CROSS-EDUCATION EFFECT OBSERVED IN VOLUNTARY AND ELECTROMYOSTIMULATION STRENGTH TRAINING

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This study investigated the effects of four weeks of unilateral electromyostimulation (EMS) versus isometric strength training (IM), on knee extension strength of contralateral limb in previously untrained young adults. Subjects performed (IM, n=10) or evoked (EMS, n=10) 40 isometric knee extensions, at an intensity of 65% of maximum voluntary contraction (MVC) force, three times per week, for four weeks. Pre and post training, both legs were tested for maximum voluntary strength on an isokinetic dynamometer, at 0 deg/s (isometric), 60 and 180 deg/s velocities. The results showed that the EMS and IM training had a similar effect in strength improvement in these subjects. Both types of training induced significant cross-education effect on isometric MVC of the untrained limb, but not in isokinetic torque. The mechanisms underlying this phenomenon require further study.

KEY WORDS: cross-education, electromyostimulation, isometric, strength training, quadriceps.

INTRODUCTION: It has been shown that unilateral training may improve muscular strength in both the trained and contralateral limb simultaneously. This phenomenon is called the cross-education effect (Enoka, 1988). Both voluntary isometric contraction and electromyostimulation (EMS) have been regarded as valid means of strength training for improving muscular strength and/or facilitating rehabilitation (Hortobagyi et al., 1997; Morrisey, 1988). However, no study has investigated whether the EMS training would be as effective as voluntary training in inducing a cross-education effect in strength gain.
The aim of this study was to investigate the effect of four weeks of unilateral voluntary and EMS isometric training, at 65% maximum voluntary isometric strength level, on strength development of the contralateral limb. The outcome of such investigation will provide more evidence regarding the effectiveness of EMS training to induce the cross-education effect, and the application significance of such training in strength development and neuromuscular rehabilitation.

METHOD: Subjects. Thirty habitually active but not specifically trained male subjects volunteered to participate in the study. Subjects were arbitrarily assigned to one of three groups, 10 in each, for voluntary isometric training (IM), EMS training, or control without training (CON).

Table 1 Subject Characteristics

Group(mean±SD)	Age (yrs)	Height (m)	Mass (kg)
Total	**22.6 ± 3.0**	**1.755 ± 0.075**	**76.8 ± 9.9**
IM	**22.9 ± 4.7**	**1.749 ± 0.077**	**75.6 ± 4.7**
EMS	**22.3 ± 3.8**	**1.757 ± 0.076**	**78.9 ± 12.0**
CON	**22.6 ± 3.6**	**1.758 ± 0.072**	**76.9 ± 13.2**

Training. Each training group completed three sessions per week for four weeks, of unilateral isometric training on the knee extensors of the dominant leg. The training was performed on the testing chair of a Cybex II dynamometer (Lumex Corp., Bayshore, New York, USA) under supervision. The torque output of contractions was governed by displaying a graphical force trace on a computer monitor attached to the dynamometer, by which the researcher could instruct subjects to alter their volitional effort or the electric current to the desired level.

In each training session, the IM group performed five sets of voluntary isometric contractions of eight repetitions (ie. 5 × 8 = 40 repetitions), at the intensity of 65% maximal voluntary isometric contraction force (MVIC) (McDonagh and Davies, 1984) which was determined in the pre-training test. For each repetition, the subject was asked to produce the required level of force for five seconds, followed by five seconds of rest. A two-minute recovery period was allowed after each set. The required level of force was adjusted after two weeks of training according to the improvement in strength.

In EMS training, the contractile intensity was matched to IM group, ie. at approximately 65% MVIC. Electrical stimulation was delivered using a two-channel battery powered electrical neuromuscular stimulator (R-STIM II, American Imex, Irvine California, USA) via two pairs of self-adhesive electrodes, coated with conductive gel (Dermatrode, American Imex, Irvine California, USA). The size of each electrode was 100 mm × 50 mm. Electrode configuration was similar to that used by Brooks et al. (1990) in that a transverse distal and proximal thigh electrode placement was selected for the anode (+) and cathode (-) respectively. The stimulation pulses were delivered at 100 Hz with a fixed pulse width of 250 microseconds. The electrical current required to produce 65% MIVC was found to be always below 100 mA which was the maximal capacity of the stimulator. In each training session, the subject produced 40 EMS isometric contractions, each contraction lasted five seconds in duration followed by 20 seconds of rest.

