{-1} when using the biphasic waveform. Thus, at the beginning of the training study, subjects were actually receiving stimulation at a frequency of 90 pulses·s^{-1}, even though the rate con-

Table 8. Perceived changes in strength and muscle firmness/tone over the course of the study.†

	Control				EMS‡			
	Week 2	Week 4	Week 6	Week 8	Week 2	Week 4	Week 6	Week 8
Strength	1.2 ± 1.25	1.0 ± 0.98	0.96 ± 0.51	1.0 ± 1.11	3.9 ± 2.08*	4.0 ± 2.01*	3.9 ± 2.14*	4.1 ± 2.21*
Tone	1.2 ± 1.40	1.2 ± 1.32	1.0 ± 1.26	1.2 ± 1.03	4.2 ± 2.13*	4.0 ± 1.77*	4.0 ± 2.14*	4.3 ± 2.14*
Others	0.39 ± 0.57	0.36 ± 0.40	0.42 ± 0.36	0.48 ± 0.35	3.2 ± 2.37*	3.0 ± 2.59*	3.0 ± 2.94*	3.2 ± 3.04*

† Scores represent responses ($\bar{x}$ ± SD) to the following statements:
Strength = My arms, legs, abdomen feel stronger.
Tone = My arms, legs, abdomen, feel more toned and firm.
Others = People have commented that my arms, legs, abdomen look more toned and firm.
‡ EMS = electrical muscle stimulation.
* Significantly different from control ($p < 0.05$).

trol knob indicated that the frequency was only 45 pulses·s^{-1}. This very high stimulation frequency in combination with the short rest period between contractions led to extreme fatigue of the stimulated muscle fibers and may have accounted for the failure to achieve any increases in muscle strength after EMS. In addition, increasing the frequency parameter during the training study (to increase the endurance of the stimulated muscle) most likely had little effect.

Other factors to consider when using EMS to achieve strength changes in an apparently healthy population are the logistics involved in stimulating a large number of different muscle groups. Stimulation sessions in the current study averaged 45 minutes per session. Most of the subjects anecdotally said that they would rather go to the gym and lift weights for that period of time as opposed to going through the EMS training. Additionally, applying the electrodes to the different body parts was problematic and frustrating using the Velcro straps provided with the stimulators. To make the application of electrodes more user friendly, we had Lycra sleeves fabricated to facilitate the application of the electrodes. Subjects applied the sleeves and then slipped the electrode/sponge combination under the sleeve to the appropriate position over the muscle belly. These sleeves would not be provided to the average consumer who purchased a unit, and the resulting application of electrodes would be very cumbersome and frustrating.

The marketing campaigns for many over-the-counter electrical stimulation units are focused on the desire of individuals to improve their physical appearance. The idea of obtaining firmed, toned muscles while working on a computer or driving a car is appealing. The scores for the EMS group were slightly higher in the areas of perceived strength, perceived muscle tone and firmness, and perceived appearance. This finding most likely reflects the fact that the EMS group could actually feel some muscle contraction during the training sessions, whereas the control group (who were getting no electrical current whatsoever) felt nothing at all. It should be noted that the responses of the subjects in the EMS group did not change over the course of the study. These results suggest that healthy individuals using stimulation unit fail to note progressive improvements in muscle tone, muscle firmness, or their physical appearance.

One final thought is that we chose a stimulator that we felt represented a typical over-the-counter quality product. As can be seen, it fell far short of what would be expected of a medical-grade stimulator. Health-care providers purchasing medical-grade stimulators typically select units that have been approved by national testing laboratories such as the Underwriters' Laboratories or the Electronic Testing Laboratories. Approval by these laboratories assures the consumer that the electrical stimulator has passed a series of standard tests. Stimulators marketed over the counter are not advertised for medical purposes and may not meet these rigid standards. It would be interesting to see if other stimulators that are marketed to the apparently healthy consumer perform as poorly as the units tested in this study.

Practical Applications

Companies claim that EMS is an easy and painless method for improving muscle strength, body composition, and appearance. These claims were unsubstantiated in the current study. Several factors, including the poor quality of the stimulator itself, probably combined to produce the results seen in this study. Subjects tolerated EMS amplitudes that produced discomfort but still were not able to achieve a muscular contraction of sufficient intensity to induce strength gains. Additionally, although manufacturers claim that workouts can be conducted quickly, workouts in the current study averaged 45 minutes in duration. Workouts using units with fewer stimulation channels would take even longer. Thus, EMS used under the conditions studied here does not appear to be a pain-free, quick method to increase muscular strength and is not recommended for the apparently healthy consumer.

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