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EFFECT OF ELECTRO-MOTOR STIMULATION ON THE POWER PRODUCTION OF A MAXIMALLY STRETCHED MUSCLE

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ABSTRACT. The effect of electro-motor stimulation (EMS) upon the increase in power production of the tibialis anterior muscle (TA) of healthy individuals in both the maximally stretched (ST group) and shortened (SH group) positions was investigated. The effect of cross-education upon the contralateral muscle was also examined. EMS with a frequency of 50 hertz, a duration of 0.2 milliseconds, and a rectangular wave was applied for ten seconds with a ten-second interval and repeated ten times per day for six weeks. The ST group gained significantly 9.4 %, 15.5 %, and 16.4 % after two, four, and six weeks of stimulation, respectively, while the SH group also showed a significant gain of 5.1 %, 8.3 %, and 3.0 %. When comparing the two groups at the end of the six-week period the ST group's gain was significantly greater. The increase of power production of the unstimulated TA was 5.5 %, 8.0 %, and 4.3 % in the ST group, which was significant at the end of the second and fourth week of stimulation. The SH group, however, registered a non-significant increase of −2.7 %, 1.8 %, and −1.5 %. Comparison between the two groups showed a significant increase in the power production of the unstimulated TA in the ST group commencing the second week. Conclusion: EMS of the TA in the maximally stretched position is a more effective way to gain strength.

Key words: electro-motor stimulation, stretched position of a muscle, shortened position of a muscle, cross-education.

Studies have been carried out in the past by many researchers to find effective methods for muscle strengthening (1, 2). However, the fact should be recognised that the various types of muscle contraction differ considerably in producing different results. Among the various strengthening techniques electro-motor stimulation (EMS) is the one that is done passively. Even this modality brings about different results according to the wave form used, conditions of application, duration of stimuli, type of muscle, sex and age of the subject, and method of assessment. It is, therefore, difficult at present to compare results obtained by various researchers (3, 4, 5).

It is known that a muscle can atrophy significantly if it is immobilised in a shortened position, but that it may atrophy less, or become hypertrophic, if it is immobilised in a stretched position (6, 7). The author has devised a method by which the state of the muscle to be stimulated is changed rather than the properties of EMS. Accordingly, an experiment was carried out on the tibialis anterior muscle (TA) in a maximally stretched position.

SUBJECTS AND METHODS

The subjects consisted of 20 healthy female college students who were not engaged in any specific sport before or during the study and they were divided equally into two groups. The subject was kept in a sitting position and the left ankle joint was immobilised painfree by a specially constructed ankle-stretching machine in a fully plantarflexed position in one group (ST), and in a fully dorsiflexed position in the other group (SH), so that the left TA was maximally stretched in the former group and maximally shortened in the latter. The TA was electrically stimulated with a frequency of 50 hertz, for a duration of 0.2 milliseconds, and a rectangular wave was produced by an isolator (3F36 type made by San-ei Measurement Equipment Co., Japan and SS102J type made by Nihon Kohden Industry Co., Japan). Electrical leads were connected to a 23-mm dish electrode made of silver. The active electrode was placed on the motor point of the TA and the inactive one on the lower part of the thigh. Electrical stimuli were applied to the maximum intensity tolerated by the subject. One session consisted of ten seconds each for the stimulation and the interval, and this was repeated ten times per day. The procedure was carried out in at least four sessions per week for six weeks, and more than two days of consecutive nontreatment were avoided.

The strength of the TA was tested before the experiment and at two-week intervals during the experiment, using a CYBEX II isokinetic dynamometer (Lumex, Inc.) which was set at one revolution per minute. A computation was done for the torque, work capacity, and the coefficient of fatigue of the muscle. The baseline for the measurement was set at a pre-experimental value of 100 %.