Testing. Subjects participated in a familiarisation trial one week before formal testing. All subjects were tested for their MVIC and peak voluntary isokinetic knee extension torque (MVIK) prior to and after two weeks of training, for adjustment of training workload, and within two days after the four-week training period to evaluate the training effect. Prior to all testing, subjects were asked not to perform any strenuous exercise for at least 48 hrs to minimise possible residual fatigue effect.

All strength testing was performed on a KIN-COM isokinetic dynamometer (Kinetic communicator 500-H, Chattanooga Group Inc. Chattecx, TN, USA), linked to an AMLAB system (v2.0, Associated Measurement Laboratories International, Lane Cove, NSW, Australia). The initial angles at the knee and hip joints were both 90 degrees. Force in Newtons (N), torque in Newton-meters (Nm), and force/position data were determined from the raw data through a schematic designed on the AMLAB software. All force data was sampled at a rate of 100 Hz.

For warming-up, subjects performed five minutes stationary cycling at 100 watts, followed by a series of standardised lower body stretching, then a series of submaximal isometric (0 deg/s) contractions on KIN-COM. Following a two-minute rest subjects were then required to exert a maximal force in knee extension for a period of five seconds. The peak force over the five seconds period was recorded. Three contractions were performed with a two-minute rest between repetitions.

Following a five-minute recovery from the MVIC, subjects performed MVIK at velocities of 90 deg/s and 180 deg/s through the range of motion of 90 to 180 degrees. Three trials were performed separated by a two-minute recovery period. Five minutes were allowed between the tests of different velocities.

Then, the contralateral leg was tested following the same protocol. Which leg tested first was randomised.

Data Analysis. For each testing condition, the two highest peak force/torque values among three trials were averaged for further analysis. Analysis of variance (ANOVA) with repeated measures was used to evaluate the training effects. Sheffe post-hoc comparisons were performed to identify at which testing occasion the difference occurred.

The experimental procedures were approved by the Human Experimentation Ethics Committee of Southern Cross University. Written consent was obtained from each subject prior to the experiment.

RESULTS: Significant improvement in knee extension strength, both MVIC and MVIK, were found in both IM and EMS groups ($p<0.05$) after the four weeks of training (Table 2), whilst no differences were found among the three groups prior to training.

Table 2 Variation in Knee Extension Strength of the Trained Leg Pre and Post Four Weeks of Training. (*$p<0.05$, compared to pre-training)

	(Mean ± SD)	IM	EMS	CON
MVIC (N)	Pre	1045 A260	986 f128	1023 ±176
	Post	1301 ±276*	1195 ±153*	1019 ±164
MVIK (Nm)	Pre	773 ±177	853 ±105	811 ±125
60 deg/s	Post	945 ±225*	1038 ±139*	797 ±165
MVIK (Nm)	Pre	552 ±171	635 f75	528 +96
180 deg/s	Post	644 ±196*	734 ±77*	537 +94

Both EMS and IM groups achieved significant ($p<0.05$) and similar increases in contralateral MVIC of the untrained limb. However, no strength gain in the isokinetic tests was found in the contralateral limb in both groups (figure 1).

