References and Notes

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Control and Training of Individual Motor Units

Abstract. *Experiments clearly demonstrate that with the help of auditory and visual cues man can single out motor units and control their isolated contractions. Experiments on the training of this control, interpreted as the training of descending pathways to single anterior horn cells, provide a new glimpse of the fineness of conscious motor controls. After training, subjects can recall into activity different single motor units by an effort of will while inhibiting the activity of neighbors. Some learn such exquisite control that they soon can produce rhythms of contraction in one unit, imitating drum rolls, etc. The quality of control over individual anterior horn cells may determine rates of learning.*

It is a commonplace observation that very gentle contractions of skeletal muscles recruit only a few motor units and that, on relaxation, human beings can promptly repress all neuromuscular activity in large areas under voluntary control (*1*). However, little attention has been paid to the fine voluntary control of individual motor units. In 1960 Harrison and Mortensen (*2*) reported that subjects were able to maintain isolated activity of several different motor units in the tibialis anterior as recorded from surface electrodes and confirmed by needle electrodes. The implications of this finding led to an intensive systematic investigation with special indwelling electrodes.

By definition, a motor unit includes a spinal anterior horn cell, its axon, and all the muscle fibers on which the terminal branches of the axon end (Fig. 1). This motor unit "fires" when an impulse reaches the muscle fibers, the response being a brief twitch. The electrical potential accompanying the twitch is now well documented. The twitch frequency has an upper limit of about 50 per second. With indwelling electrodes, individual motor units are identifiable by their individual shapes; these remain relatively constant unless the electrodes are shifted.

The subjects of these experiments were provided with two modalities of "proprioception" that they normally lack, namely, they heard their motor unit potentials and saw them on monitors. The subjects were 16 normal persons ranging in age from 20 to 55. All but five were under 24 and only one was female.

The main muscle tested in all subjects was the right abductor pollicis brevis (Fig. 2). In two subjects the tibialis anterior was also tested; in another, the biceps brachii and the extensor digitorum longus were tested on other occasions. The recording and monitoring apparatus is illustrated in Fig. 2.

The indwelling electrodes used have already been described in detail (*3*). They are nylon-insulated Karma alloy wires 0.025 mm in diameter, which are introduced into the muscle as a pair by means of a hypodermic needle that is immediately withdrawn. In the case of a small muscle like the abductor pollicis brevis, the activity of all its motor units are probably detected while the fascial coat of the muscle isolates the pick-up to this muscle alone.

After placement and connection of the electrodes, the subjects spent 5 to 10 minutes becoming familiar with the response of the electromyograph to a range of movements and postures. They were invariably amazed at the responsiveness to even the slightest effort. Then they began learning how to maintain very slight contractions, which were apparent to themselves only through the response of the apparatus. This led to increasingly more demanding effort involving many procedures intended to reveal both their natural talent in controlling individual motor units and their skill in learning and retaining tricks with such units. Individual units were identified by the characteristics of their potentials which show considerable difference on the oscilloscope and, to a lesser extent, on the loudspeaker. Film recordings of potentials were made for confirmation (Fig. 3).

Generally, experiments on one muscle were limited to about half a day. Within 15 to 30 minutes all subjects had achieved notably better willful control over gentle contractions. In this time almost all had learned to relax the whole muscle instantaneously on command and to recruit the activity of a single motor unit, keeping it active for as many minutes as desired. A few had difficulty maintaining the activity of such a unit, or in recruiting more units. No relationship was obvious to age, manual dexterity, or anything that might have been invoked as an underlying explanation of the differences in performance. Two of the apparently most dexterous persons performed only moderately well. The youngest persons were among both the worst and the best performers. General personality traits did not seem to matter.

