ON THE RECIPROCAL ACTION OF THE NERVE CENTERS OF THE MOTOR ANALYSOR

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In sports, athletes often tense muscle groups which do not directly affect the realization of a movement — tension in the arm, face and neck muscles of a finishing runner, constriction of a skater's arms, joined behind his back, when his foot is jarred, change of expression and movement of the head in a tired athlete, etc. Evidently, the inclusion of such "supplementary" muscular groups in the action is one of the factors increasing the efficiency of muscular activity.

The reciprocal action of the nerve centers causing the realization of coordinated movement was first observed by N. E. Vvedensky [2] in a study of the interrelations between the musculatures of animals' legs. N. E. Vvedensky and A. A. Ukhtomsky [3, 4] showed that the activity of muscle antagonists is not always opposed but can also be synergistic. The authors point out that the reciprocity of reactions is determined, not beforehand by a predetermined antagonism of the centers, but by the degree of activity in one of the centers, thereby promoting a new functional dynamics principle of reciprocity.

There is cross-innervation in human arms, similar to the cross-coordination found in animals' legs [11, 12], and these functions can also be synergistic [1, 15].

Such a phenomenon of opposite reactions is evidently explained by the different conditions present in the experiments of the various authors, which promoted various types of reaction.

In 1903, I. M. Sechenov [14] showed that efficiency can be more quickly restored to a fatigued right arm when the left arm is in action. Sechenov explained this phenomenon by the fact that "the source of fatigue is not in the muscles, but in the processes occurring in the nerve centers".

The works of later authors, who studied work and active rest conditions in more detail, [6, 7, 8, 9, 10, 13, 16] show that the effect of a muscular contraction can change depending on the conditions of activity present in other muscular groups.

The purpose of our work was to study the effect of contractions in "supplementary" muscle groups on the efficiency of muscular activity.

EXPERIMENTAL METHODS AND RESULTS

We conducted 5 series of experiments studying the force, speed, duration and frequency of movements in different kinds of muscular activity. The results of several variants of the same simple movement were examined in each experiment.

In the first series of experiments, the maximal muscular tension in "sitting" and "at ease" positions was determined in 41 men by measurement with a hand dynamometer. The tension of muscular groups which did not directly participate in pressing the dynamometer in the "sitting" position, namely, the muscles of the trunk and legs, was excluded. In the "at ease" position, the subject pressed the dynamometer in the pose most comfortable to him. The majority of the subjects, in this case, performed a series of movements – the arm was abruptly dropped down from the dynamometer, the subject squatted and inclined the trunk forward. Then the other arm usually became tense and the jaws clenched.

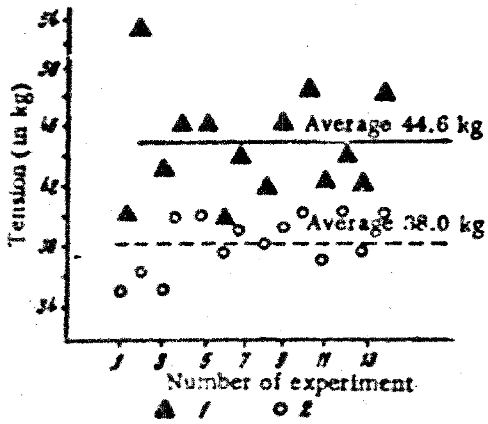

Fig. 1. Hand dynamometry in the "sitting" and "at ease" positions.
1) "at ease"; 2) "sitting"

In 95 out of 100 cases, greater muscular force was shown in the "at ease" position, in 4 cases, the results were identical in both positions, and in only one case, greater muscular force was shown in the "sitting" position. The increased force in the "at ease" position was, on the average, 12% as compared with the "sitting" position; individual fluctuations reached 30-40%.

Figure 1 shows the change in the hand dynamometer in one of the subjects.