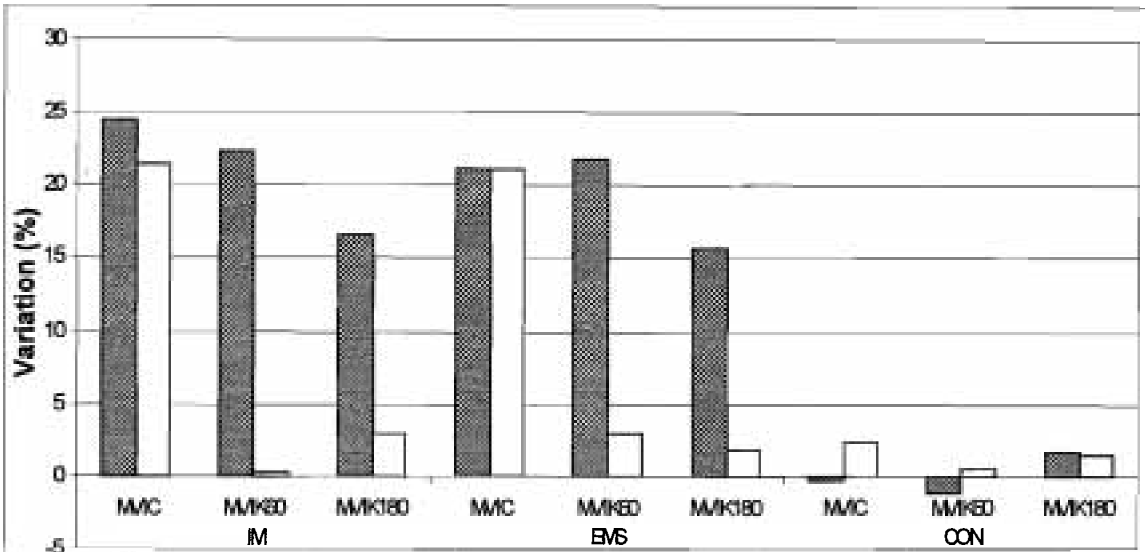

Figure 1 - Variations in isometric and isokinetic knee extension strength after four weeks training (percentage to pre-training) in trained/domiant (filled bars) and untrained/nondominant (empty bars) limbs in IM, EMS and CON groups.

DISCUSSION: The results of this study showed that the effect of the four-week EMS training was similar to that of the IM training for increasing maximal voluntary isometric and isokinetic strength in the knee extensors in these previously untrained subjects. Further, the results suggest that a strength training protocol using a relatively low contraction intensity (65% of MIVC) and a commercially available electrical stimulator, is valid as a means of improving muscular strength, although there have been controversial reports in the literature in regard to the efficacy of utilising different stimulators, stimulation protocols and modes of training (Eriksson et al., 1981; Houston et al., 1983; Lieber et al., 1996).

It was quite interesting to find a significant contralateral strength gain after the unilateral training, especially for the EMS group, and the specificity of the contralateral adaptation to the modes of muscle contraction. The cross-education effect of training has been repeatedly reported for training programs that involve maximum voluntary unilateral efforts (Moritani and deVeries, 1979; Enoka, 1988; Kannus et al., 1992; Hortobagyi et al., 1997). Speculations have been proposed to the possible mechanisms for this phenomenon. Most of the authors believe that neural adaptations play an important role. The adaptation might be due to the bilateral central drive to the homologous muscles (Carr et al., 1994), and/or motor unit recruitment in the contralateral limb due to the requirement to maintain posture during

unilateral activities (Hortobagyi et al., 1997). It has also been speculated that an improved circulation in the untrained limb due to training might bring about hormonal and metabolic stimulations to the muscles (Yasuda and Miyamura, 1983).
The contralateral strength gain produced by unilateral EMS training found in the present study supports the previous report (Cabric and Appell, 1987). However, the mechanisms underlying the adaptation produced by the unilateral EMS training is not clear and requires further investigation. The specificity of the cross-education effects, ie. the improved MVIC strength but unchanged MVIK strength, also needs further study.

CONCLUSION: The evidence gained in the present study confirmed that EMS at 65% maximum voluntary contraction force can induce significant voluntary isometric and dynamic strength adaptations. The four weeks unilateral training also induced significant strength gain in isometric contraction in the contralateral limb. This cross-education effect may have practical significance in rehabilitation, especially for those who have one limb immobilised for a period of time due to an injury or surgical operation. Further studies on the mechanisms of the cross-education effect are needed.

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