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Supplemental EMS and Dynamic Weight Training: Effects on Knee Extensor Strength and Vertical Jump of Female College Track & Field Athletes

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ABSTRACT

The purpose of this 6-wk study was to determine the effects of dynamic contractions supplemented with electromyostimulation (EMS) employed during a weight lifting exercise on knee extensor strength and vertical jump performance. Twenty female college track & field athletes were randomly assigned to 1 of 4 groups: non-weight-training/non-EMS (Control); weight-training-only (Wgt); EMS-only (Stim); and weight training + EMS (Wgt + Stim). All groups were pre- and posttested for knee extensor strength (1-RM) and vertical jump height (cm) using the bilateral knee extension exercise and countermovement vertical jump (VJ). The Wgt and Wgt + Stim groups trained 3 times a week at 85% of their 1-RM employing 3 sets of 8–10 reps; the Stim received EMS 3 times a week. Strength and VJ increased for all 4 groups. The 3 experimental groups differed significantly ($p < 0.05$) from Controls for both strength and VJ. Also, Wgt + Stim differed significantly from Wgt and Stim, while Wgt differed significantly only from Stim. These results suggest that supplementing dynamic contractions with EMS appears more effective than EMS only, or weight training only, for increasing knee extensor strength and VJ in female track & field athletes.

Key Words: electrical stimulation, resistance training, functional performance

Introduction

Transcutaneous electromyostimulation (EMS) has been used in conjunction with various forms of weight training to improve muscle strength in athletes (3, 4, 32, 34, 35), though its translatory effect on dynamic, functional performance has not been well studied. Rather than using EMS as a supplement to the dynamic, voluntarily-evoked muscular contractions involved in weight training, the majority of EMS research has involved weight training programs employing isometric or dynamic contractions that were EMS-induced (3, 4, 16, 17, 27, 28). Although it has been shown (35) that the application of EMS during the ascent phase of the squat exercise produced increases in squat strength and vertical jump performance, the increases were no different than those seen with weight training without EMS.

With the exception of our previous work (34), it seems no other study has actually used EMS as a supplement during both the voluntarily evoked concentric and eccentric phases of a dynamic weight training exercise that athletes normally employ during their strength and conditioning program. However, in our previous study (34) we made no attempt to determine to what extent this strength increase carried over to the dynamic, functional performance of a sport-specific activity.

In light of continued interest in using EMS as a way to increase strength and possibly athletic performance, further research on the application of EMS using protocols that are more specific to the muscles used during sports is warranted. Thus the purpose of this study was to determine the effects of supplementing dynamic contractions (both concentric and eccentric phases) with EMS employed during a weight lifting exercise on the knee extensor strength and vertical jump of female college athletes.

Methods

Subjects and Procedures

The subjects in this study were 20 healthy female college track & field athletes, age 20 ± 1.09 yrs, Ht 165.86 ± 6.55 cm, Wt 57.72 ± 7.87 kg. All were familiar with resistance training and the specific training exercise, but had not engaged in any structured weight training for approx. 6 months (±1.5 mos; range = 5–8 mos). The study was conducted in September and October, prior to their competitive spring track & field season while the athletes were involved in a general conditioning program 3 times a week consisting of flexibility, calisthenics, and low-intensity endurance running (2–3 miles) at their own pace. Throughout the study, the only lower body weight training they engaged in was the one involved in the study. Prior to the study, all subjects signed informed consent, agreed to limit their lower body weight training activity to the training sessions, and agreed to make up any missed sessions.

Subjects were randomly assigned to 1 of 4 groups, 5 subjects per group. The groups were designated as: non-weight-training/non-EMS control (Control), weight-training-only (Wgt), EMS-only (Stim), and weight-training + EMS (Wgt + Stim).