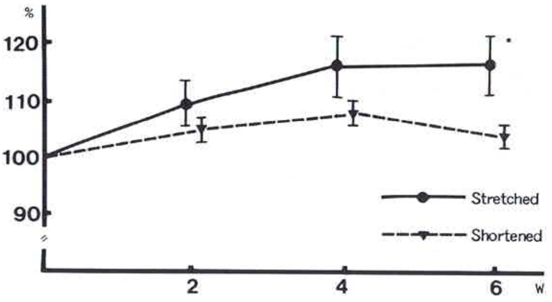

Fig. 1. Per cent change in muscle strength. $^*p<0.05$.

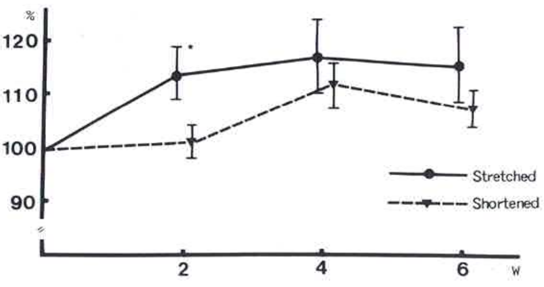

Fig. 2. Per cent change in work capacity. $^*p<0.05$.

RESULTS

There was no statistically significant difference in the subjects' age, height, weight, and strength of the TA between the two groups (Table I). The torque of the TA in the ST group increased to 109.4±12.1%, 115.5±16.1%, and 116.4±16.2% after two, four, and six weeks of stimulation, respectively. The SH group showed a similar increase of 105.1±7.8%, 108.3±7.8%, and 103.0±6.5%. Both increases were statistically significant. In comparing the two groups the ST group's increase was significant at the beginning of the six-week period (Fig. 1). The work capacity of the TA in the ST group significantly increased to 114.2±16.2%, 118.2±23.0%, and 116.2±23.0% after two, four, and six weeks, respectively. The SH group showed an increase of 101.6±10.6%, 112.3±12.5%, and 108.0±12.4%, of which the values after four and six weeks were significant. In comparing the two groups the ST group's increase in work capacity was significant after two weeks (Fig. 2). The coefficient of fatigue of the TA showed no statistical significance when comparing the rate of increase in the torque for each group and for each week period in both groups (Fig. 3).

The torque of the unstimulated TA in the ST group increased to 105.5±6.4%, 108.0±7.7%, and 104.3±7.5% after two, four, and six weeks, respectively, of which the values at the end of the two- and four-week periods were significant. The SH group, however, showed a non-significant increase of 97.3±9.7%, 101.8±9.6%, and 98.5±11.1%. The comparison between the two groups showed that the torque value at the end of the two-week period was significant (Fig. 4).

Intensity of the EMS varied from subject to subject according to the individual's threshold of pain and diurnal change in pain tolerance. There was, however, no significant difference in the amount of intensity tolerated by the two groups.

Table I. *Characteristics of the subjects*

Group	Height (cm)	Weight (kg)	Age (yr)
Stretched (n=10)	160.1±5.6	52.2±5.7	19.7±1.1
Shortened (n=10)	160.0±4.9	52.5±6.2	19.5±1.2

DISCUSSION

Although the types of muscles and/or conditions for EMS vary, many researchers have reported methods of muscle strengthening by means of EMS to be effective: a minimum increase of 6% obtained by Singer (8) and a maximum increase of 44% obtained by Selkowitz (9) as summarized by Lloyd (10). These reports, however, do not mention the state of the muscle. Studies on the state of muscles include the experiments by Summers et al. on the

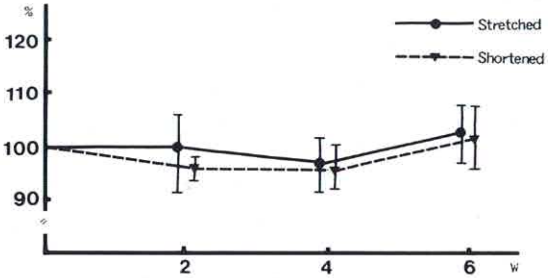

Fig. 3. Per cent change in fatigue pattern.