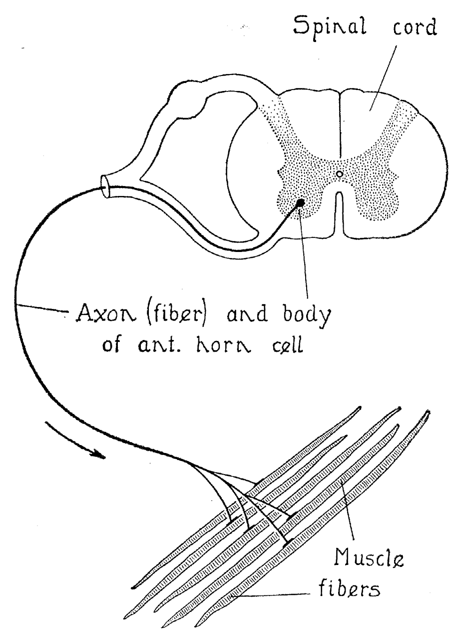

Fig. 1. Diagram of a motor unit of skeletal muscle.

After about 30 minutes the subject was required to learn how to repress the first motor unit he had become familiar with and to recruit another one. Most subjects were able to do this and gain mastery of the new unit in a matter of minutes; only one subject required more than 15 minutes. More than half of the subjects could repeat the performance with a third new unit within a few minutes. A few subjects could recruit a fourth or a fifth isolated unit. The next problem facing a subject was to recruit, unerringly and in isolation, the several units over which he had gained control.

Here there was a considerable variation in skill. About one in four could respond easily to the command for isolated contractions of any of three units. About half the subjects displayed much less skill in this regard, even after several hours and even though they may have learned other bizarre tricks. Several subjects had particular difficulty in recruiting the asked-for units. They groped around in their conscious efforts to find them and sometimes, it seemed, only succeeded by accident.

The subjects with the finest control were then trained to learn various tricks. Several were tested for their powers of recalling specific units into activity in the *absence* of the aural and visual feedbacks which were so important to most of the subjects. Three subjects could recall units voluntarily under these handicaps, but they were unable to explain how they could do it.

Other tests showed that in all subjects the aural feedback is more useful than the visual display on the cathode ray tube monitor. The latter served only a subsidiary purpose.

After 60 to 90 minutes, most of the subjects were tested and trained in the production of specific rhythms. Almost all could reduce and increase the frequency of a well-controlled unit. It soon became apparent that motor units do not have a single characteristic frequency. Rather, they have an individual maximum rate below which their firing can be greatly slowed and single isolated contractions can be produced. Above the maximum rate that is characteristic for a specific unit, overflow takes place and other motor units are recruited.

Subjects learned to control units so that they could produce various rhythms. Almost all the subjects in the later experiments who were asked to try these (10 of 11) succeeded. Various gallop rhythms, drum-beat rhythms, doublets, and roll effects were produced and recorded (*4*).

The experiments reported above suggest that pathways from the cerebral cortex can be made to stimulate single anterior horn cells while neighboring anterior horn cells remain dormant or are depressed. Although the skills learned in these experiments depended on aural and visual feedbacks from muscles, the controls are learned so quickly, are so exquisite, and are so well retained after the feedbacks are eliminated in some subjects, that one must not dismiss them as tricks. The underlying mechanisms seem to involve active suppression of neighboring anterior horn cells.

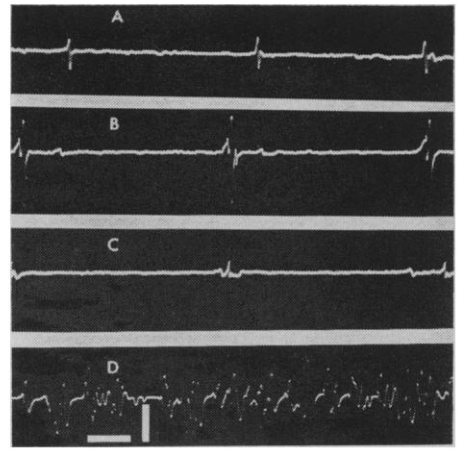

Fig. 3. Electromyograms of potentials from motor units, *A*, *B*, and *C*, and of a weak-to-moderate contraction (tracing *D*) in the abductor pollicis brevis of one subject. Calibrations lines: 25 msec and 200 μv.