Exercise Testing

Knee Extensor Strength. Prior to the 6-wk training period, all groups were subjected to an initial pretesting session (T1) in which each subject's one repetition maximum (1-RM) was determined using the bilateral knee extension exercise (Universal, Cedar Rapids, IA). This exercise was chosen because the technique is easy to perform and it is a single-joint exercise that involves the isolation of the primary agonist, the quadriceps muscle group. Also, with the exception of the vastus intermedius, this muscle group is relatively easy to palpate and isolate with EMS electrodes. Each subject's absolute strength 1-RM (kg) was divided by her body weight (kg) to ascertain a relative measure of strength. Relative strength was used as a criterion variable because it corrects for variation in body weight among subjects, thereby providing a more accurate estimate of strength (1, 11, 34).

The electrical stimulation protocol was based on the guidelines set forth in our previous investigation (34). Muscles were stimulated at a frequency of 2,500 Hz using a Dynatron 500 (Dynatronics, Salt Lake City). Amplitude was modulated using a 50-Hz sinusoidal waveform with the burst duration of 0.1 msec and the interburst interval of 19.9 msec (50 bursts/sec) (14, 17). The placement of flexible rubber electrodes (100 cm^2 each) on each leg was based on previously established guidelines (32), but modified so that one electrode was placed medially on the midportion of the belly of the vastus medialis. The other was placed at the midportion of the lateral belly of the rectus femoris and medial belly of the vastus lateralis, overlapping the line of demarcation between the two muscles by 5 cm to ensure adequate stimulation of both.

Prior to the pretest, a goniometer was aligned parallel to and over the lateral midline of the femur and tibia with the axis positioned approximately over the lateral condyle of the femur of each subject to evaluate range of motion (ROM) of the knee joint during the knee extension exercise. In all subjects, the ROM that the knee extension machine would allow was approximately 110°. In order to standardize exercise technique during testing and training, each repetition was monitored to ensure that each subject performed all repetitions at approximately 100% of the allowed ROM.

Vertical Jump. The countermovement vertical jump (VJ)—a standing vertical wall jump in which each subject was allowed to flex the hip, knee, and ankle (referred to as the prestretch) before jumping vertically—was performed at each testing session as an indicator of dynamic, functional performance. To standardize jump technique and control the countermovement depth between subjects, each subject squatted until the tops of her thighs were parallel to the floor prior to the vertical jumping phase of all jumps. All jumps were recorded to the nearest 0.5 cm. Also, the VJ was done as a continuous movement with no observable pause between downward and upward phases. No instructions were given as to the descent speed of the countermovement, and subjects were allowed to use an armswing during the jumps (32).

The VJ was chosen because it involves coordinated movements specific to many sport activities and also requires a significant contribution from the quadriceps muscles (the ones targeted for EMS). It has been estimated that the knee extensors contribute approximately 50% to the work done during the VJ (12).

Exercise Training

Using the bilateral knee extension exercise 3 times a week during the 6-wk training period, each subject in Wgt and Wgt + Stim trained at 85% of her 1-RM employing 3 sets of 8–10 reps (3 × 8–10), with a 3-min rest between sets (33, 34). The strength levels of all 4 groups were tested biweekly (T2 and T3) and adjustments were made so both weight training groups could continue to train at 85% of their 1-RM. This training protocol was selected based on results from our previous investigation (34), and because it has also been shown to provide an adequate stimulus to elicit strength gains (33). At the end of the 6-wk training period, all 4 groups were posttested (T4) using the same procedures as for the pretest.

During each training session the Wgt group performed the training exercise without the use of EMS. However, the Wgt + Stim group received electrical stimulation continuously during the concentric and eccentric phases of the dynamic contraction, as outlined previously (34). Each set was performed once the intensity of the stimulation was increased until the subject experienced involuntary contractions that evoked extension of the knees. The intensity of the stimulation prior to each set throughout the study was recorded to determine if each subject was being conditioned and better able to withstand greater intensity of stimulation. Repetitions were then performed repeatedly without a pause between. The duration of each set was timed (nearest 0.05 sec) for each subject in the Wgt + Stim group every training day. The average amount of time it took Wgt + Stim to complete each set was used as a baseline control duration to administer EMS to the Stim group for each training session (34).

