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Training Effect of Muscular Endurance by Means of Voluntary and Electrical Stimulation

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Summary. The training effect on muscular endurance was studied by voluntary effort as well as electrical stimulation. The results were summarized as the followings:

1. The endurance of the muscle was observed to be about 13% of final voluntary contractions higher by electrical stimulation than that by voluntary contractions.
2. After the training for 12—13 weeks, the muscular endurance was increased by about 130% in voluntary muscle contractions.

The number of contractions due to electric stimuli, given after complete exhaustion in voluntary contraction, was practically the same in the beginning and in the end of one experiment.

Key-Words: Muscle Strength — Electrical Stimulation — Muscular Endurance.

By means of electrical stimulation on the ulnar nerve of the upper arm, the absolute value of the maximum strength of the muscle had been studied by the present authors at the first step of this series of experiment. As reported elsewhere by the authors the maximum strength of the thumb adductor induced by electrical stimulation was observed to be about 30% higher than that produced by ordinary voluntary maximum effort [6]. This means that the human subject could release an additional 30% of strength in case of emergency. This study is aimed to find out a mechanism of training effect of muscular endurance on a hand finger ergometer by using electric stimulation and by voluntary maximum effort.

Method

The experiment was consisted only of two series of training of muscular endurance in two healthy adults aged 23 and 28, but it is very difficult to get subjects for these very painful experiments due to the electric stimuli. The training was performed by dynamic contractions to exhaustion of the thumb adductor on the ergometer lifting the load of one third of the maximum strength up to 1.5 cm, 60 times per minute. The number of contraction was chosen as an index of muscular endurance as reported by the author [3]. The training was conducted once a day except Sunday for 12 to 13 weeks. The hand and four fingers except the thumb was fixed with plaster on the measuring desk.

Every 3 weeks we arranged the test for endurance in the way that we count at first the number of contractions till exhaustion by voluntary effort. After complete fatigue electrical stimuli were given till complete exhaustion.

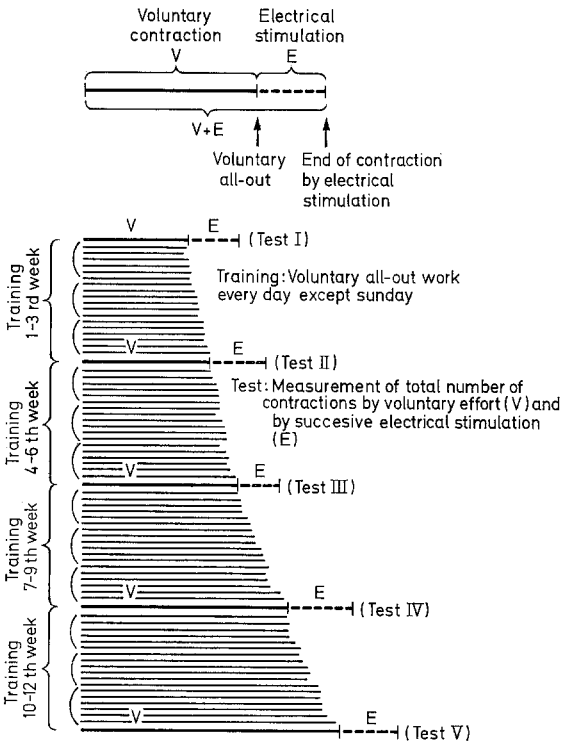

Fig. 1. Schematic explanation of experiment including muscular endurance training and its test

The number of contractions by means of electrical stimulation was counted also. The number of contractions in voluntary and electrical stimuli shows the increase in muscular endurance (Fig. 1). The electrical stimulation was applied on the ulnar nerve by electrodes attached on the skin of the upper arm near the elbow joint. The optimal condition of electrical stimulation was settled as follows: a rectangular current of 5 milliseconds duration of 50 cps (Hz) and of about 40 volts. The stimulation was applied for 0.5 sec. In this condition, the intensity of electrical stimulation was selected as that for one third of the maximum strength induced by maximal voluntary effort (Fig. 2).

Furthermore we measured with same equipment the maximum strength by voluntary isometric muscle contraction.

Results

The number of contractions of the thumb adductor lifting the load to exhaustion by voluntary effort was counted to be 68 and 86 in these subjects. After the subjects gave up their work by voluntary effort, the electrically induced involuntary additional dynamic contractions was counted to be 20 and 24. One of the results of this experiment is

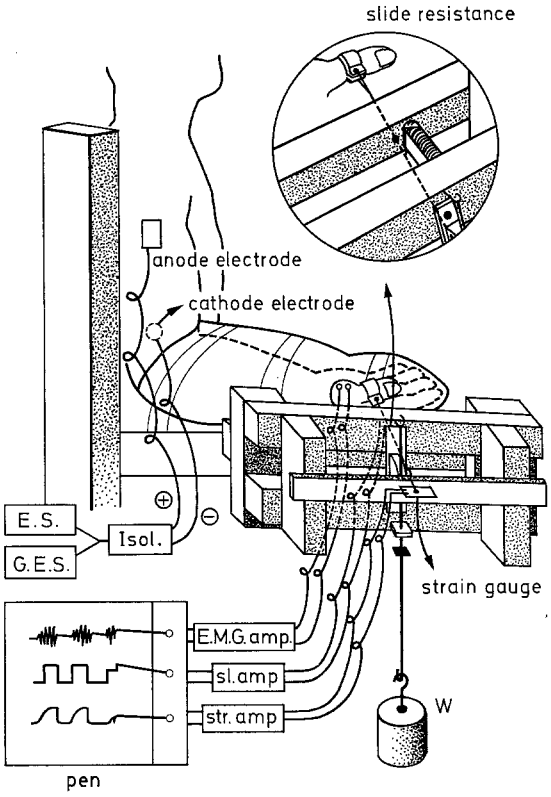

Fig. 2. Arrangement of finger ergometer for voluntary and by electrical stimulation

presented here in Fig. 3. The force curve lifting the load, electromyogram from the thumb adductor and signals of electrical stimulation. In this experiment the subject could not repeat his voluntary contractions after the 93rd bout. It is observed in this figure that the subject tried three contractions without success, accompanied with a decreased motor unit discharge. By applying the electrical stimulation 25 successive contractions were recorded.

