Electromyography Comes of Age

The conscious control of individual motor units in man may be used to improve his physical performance.

John V. Basmajian

Man has shown a perpetual curiosity about the function and control of skeletal muscles. Aristotle, Galen, Leonardo da Vinci, and Vesalius, the "father of modern anatomy," all were fascinated by the organs of locomotion and power (*1*). Galvani may be considered the originator of electromyography, or the study of electrical activity in muscle. He believed that muscles stored and discharged electricity received from the nerves, very much like Leiden jars (*2*). While many uses were made of Galvani's other findings, muscle electricity remained a scientific curiosity until the 20th century when improved methods of detecting and recording minute electrical discharges became widely available.

Much of the credit for launching modern electromyography about 40 years ago goes to Adrian and Bronk (*3*) and their colleagues. Being neurophysiologists, they did not attempt to determine the functions of individual muscles and groups of muscles; instead they improved electrical methods of studying the nervous system. It was not until the end of World War II, when there was a marked improvement in the technology and availability of electronic apparatus, that anatomists, kinesiologists, and clinical scientists began to make increasing use of electromyography.

The first study to gain wide acceptance was that of Inman *et al.* who investigated the movements of the human shoulder region (*4*). During the 1950's electromyography was used frequently in kinesiological studies, and it is now used in many different fields of biology, in studies ranging from the activity of the middle ear muscles of bats to the psychophysiology of human relaxation (*5*).

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The Basis of Electromyography

The cellular unit of contraction in skeletal muscle is the muscle cell or muscle fiber (Fig. 1). Best described as a very fine thread, this muscle fiber has a length of up to 30 centimeters or more but is less than 100 micrometers (0.1 millimeter) wide. On contracting it will shorten to about 57 percent of its resting length. By looking at the intact normal muscle during contraction one could easily believe that all the muscle fibers were in some stage of continuous smooth shortening. But in fact, there is a widespread, rapid series of twitches which occur asynchronously among the fibers. The apparently smooth contraction is a summation of the asynchronous twitches.

In normal mammalian skeletal muscle, single fibers probably never contract individually. Instead, small groups of them contract at the same moment because they are supplied by the terminal branches of one nerve fiber or axon. The cell body from which the axon arises is in the anterior horn of the spinal gray matter or related brainstem areas. Collectively, the nerve cell body, its axon, and its terminal branches, and all the muscle fibers supplied by these branches, constitute a motor unit; this is the functional unit of striated muscle (Fig. 2). An impulse descending the nerve axon causes all the muscle fibers in one motor unit to contract almost simultaneously. In man, impulses are generated at various frequencies, usually below 50 per second.

The number of muscle fibers that are served by one axon, that is, the number of fibers in a motor unit, varies widely. Generally, muscles controlling fine or delicate movements and adjustments have the smallest number of muscle fibers per motor unit. For example, the muscles that move the eyes have fewer than ten fibers per unit, as do the muscles of the middle ear and the larynx (*5*). On the other hand, large muscles in the limbs have larger motor units. One of the muscles of the thigh has motor units with about 2000 muscle fibers supplied by each axon. Individual muscles of the body consist of many hundreds of such motor units and it is their summated activity that develops the tension in the whole muscle.

The amount of work produced by a single motor unit is quite small. In a living human being it is usually insufficient to show any external movement of a joint spanned by the whole muscle of which it is a part. Even in small joints, such as those of the thumb, at least two or three motor units are needed to give a visible movement. Under normal conditions small motor units are recruited early, and, as the force is automatically or consciously increased, larger and larger motor units are recruited (*6*), while all the motor units also increase their frequency of twitching. There is no single, set frequency; individual motor units can fire very slowly and will increase their frequency of response on demand (*7*).

Motor Unit Potentials

The motor unit potential has a brief duration (with a median of 9 milliseconds) and a total amplitude measured in microvolts or millivolts. When displayed on the cathode-ray oscilloscope, most potentials are sharp triphasic or biphasic spikes (Fig. 3). Generally, the larger the spike the larger is the motor unit that produced it. However, the distance from the electrode, the type of electrodes used, and the equipment are among the many factors which influence the final size and shape of the oscilloscopic display.

Much disagreement in electromyography has centered around the different types of electrodes used. Because kinesiological studies are often made by investigators who are not medically qualified, surface electrodes have been popular. However, for discrete recordings without "cross talk" between muscles, there are many difficulties with surface electrodes. Electrodes inserted through the skin are no longer as forbidding as they once were. They are made from a nylon-insulated Nichrome alloy or any other similar material and are only 25 or 75 micrometers in diameter (Fig. 4) (*5*). Because of their size they are painless and are easily injected and withdrawn. They can collect as much data from a specific muscle as can the best surface electrodes, and give excellent recordings on the oscilloscope. With 1 millimeter of an inserted electrode left exposed, the voltage from a muscle can be recorded much better than with a surface electrode. Bipolar electrodes restrict their pickup either to the whole muscle being studied or to the confines of the compartment within a muscle if it has a multipennate structure. Barriers of fibrous connective tissue within a muscle or around it act as insulation. Thus, one can record all the activity as far as such a barrier without interference from beyond it.

Electromyograms are obtained by means of amplifiers with most sensitive to frequencies from about 10 to 2000 hertz. Amplifiers sensitive to frequencies of no more than 1000 hertz are satisfactory. Ideally, the results should be recorded either photographically, or by means of electromagnetic tape. In recent years multitrack tape recorders have provided a relatively cheap means of storing electromyogram signals, especially for computer analysis later.