The Stim group received electrical stimulation continuously for 3 sets with the same amount of time it took Wgt + Stim to complete each set (mean = 25 sec ±

Table 1
Physical Characteristics at T1 and Track & Field Events for Subjects in Each Group

Subject & Group	Age (yrs)	Hgt (cm)	Wgt (kg)	Event*
Control				
1	21	154	70	Shot/Discus
2	22	175	52	Distance
3	21	162	50	Distance
4	19	167	56	Sprints
5	20	170	63	Hurdles
M	20.60	166.12	58.64	
SD	1.14	7.72	8.41	
Stim				
6	21	154	46	Distance
7	21	160	55	Middle-distance
8	21	167	59	Hurdles
9	20	170	55	Hurdles
10	19	165	75	Shot/Discus
M	20.40	163.58	58.52	
SD	0.89	6.12	10.56	
Wgt				
11	23	162	49	Sprints
12	21	162	59	Hurdles
13	21	165	61	Distance
14	19	162	61	Middle-distance
15	21	170	48	Shot/Discus
M	21.00	164.59	55.81	
SD	1.41	3.30	6.51	
Wgt & Stim				
16	21	170	70	Heptathlon
17	20	172	53	Sprints
18	20	180	60	Hurdles
19	19	165	50	Distance
20	19	157	53	Shot/Discus
M	19.80	169.34	57.90	
SD	0.84	8.53	7.94	

*Sprints = 100 & 200-m; Middle-distance = 400 & 800-m; Distance = 1,600+; Hurdles = 100 & 400-m.

Table 2
Group Means (±*SD*) for Absolute Strength and Body Weight (kg) at Each Testing Session

	Control	Stim	Wgt	Wgt + Stim	$p < 0.05$
Absolute Strength (kg)					
T1 Pretest	73.48	70.07	78.09	71.94	
	±20.08	±18.87	±24.96	±11.28	
T2 Week 2	75.04	81.31	90.90	78.78	S>C,W>C, W+S>C,W>S, W>W+S
	±17.12	±19.50	±23.99	±11.65	
T3 Week 4	78.68	85.45	103.64	93.18	S>C,W>C, W+S>C,W>S, W>W+S
	±20.56	±18.36	±18.50	±19.60	
T4 Posttest	81.06	92.22	110.23	120.67	S>C,W>C, W+S>C,W>S, W+S>S,W+S>W
	±15.18	±16.74	±19.90	±13.58	
Body Weight (kg)					
T1 Pretest	58.64	58.52	55.81	57.90	
	±8.41	±10.56	±6.51	±7.94	
T2 Week 2	59.04	64.31	58.90	61.78	
	±10.12	±15.50	±13.99	±11.65	
T3 Week 4	60.68	64.45	61.64	60.18	
	±10.56	±18.36	±13.50	±12.60	
T4 Posttest	61.06	65.22	63.23	62.67	
	±11.18	±16.74	±14.90	±13.58	

Note. Pretest = Week 0, Posttest = Week 6.

1.67). Each subject was positioned on the knee extension machine with her knees passively flexed during the treatment. Each set of electrical stimulation was performed once the intensity of the stimulation was increased until the subject experienced involuntary contractions that evoked knee extension. Again, intensity of stimulation was recorded for each subject.

Statistical Analysis

The relative effectiveness of the three interventions vs. the control condition was evaluated by a 4 × 4 (group × test) two-way ANOVA for each dependent variable (relative strength, absolute strength, vertical jump). The percent change from T1 to T4 for relative strength and vertical jump, intensity of stimulation, relative training resistance, and body weight were analyzed with separate one-way ANOVAs. Significant interactions and main effects were followed up with the Neuman-Keuls post hoc test where appropriate. Correlations between relative strength and vertical jump were determined via the Pearson product moment correlation coefficient. An alpha level of 0.05 was adopted throughout.

Results

Physical characteristics and track & field events for each subject are shown in Table 1. Groups means and standard deviations for body weight and absolute strength are listed in Table 2. Relative strength and vertical jump are presented in Figures 1 and 2, respectively. Percent changes from T1 to T4 for relative strength and vertical jump are presented in Figure 3.