A number of obvious problems emerge from the differences in the rates of learning of motor unit skills by different subjects. New but limited studies by Harrison (*5*) suggest that accomplished athletes have no better control than other subjects over their motor units. Future studies to ascertain the relation of rates of motor unit learning to dexterity, special abilities, and techniques of teaching motor skills are called for.

The extremely fine ability to adjust the rate of firing of individual motor units is a novel concept. Above a characteristic frequency, which varies from cell to cell, overflow to neighbors occurs. Detailed studies of these characteristics should expose some of the underlying control mechanism in the spinal cord (*6*).

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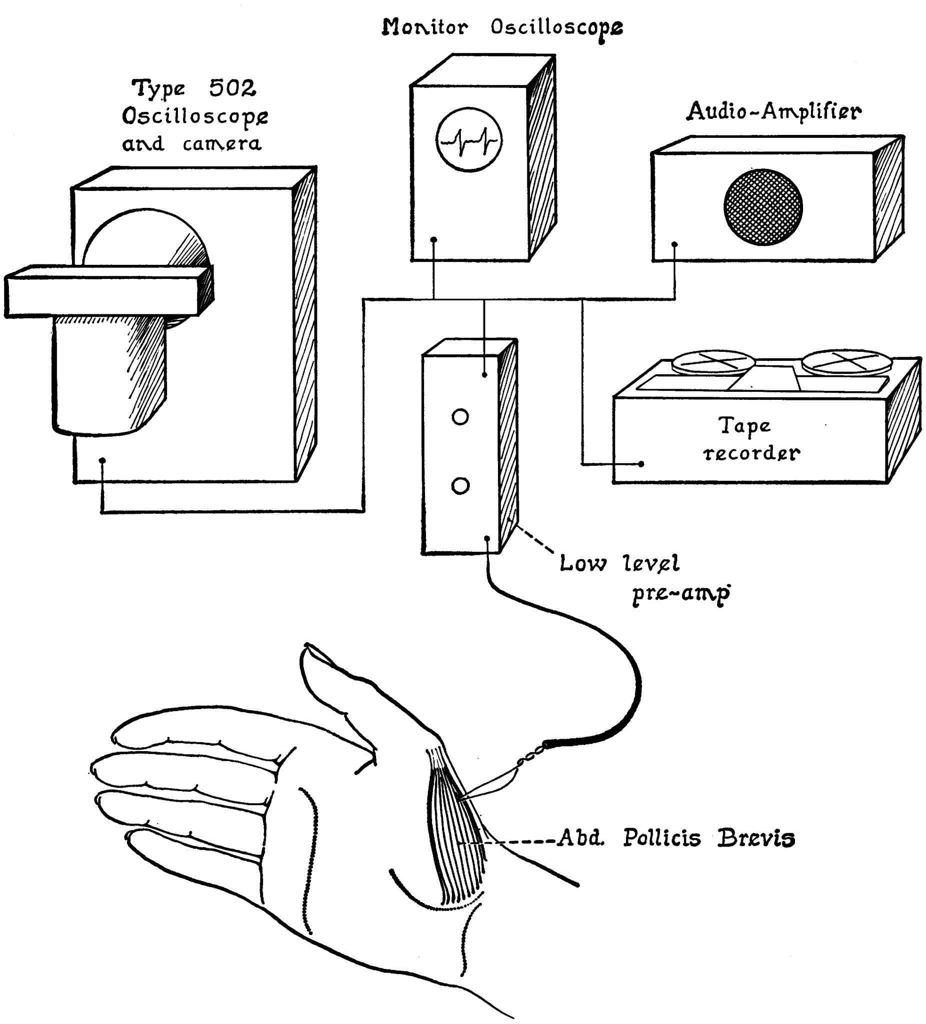

Fig. 2. Technique of recording from abductor pollicis brevis.

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