The force of muscular contraction was studied with an inertia dynamometer in the second series of experiments. The principle of the inertia dynamometer, which was constructed by N. N. Goncharov [5] consists in contrasting the force of inertia with the force of muscular contraction. Flexing the arm at the elbow in the frontal plane with maximal force, the subject stretched the rope, unwinding the discs. According to the speed at which the discs rotated, which was automatically recorded, the force, rate, time and their derivatives – the work and power of the forearm flexion and also the change in these indices during one flexion – could be determined.

When the right forearm was flexed, the force of the muscular contraction was compared with three variants – the left arm relaxed, the left arm simultaneously flexed with a load of 5 kg ("symmetrical" movement), and the left arm simultaneously extended with a load of 5 kg ("asymmetrical" movement).

A total of 600 movements in 5 men was recorded on the inertia dynamometer. The force of the right arm flexions increased an average of 9% when the left arm was simultaneously flexed. The right arm flexion was not as strong when the left arm was simultaneously extended.

These effects appeared more clearly in work with great resistances (power method). The amount of effort in asymmetrical movements increased from day to day, which did not occur in the contraction of symmetrical muscles (see table).

The example given shows that asymmetrical movement could have a slight positive effect on the very first day in one subject, but a negative effect in another, only gradually, after 5 days, becoming positive. This is explained by the difference in individual abilities to master new movements, which is confirmed by the athletic characteristics of the subjects and by careful and systematic observations made on them.

The other indices of muscular activity also changed depending on the experimental variant. When the left arm performed a symmetrical movement, the speed of right arm flexion increased; the time of flexion decreased in comparison with the first variant, i. e., when the left arm was relaxed.

In the third series of experiments, we studied the effect of left arm muscle contractions during fatigue caused by many repeated flexions of the right arm with maximal force. The subject flexed the right arm at the elbow many times, quickly, and these flexions were recorded on the inertia dynamometer. At different times, the work fatigue of the right arm included the left arm, and the subject continued to flex the right arm while the symmetrical muscles of the left arm contracted simultaneously. In all 5 of the subjects, the effort of the fatigued right arm was raised to the original level or higher by the inclusion of the left arm in the work (Fig. 2). The average increase in effort was 13%, reaching 25-30% in individual movements.

Varying the number of left arm muscular contractions and grouping them in a definite order and time of inclusion, we found certain patterns: the positive effect of including the left arm in the work increased with fatigue; the inclusion of the groups containing 5-8 flexions produced the greatest efficiency; the greatest increase

Change in the Force of the Right Arm in 2 Men Resulting From Simultaneous Flexion or Extension of the Left Arm (average effort of 10 movements in percent of the average efforts exerted by the right arm when the left was relaxed)

Day of experiment	1	2	3	4	5	6	1	2	3	4	5	6
When left arm was simultaneously flexed . . .	114	125	110	123	116	121	105	113	107	104	112	112
When left arm was simultaneously extended	101	105	105	114	112	114	98	96	97	98,5	108	110

in the work of the right arm was 4-5% and was obtained when the left arm was included several times in the work (Fig. 2); the effect of including the left arm in the work had a peak-like character (Fig. 2), which, it would appear, reflects the development of successive positive induction at the time.

In the fourth series of experiments, we studied the maximum duration of static effort. The subject held a load weighing from 1.3 to 5 kg in his right arm, which was extended sideways as far as possible. The movement of the loaded arm was recorded directly on a kymograph tape. When signs of fatigue appeared in the right arm (drooping, marked tremor, etc.), at a signal, the subject extended his left arm sideways, or moved his left arm or leg rhythmically. The tension of the left arm or leg muscles prolonged the time that the right arm could hold the load. According to the data from 150 experiments, the average increase in the 5 subjects was 7%. The effect of including the left arm muscles in the activity can be seen in the mechanogram – the right arm, holding the load, was elevated as soon as the left arm joined in the activity; the fluctuation amplitude of the right arm decreased, etc.