As to the training effect, it was observed that the number of contractions by voluntary effort was increased progressively throughout the period extending from 12 to 13 weeks. At the end of training, the number of voluntary contractions was increased by 166 and 91% in the different subjects. The total number of contractions (V + E) (voluntary effort (V) + involuntary additional contractions (E)) was counted to be about 128 and 67% related to the beginning value.

The absolute number of voluntary contractions increases in subject 1 from 68 to 181. The number of contractions by electrical stimulus at

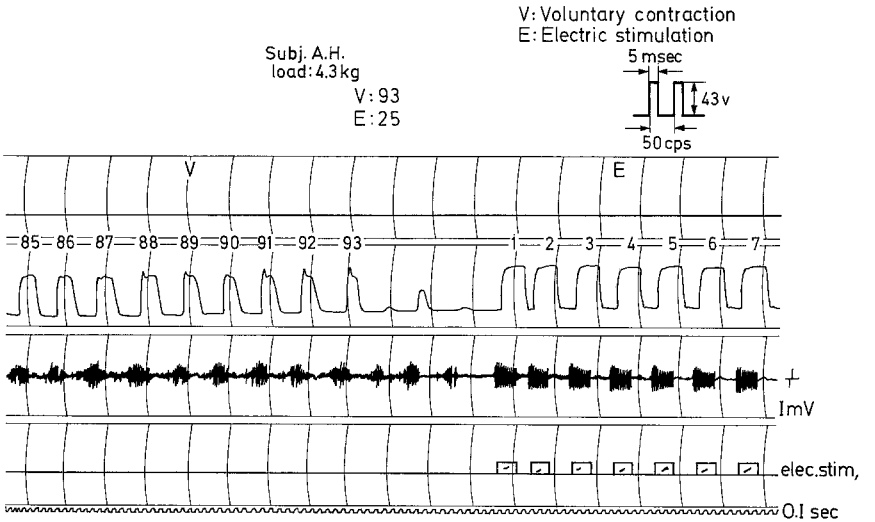

Fig. 3. A record of mechanogram (upper curve), electromyogram (middle curve) and signal of electrical stimulation (lower curve). Time signal of 0.1 sec at the bottom

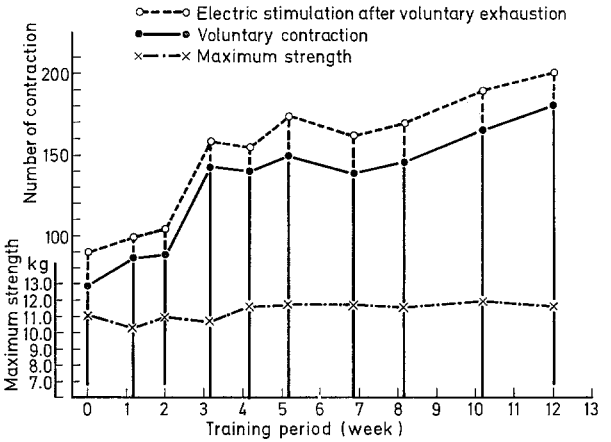

Fig. 4. Training effect on muscular endurance (Subj. s Taguchi, Age, 23)

the beginning and the end of the experiment was 20. In subject 2 the voluntary contraction increases from 86 to 164, in electrical contractions we found at the beginning of the experiment 24 in the end of the experiment 20 contractions.

On the other hand, the maximum strength remained unchanged for the period of endurance training. One example of the results of training is presented in Fig. 4.

Discussion

It was expected from other studies that the number of contractions by voluntary effort would be improved after the training over several weeks [3, 5]. However, it was a newly informed result in this study that the muscular endurance induced by electrical stimulation was always higher than by voluntary effort. The number of contractions after complete exhaustion for voluntary muscular contractions given by electric stimuli was practically the same in the beginning and in the end after 2 till 3 weeks of endurance training.

As to the maximum strength of the muscle, it had been observed by Steinhaus and the present author [4] that the highest value of strength could be obtained at 120—130% of the ordinary voluntary maximum by means of "*Shot*", "*Shout*" or "*Hypnosis*". The highest value of maximum strength produced in specially concentrated condition had been named as "physiologic limit", while the maximum strength in ordinary condition as "psychologic limit". Ikai, Yabe, Ischii have shown the same effect by means of electrical stimulation [6].

In this sense, the muscular endurance induced by electrical stimulation immediately after giving up the voluntary work could be interpreted as the „physiologic limit" of muscular endurance, while the maximum muscular endurance by voluntary effort could be interpreted as "psychologic limit".

In these results the "physiologic limit" of muscular endurance was improved with the same rate as "psychologic limit" throughout the training period. It could be understood that the difference between the "physiologic" and "psychologic" limits suggests "Reserved work capacity" in endurance nature.

The main cause of the improvement of physiologic limit must be due to the increase of blood flow and oxygen intake in the muscle based on the capillarization as suggested elsewhere [1, 3, 5, 7, 8]. On the other hand, the main cause of psychologic limit must be the improvement of increased discharge of neuromuscular unit.

It is very easy understandable from works by Hettinger and others [2] that any increase was not observed in maximum strength of the muscle throughout the endurance training using the load of one third of the maximum strength.

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