Table II. *Percentage of increase in muscle strength, work capacity, rate of fatigue, and cross-education between the ST and SH groups*

	Group	Two-week	Four-week	Six-week	*t*-test
Muscle strength	ST group	109.4±12.1	115.5±16.1	116.4±16.2	<0.05 after six-week period in both groups
	SH group	105.1±7.8	108.3±7.8	103.8±6.5	
Work capacity	ST group	114.2±16.2	118.2±23.0	116.2±23.0	<0.05 after two-week period in both groups
	SH group	101.6±10.6	112.3±12.0	108.0±12.4	
Rate of fatigue	ST group	100.1±11.2	97.6±8.5	103.1±9.2	NS
	SH group	96.6±7.7	96.0±7.6	101.6±10.9	
Cross-education	ST group	105.5±6.4	108.0±7.7	104.3±7.5	<0.05 after two-week period in both groups
	SH group	97.3±9.7	101.8±9.6	98.5±11.1	

cat's soleus muscle in a stretched position (11), and by Furguson on the rabbit's TA immobilised with tension (12), as well as Thomsen's similar animal experiment (13), all of which were effective in producing hypertrophy of the muscle. Furthermore, our experiment resulted in an increase of 32% of the wet weight of a rat's soleus muscle which was maintained in a stretched position (7). The author therefore assumed that it might be possible to stimulate electrically a muscle in the stretched position so as to increase the power production effectively, and at the same time to ascertain the effect upon cross-education.

According to the animal experiment by Williams et al., electrical stimulation combined with stretch for a period as short as four days on fast contracting muscle showed that reprogramming of the synthesis of fiber type-specific contractile proteins could be achieved (14).

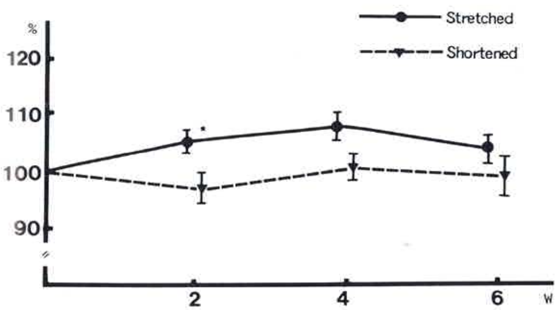

Fig. 4. Per cent change in strength of the unstimulated muscle. *$p<0.05$.

Application of the EMS to the TA increased the force production in both the ST and SH groups, the result being the same as that reported by the other researchers (8), though the ST group's increase was significantly larger at the end of the six-week period. This fact suggests that trophic activity is at work from the muscle to the nerve. The increase in power production in the stretched position is, therefore, thought to have been brought about by the addition of contractile activity produced by EMS on the metabolic activity mentioned above (15).

The fact that the ST group had a significant gain in power production in their unstimulated TA after two- and four-week periods suggests the presence of a cross-educational effect. Moritani considered cross-education to be neurological (16). Stromberg investigated the effect upon the contralateral side in exercise therapy for the upper limb and reported especially the fact that the grip strength increased to 150% after one month compared with the control group (17). He thus stated that this phenomenon could be explained by contralateral motoneurone excitability, involvement of synergic movement, or the psychological effect of training. Hellebrandt et al. have argued that the effect of cross-education is brought about not by the training period but by the training intensity, and that the cross-education has a dual genesis in the diffusion of motor impulses and tonic postural reflex (18). Singer recognised cross-education in his experiment with EMS, and advanced the hypothesis that the mechanism is caused by facilitatory influences on the contralateral motoneurone pool, related to the afferent input from the EMS (9). Because the effect of cross-education from the present experiment occurred only in the ST group it must be attributable to the fact that the muscle stretch generated impulses to excite the I and II fibres, in addition to the EMS which generated overflow of stimuli by facilitating the contralateral motoneurones.

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