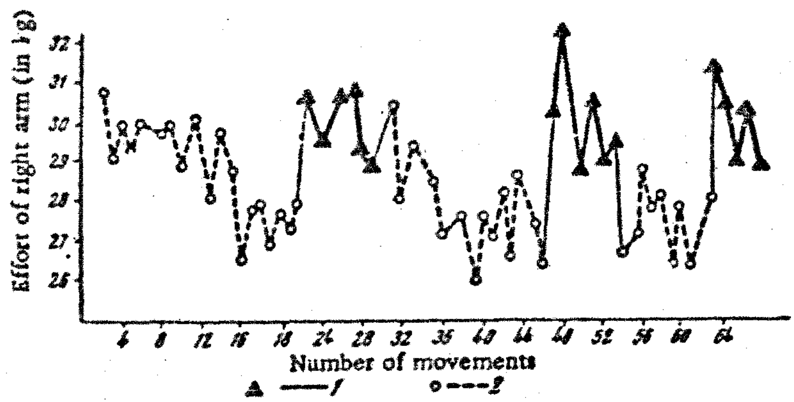

Fig. 2. Effect of contraction of left arm muscles on the efficiency of the right arm in one of subjects.
1) With supplementary flexion of the left arm; 2) without supplementary movements.

In the fifth series of experiments, we studied tension in the upper portion of the body from rhythmic movements of the legs. Sitting in a relaxed pose, the subject turned the pedals of a bicycle ergometer (40-50 pedal turns per minute), then, at a signal, tensed the muscles of the body, grasped the handle more tightly, lightly flexed tensed arms, and clenched his jaws. The result of 70 experiments was that the rate of movement increased an average of 30% in all 7 men during the tension, and remained increased throughout the tension period (Fig.3).

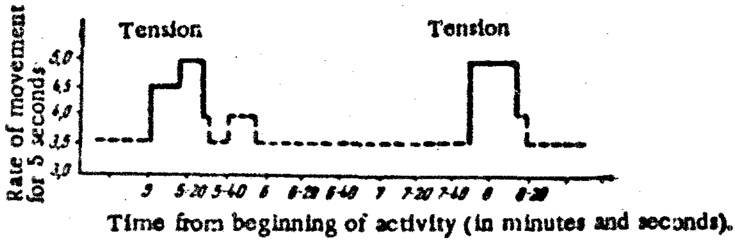

Fig. 3. Change in rotation rate of bicycle ergometer pedals in one of the subjects when the muscles of the upper part of the trunk were tensed.
— With supplementary body muscle tension; --- without supplementary movements.

DISCUSSION OF RESULTS

The data obtained can be considered to be the result of inducted influences from one region of the cerebral cortex upon another region. Yet I. M. Sechenov observed that afferent impulses entering nerve centers from single working muscles influence the condition of other muscular group centers. A. A. Ukhtomsky [4] showed that stimulation of single centers can only intensify the stimulation process in other centers when these other centers become a dominating focus. In our experiments, the dominant regulating unit originated during oral instruction, which created a condition of heightened excitability in the motor analysor even before any movement was begun. The afferent impulses, which arose at a definite time due to tension of "supplementary" muscle groups, caused increased stimulation in the dominant focus and an intensified contraction.

Symmetrical movement of the arm produced the greatest effect in the experiments on the inertia dynamometer, since asymmetrical movement first produced a weaker, or negative, effect, which only gradually, with practice, became positive. There can evidently be a negative inducement along with the positive, depending on the kind of movement performed simultaneously.

It is possible that the greatest positive effect is produced by the type of movement combinations found most frequently in labor and athletics, which are fixed conditioned reflexes (symmetrical movement of the arms).

The positive effect obtained by including certain "supplementary" movements in the activity is especially marked on a background of fatigue, which is evidently connected with change in the functional condition of the nerve centers in the cortex of the cerebral hemispheres. Acting through proprioceptors on the central nervous system, one can increase the efficiency of a fatigued body and eliminate, for some time, the advance of fatigue.

SUMMARY

The effect of muscular tension in "supplementary" muscle groups on the efficiency of other muscles was studied in five series of experiments with various forms of muscular activity: muscular contraction, static effort, cyclic movements.

It was established that the inclusion of muscular groups which are not involved directly in the performed movements improves the efficiency of the main movement. The effect was most conspicuous during fatigue. The results were analyzed on the basis of the Sechenov, Pavlov, and Ukhtomsky theories.

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