Body Weight and Strength

In spite of the weight training program, body weights neither significantly increased nor decreased, $F(3, 18) = 1.02, p > 0.05$, during the study (Table 2). However, with respect to *absolute* strength (Table 2), an overall significant group × time interaction was found, $F(3, 18) = 8.62$, $p = 0.0001$. Post hoc analyses showed no significant differences at T1, suggesting that the 4 groups were not significantly different when the study began. At T2, the 3 experimental groups were all significantly different from the Control group. Also Wgt differed significantly from both Stim and Wgt + Stim. At T3 and T4, the 3 experimental groups again were all significantly differ-

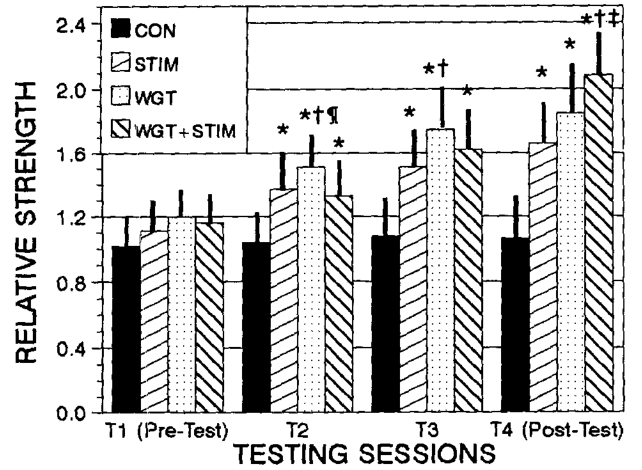

Figure 1. Relative strength means for each group at the 4 testing sessions. Significant differences, $p < 0.05$: *from Control; †from Stim; ‡from Wgt; ¶from Wgt + Stim.

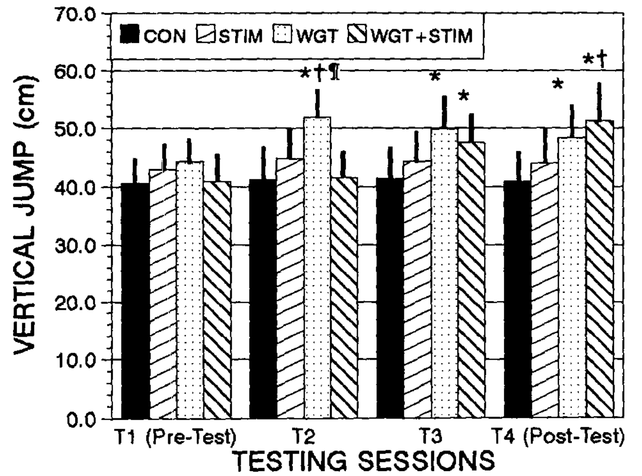

Figure 2. Vertical jump means for each group at the 4 testing sessions. Significant differences, $p < 0.05$: *from Control; †from Stim; ¶from Wgt + Stim.

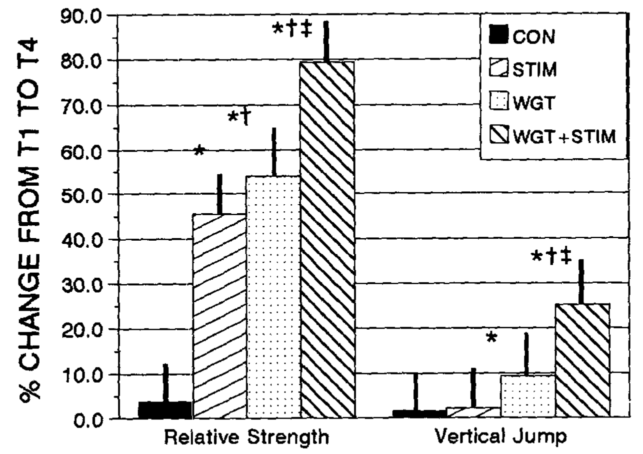

Figure 3. Percent increases in relative strength and vertical jump from T1 (pretest) to T4 (posttest) for all 4 groups. Significant differences, $p < 0.05$: *from Control; †from Stim; ‡from Wgt.

ent from Control, although Wgt was significantly different from both Stim and Wgt + Stim. However, at T4 the opposite effect occurred, with Wgt + Stim making strength improvements that differed significantly from Wgt.

