Thus the rats of EG, after immunization with the conjugate of β-endorphin and BSA, developed definite changes in their feeding and aggressive-defensive behavior and motor activity, and these changes were only partially similar to the effect of injection of exogenous β-endorphin. The β-endorphin concentration was lowered in certain brain structures. Only in animals immunized with the conjugate of β-endorphin and BSA, by contrast with all rats of CT, was a prolonged increase in food consumption without any corresponding increase in body weight observed together with changes in the water intake, and also loss of the response to handling. It can be tentatively suggested that the changes described above are the result of modifications to the processes of synthesis, secretion, and degradation of β-endorphin in the animal under these conditions.

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EFFECT OF POTENTIATION OF ELECTROMYOGRAM—FORCE RELATIONSHIP

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KEY WORDS: potentiation of muscular contraction; electromyography

Electromyography is widely used in the physiology of movement, in clinical practice, and in sport medicine. It can be used to determine which muscles participate, and in what order, in the performance of a studied movement, and the intensity and duration of their excitation. The possibility of estimating the force developed by a muscle on the basis of parameters of its electrical activity is very attractive, but to do so it is necessary to have information on the relationship between the electromyogram (EMG) and force. Lippold [6] first discovered the linear relationship between the rectified integrated EMG of the gastrocnemius muscle and the force developed by the muscle. Subsequent investigation [4, 8, 9, 11] on various muscles revealed both a linear and a nonlinear relationship between these parameters. Very simple theoretical analysis predicts that the rectified integrated EMG ought to rise as a root of force, but there are virtually no relevant experimental data. The composition of the muscle fibers [11], the method of deriving the EMG (monopolar or bipolar) [11], and the length of the muscle [4, 9] are known to influence the EMG — force relationship. The view has been expressed [9] that this relatinship also is affected by factors such as the frequency characteristics of the motor units, the content and local distribution of fast and slow fibers, the signal from neighboring muscles, the work of antagonists and agonists, and the viscoelastic properties of the muscle. Yet another factor is evidently potentiation, which leads to an increase of force, and this must alter the EMG—force relationship

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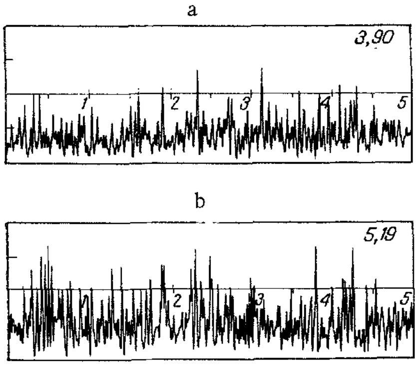

Fig. 1

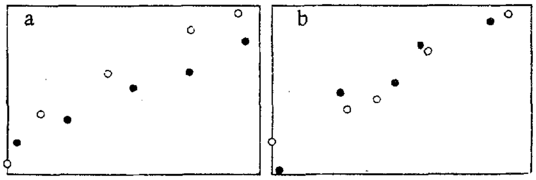

Fig. 2

Fig. 1. EMG of flexor digitorum sublimis after (a) and before (b) potentiation, during maintenance of an equal force. Numbers indicate average EMG level (in relative units). Abscissa, time (in sec).

Fig. 2. Correlation between EMG (vertical axis) and muscular force (horizontal axis) for subject of group 1 (a) and for subject of group 2 (b). Empty circles — before potentiation, filled circles — after potentiation.

for the amplitude of the action potential remains unchanged during potentiation [3].

The aim of this investigation was to study the effect of potentiation on the EMG—force relationship.