With respect to *relative* strength (Figure 1), an overall significant group × time interaction was found, $F(3, 18) = 6.83$, $p = 0.0001$. Post hoc analyses showed no significant differences at T1, suggesting again that the 4 groups were not significantly different when the study began. At T2, the 3 experimental groups again were all significantly different from Control. Also Wgt differed significantly from both Stim and Wgt + Stim. For T3 and T4, the 3 experimental groups were all significantly different from Control, although Wgt was significantly different from both Stim and Wgt + Stim. However, at T4 the opposite effect again occurred, with Wgt + Stim making strength improvements that differed significantly from Wgt.

For percent changes between T1 and T4 (Figure 3), the relative increases in the ratios differed among the 4 groups. The experimental protocol produced increases for Control, Stim, Wgt, and Wgt + Stim of 3.92% ±0.73, 45.61% ±4.12, 54.16% ±3.76, and 79.54% ±4.98, respectively. Results showed that Wgt + Stim differed significantly from Control, Stim, and Wgt. Also, Wgt differed significantly from Control and Stim, while Stim differed only from Control.

Vertical Jump

With respect to the measure of vertical jump (Figure 2), an overall significant group × time interaction was found, $F(3, 18) = 2.43$, $p = 0.0184$. Post hoc analyses showed no significant differences at T1, suggesting that the 4 groups were not significantly different when the study began. For T2, Control, Stim, and Wgt + Stim were all statistically equal but significantly less than Wgt. The only differences observed at T3 were that Wgt and Wgt + Stim were both significantly different from Control. At T4, however, Wgt was significantly different from Control only, while Wgt + Stim differed significantly from Control and Stim.

For percent changes between T1 and T4 (Figure 3), the increases in vertical jump differed among all 4 groups. The experimental protocol produced increases for Control, Stim, Wgt, and Wgt + Stim of 0.74% ±0.47, 2.33% ±1.04, 9.54% ±1.73, and 25.18% ±4.28. Results showed that Wgt + Stim was significantly different from the other 3 groups. Also, Wgt was significantly different from Control but not from Stim, while Stim was only different from Control.

Other Measures

For intensity of stimulation, subjects in both Stim and Wgt + Stim showed a trend toward withstanding greater intensity of stimulation between sets and throughout the study. However, this increase was not significantly different during or between training sessions.

For relative training resistance, it was shown that subjects in both Wgt and Wgt + Stim increased their relative training resistance throughout the study; however, at no point were the relative training resistances between the two groups—as determined from the 1-RM assessment at strength tests T1, T2, and T3—significantly different from one another.

Significant correlations of 0.57 and 0.63 were found between relative strength and vertical jump in the Wgt and Wgt + Stim groups, respectively.

Discussion

The efficacy of EMS to increase strength is based on the assumption that the output of voluntary neuromuscular excitation is insufficient and requires supplementation by artificial means (7). Thus, EMS may possibly increase the recruitment of high-threshold motor units (6) of the muscle that is stimulated and thereby induce greater adaptive responses (4). This line of reasoning is based on the premise that a normal maximal voluntary contraction (MVC) has a force deficit—which is the inability to maximally recruit all available motor units—with 10–40% of all available motor units either submaximally recruited or electrically silent (28). Therefore, as Kots and Chwilon (14) have hypothesized, an EMS-induced contraction would correct this force deficit by achieving a maximal motor unit recruitment, and this would allow for greater force production strength improvement. The results of the present study seem to support Kots and Chwilon's hypothesis by showing that supplementing a dynamic weight training exercise with EMS produced significant increases in knee extensor strength.

The effectiveness of supplementing strength training with EMS is based on the concept that fast-twitch fibers, which are difficult to activate during maximal voluntary isometric efforts, are preferentially stimulated (4, 5, 29). It has been demonstrated that the acute administration of EMS results in the larger, high-threshold motor units showing a lower threshold of electrical excitability (18, 30). This apparently occurs as a result of a lower resistance and increased firing rate offered by larger motor units (18). Therefore, the use of EMS may activate the largest motor units at the lowest stimulation level (6). Since the application of EMS to the muscle bypasses the nervous generation of the excitation, the larger motor units, particularly fast-twitch Type IIb, receive a larger training stimulus than they would under voluntary conditions (8, 20).

It is known that as the force of voluntary isometric effort is progressively increased, motor units are recruited in a precise, orderly manner (10, 29) from smallest to largest (size principle). However, when motor units are activated by EMS, the opposite situation (largest to smallest) occurs (9). Therefore, EMS may provide the ability to activate the fast-twitch motor units that are not recruited during high-intensity, dynamic weight training. As a result, strength gains that occur from supplementing weight training with EMS may be a result of the continued activation of the fast-twitch motor units. However, it appears there is no evidence to indicate that the chronic administration of EMS (i.e., during a 6-wk period) in conjunction with dynamic weight training can lower the threshold of fast-twitch motor units.

There is also evidence to suggest, however, that EMS does not preferentially activate fast-twitch fibers but instead activates slower motor units (13), indicating that motor unit activation by EMS does not occur in reverse of the normal recruitment order. Regardless of recruitment order, the questions remain as to whether gains in maximum strength due to supplementing dynamic muscle contractions with EMS are actually useful (a) in maximal activities without EMS since there is evidence of an inability to voluntarily recruit motor units that are considered recruitable only with EMS (28), or (b) in submaximal activities.

Rather than combining EMS with dynamic, voluntarily evoked contractions to strengthen muscles, most research has indicated that isometric or isokinetic strength changes seen after EMS-induced contraction training are no greater than after conventional training (3, 5, 14, 16, 27, 32). Various investigations have used EMS to facilitate strength gains and assess the magnitude of strength improvement after training sessions with EMS alone (24, 25) or in conjunction with voluntary isometric contractions (4, 14, 27). Others have evaluated the relationship between EMS characteristics and force production capability of a voluntary isometric contraction with a superimposed EMS-induced contraction (23).

It has been shown (35) that supplementing the ascent phase of the squat exercise with EMS was effective in improving the associated knee extensor strength specific for that exercise and also for the vertical jump; however, these increases were no greater than those observed in squatting without EMS. With the exception of Kots and Chwilon (14), who found that EMS-induced contractions resulted in 30–40% greater strength than training without EMS, the general conclusion to emerge from the most of these studies is that any gains associated with EMS are similar to, but not greater than, those that can be achieved with normal voluntary training (7).

There is evidence suggesting otherwise, that supplementing both the voluntarily evoked concentric and eccentric phases of dynamic contractions with EMS seems to have a significant impact for improving muscular strength (34). In the present study, after 6 weeks of training, elbow flexor strength was significantly increased 26% in the Wgt + Stim group as compared to 20 and 16% for the Wgt and Stim groups, respectively.

In agreement with our previous results, the present study suggests a similar scenario, that supplementing dynamic weight training with EMS seems to significantly increase knee extensor strength. Even though the present results showed no significant differences between the relative training weights of Wgt and Wgt + Stim, there was a strength increase of 79% for Wgt + Stim vs. 54% for Wgt and 45% for Stim. The reason for the large strength increase for Wgt + Stim could be due to EMS prolonging the neural factors known to contribute to strength gains in the first few weeks of a weight training program (19). Therefore, supplementing the knee extensors with EMS during the bilateral knee extension exercise likely provided the necessary impetus with which strength was increased beyond the increase seen with Wgt.

Interestingly, the present study also showed a significant increase in vertical jump of 25% for Wgt + Stim vs. 9% for Wgt and 2% for Stim. The significant correlation between the increases in strength and vertical jump suggests that this type of training protocol may also improve this specific dynamic, functional performance parameter. Several studies have investigated the effects of EMS-induced muscle contractions on vertical jump but found it had no significant effects on jump height (32, 35).