EXPERIMENTAL METHOD

Experiments were carried out on 10 healthy subjects aged 20-30 years. The subject's forearm, hand, and fingers were fixed immovably to an armrest, and his ring finger was fixed in a ring mounted on a steel bar (7 × 7 mm), to which strain-gauge resistors were glued. The signal, proportional to force, was led to an amplifier (full details of the technique were described in [2]). After amplification the signal was led to the analog-to-digital converter (ADC) of a Neman computer and to an oscilloscope for visual monitoring of force. The EMG was derived by means of two cup-shaped electrodes (Beckman, USA), filled with electrically conducting paste. The electrodes were placed at a distance of 1.5 cm apart, above the flexor digitorum sublimis in the region of that portion of the muscle which flexes predominantly the ring finger. The signal was led to the extension unit of a preamplifier, after which it was subjected to full-wave rectification and smoothing (active filter with cut off frequency 45 Hz), and then led to the ADC unit of the computer (digitization frequency 200 Hz). The scheme of the experiment was as follows: under visual control the subject maintained the assigned level of force for 10 sec, during which time the force and EMG were recorded. The subjects then made a maximal voluntary contraction of the muscle lasting 3-4 sec, inducing potentiation [10]. The subject then relaxed the muscle, and, when instructed to do so, again developed the assigned level of force. During data processing the mean area of the EMG per second (the EMG level) and the average force were calculated. To obtain quantitative characteristics for different levels of force, the ratio of the EMG level to the force was calculated. Measurements were repeated 5 or 6 times at different levels of force, not exceeding 30-40% of maximal. Between measurements the subject rested for at least 15 min. With a somewhat modified experimental scheme the subject maintained two or three assigned levels of force in succession, each one for 5 sec, and after development of potentiation, repeated them by a voluntary contraction. In some experiments the subject was instructed to memorize the initial level of force and, after potentiation, to reproduce that level from memory without visual control. Under these circumstances the reproduced level of force and the EMG were recorded.

EXPERIMENTAL RESULTS

EMG before Development of Potentiation. Within the range of force investigated (under 30-40% of the maximum) the EMG level depended on developed force as a linear function with a certain degree of scatter. The same kind of relationship is described in many publications [5, 6, 11].

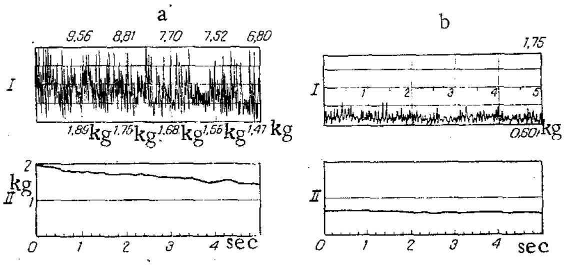

Fig. 3. Reproduction of force from memory. a) Subject of group 1 (numbers indicate average levels of EMG and force in each second; initial values 9.57 relative units and 1.19 kg, respectively); b) subjects of group 2 (numbers indicate average EMG and force levels in 5 sec; initial values 1.56 relative units and 0.61 kg, respectively). I) EMG; II) mechanogram.

EMG after the Development of Potentiation. For the majority of subjects the EMG level after development of potentiation was lower than initially in virtually all measurements (Fig. 1). Lowering of this parameter was observed in eight of the 10 subjects; in one subject the EMG level rose after potentiation, and in yet another, no consistent results could be obtained. If the ratio of EMG level to force is examined, it can be seen that in seven subjects it decreased significantly: by 1.7, 1.7, 1.4, 1.4, 1.3, 1.3, and 1.2 times, respectively (group 1). In the remaining three subjects it changed but not significantly: by 1.08, 0.95, and 0.85 times, respectively (group 2). Data of two experiments are given in Fig. 2 — one is characteristic of a subject of group 1, the other represents the results for one subject in group 2.

Maintenance of Force from Memory. In the experiments described above, many subjects had the sensation that it was easier to maintain a force of the same magnitude after the development of potentiation. Accordingly the next series of experiments was undertaken: the subject was asked to remember the level of force and, after development of potentiation, to reproduce it from memory. Two traces of this series are shown in Fig. 3. The subjects of group 1 characteristically reproduced initially a force much greater than the initial level. Under these circumstances the EMG corresponded approximately to the initial recording. The force was quickly reduced and, after 10 sec, it stabilized at values a little higher than initially; the EMG also was reduced. A trace of an experiment in which the subject reproduced the force correctly also is shown in Fig. 3; no appreciable drop of force likewise was observed, but only two subjects (of group 2) gave results of this kind.

Potentiation may thus have a significant effect on the EMF—force relationship and it is a factor to be taken into account when the EMG is used as an indicator of force. The results of some investigations might be partly explained by the effect of potentiation: for example, during maintenance of an assigned force the EMG first decreases, then stabilizes at a lower level [1]. Data indicating that after the beginning of contraction, during maintenance of a definite force, the firing rate of the motor units decreases, are given in [7]; since force remains constant, potentiation of the muscle could compensate for the decrease in firing rate.

One fact connected with the results of experiments with maintenance of force from memory is worthy of attention. The closeness of the values of the EMG before and after potentiation can be regarded as evidence that, when solving the problem of reproducing the level of force, the subject is guided mainly by the level of the efferent command and not by peripheral feedback signals. Partial correction of the mistakes does not take place until a few seconds later.

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