In the present study, the improvement of vertical jump concomitant with increased knee extensor strength as a result of EMS supplementation suggests a possible translatory effect. In other words, supplementing dynamic contractions with EMS produced strength increases that may have been directly related to improved functional performance. Since it has been estimated that the knee extensors contribute approximately 50% to a vertical jump (12), it could be assumed that strengthening the knee extensors might improve VJ performance. This merits consideration since strength increases are normally assumed to be associated with improvements in functional performance.

The physiological mechanisms by which the knee extensor strength increases as a result of supplementing dynamic weight training exercises with EMS are not completely understood. The interesting aspect from the present study and our previous work (34) is that supplementing both concentric and eccentric phases of a respective weight training exercise seems to provide the impetus needed to increase strength. Even though the weight training exercises were different, we have shown the same trend of improvements in the elbow flexors of men and the knee extensors of women when compared to training with EMS only, weight training without EMS, and in studies involving EMS-induced isometric contractions (2, 4, 23, 28, 31, 32).

Another interesting comparison can be drawn between our work and that of Wolf et al. (35), who showed that supplementing the ascent phase of the squat (concentric phase for the knee extensors) produced increases in strength and vertical jump that were no different than squat training without EMS. Even though we have not used the squat exercise in our work, the increases in strength in our studies could be due to EMS supplementation during the eccentric component of the exercises. While the large fast-twitch motor units may be difficult to activate during isometric efforts, they appear to be preferentially recruited during voluntary eccentric actions (21, 22, 26). Thus it is not difficult to envision their repeated use during the high force repetitions of a weight training exercise involving both eccentric and concentric muscle actions (6).

During the concentric phase of an exercise, motor units are recruited and remain active until approximately 85% of maximum force (15), at which point the force declines. Thus as the force is reduced, motor units are sequentially inactivated or derecruited (8), which increases the amount of tension per muscle fiber.

Derecruitment continues into the eccentric phase of the exercise, and since voluntary eccentric contractions (21, 22, 26) and EMS (4, 5, 29) appear to preferentially activate larger fast-twitch motor units, these motor units could possibly remain activated throughout the eccentric phase while the smaller motor units become inactivated. Therefore, the tension per muscle fiber ratio may be the net result of the amount of fast-twitch motor units that remain active in relation to the amount of slow-twitch (or fast-twitch not affected by the EMS) that become deactivated.

To better understand this assumption in relation to increasing muscle strength, more research needs to be conducted that compares EMS supplementation during the concentric and eccentric phases only, in addition to supplementation in both phases of the weight training exercise. The results of the present study imply that dynamic contractions supplemented with EMS when the muscle is stimulated during both concentric and eccentric phases produce greater strength gains than training with weights or EMS alone. The present results also imply that the increases in knee extensor strength as a result of this particular training protocol are effective for improving a dynamic, functional performance parameter such as the vertical jump.

Practical Applications

Most movements in athletics are dynamic. Therefore it is reasonable to assume that a muscle should be trained dynamically, and in such a way that it is specific for the sport/activity for which the muscle is being conditioned. Unfortunately, a limitation to most of the studies is that EMS was not applied in conjunction with dynamic movements.

In light of previous EMS research, the results of this study present much more specific and relevant information on the use of EMS while combined with dynamic exercise as a means of possibly increasing muscular strength in athletes. Therefore, more research is warranted comparing different EMS protocols before one can accurately compare the strength gains from combined EMS and dynamic contractions to those studies that combined EMS with voluntary isometric contractions between weight training sessions. Although the maximum muscle strength of the athletes in the present study increased significantly as a result of supplementing a dynamic weight training exercise with EMS, one should interpret these results carefully. As noted earlier, the question remains as to whether gains in maximum strength due to EMS are actually useful for maximal activities without EMS or submaximal activities.

Based on the continued importance of improving muscular strength in athletes, it is paramount to gain a better understanding of the processes by which increasing muscle strength translates to enhanced sport performance. Yet the results of this study also indicate that the actual physiolgical mechanisms for strength increases as a result of incorporating EMS into a weight training program remain unclear.

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