As with any electric signals, motor unit potentials can be transmitted for long distances either by telephone lines or by FM radio. The latter promises to be useful in field studies of wild animals or in experiments in which the subjects must be completely unfettered by dragging cables (as in running and jumping, for example). A number of excellent telemetering systems have been described and good standard equipment is available from commercial sources. Single-channel telemetering in electromyography is simple; multichannel telemetry is more difficult but will be used more frequently as techniques and equipment improve.

Muscle Tone and Fatigue

Most neurophysiologists agree that the complete relaxation of normal human striated muscle at rest can be demonstrated conclusively by electromyography. That is, a normal human being can abolish neuromuscular activity in a muscle by relaxing it. This

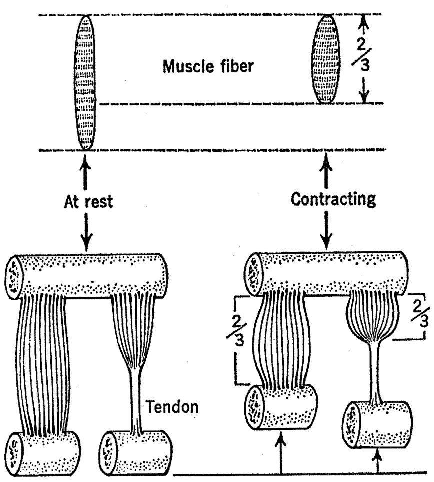

Fig. 1. The structural unit of contraction in skeletal muscle is the muscle fiber which can shorten to approximately two thirds of its resting length. Thus, the excursion of the ends of a whole muscle is limited by this constraint.

does not mean that there is no tone (or tonus) in skeletal muscle, as some investigators have claimed. It does mean, however, that the usual definition of tone should be modified to state that the general tone of a muscle is determined both by the passive elasticity or turgor of muscular (and fibrous) tissues and by the active (though not continuous) contraction of muscle in response to the reaction of the nervous system to stimuli. Thus, at complete rest, a muscle has not lost its tone even though there is no neuromuscular activity (*5*).

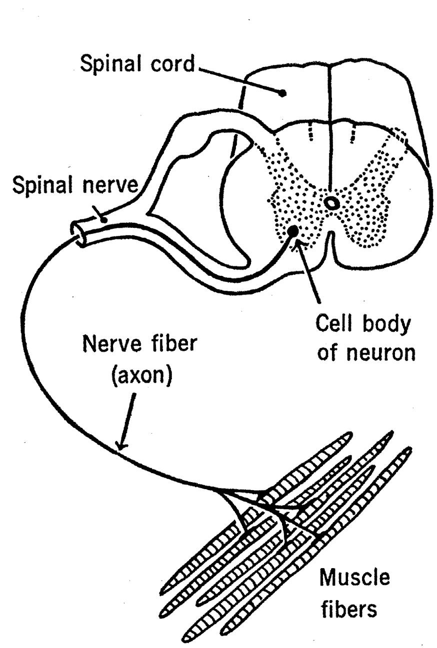

Fig. 2. Diagram of a single motor unit, the functional unit of contraction.

In the clinical appreciation of tone, the more important of the above two elements is the reactivity of the nervous system. One cannot lay hands on a normal limb without causing such a reaction. Therefore, the clinician soon learns to evaluate the level of tone and it may seem of little consequence to him that the muscle he is feeling is, in fact, capable of complete neuromuscular inactivity. In spite of this, he would be surprised to learn that an experienced subject can simulate hypotonia or even the atonia of complete paralysis and so deceive—if only for a brief period—the most astute physician (*8*).

Electromyograms from normal human muscles generally show that relaxation occurs completely and almost instantaneously when subjects are ordered to relax. However, a small number of normal subjects do have great difficulty in relaxing quickly. In no normal muscle at complete rest is there any sign of neuromuscular activity, even with multiple electrodes. As Stolov (*9*) has said: "We can therefore conclude that no alpha motor neuron discharge is present in normal muscle at rest, but may be present during a stretch that is rapid enough to initiate a reflex response."

"Complete rest" requires some qualification. A normal person does not completely relax all his muscles at once. Reacting to multiple internal and external stimuli, various groups of muscles show increasing and decreasing amounts of activity. Goldstein (*10*) found that certain muscle groups at rest showed electromyogram activity related to a general muscular tension: these muscles were mostly in the limbs and neck. Anxious subjects were not greatly different from nonanxious ones —except that the very anxious subjects showed marked reaction to new stimuli.

Electromyography has been used by some workers in the investigation of fatigue. The fatigue of strenuous effort may be quite different from the weariness felt after a long day's routine sedentary work and undoubtedly the following types of fatigue exist: emotional fatigue, central nervous system fatigue, "general" fatigue, and peripheral neuromuscular fatigue of special kinds.

Investigations in my laboratory have shown that postural fatigue is caused largely by painful strain not on muscles (which often have been quite quiescent) but on ligaments, capsules, and other inert structures. This has led to the concept that muscles are spared when ligaments suffice. This is important not only in understanding the sources of postural fatigue in man but also because it underlies another important principle of man's posture: There should be a minimal expenditure of energy consistent with the ends to be achieved. Thus, MacConaill and I (*11*) proposed two laws which express the operation of this principle: (i) The law of minimal spurt action: no more muscle fibers are brought into action than are both necessary and sufficient to stabilize or move a bone against gravity or other resistant forces, and none are used insofar as gravity can supply the motive force for movement. (ii) The law of minimal shunt action: only such muscle fibers are used as are necessary and sufficient to ensure that the transarticular force directed toward a joint is equal to the weight of the stabilized or moving part together with such additional centripetal force as may be required because of the velocity of that part when it is in motion.

That these two laws are valid has been demonstrated clearly by electromyography. In studies of the biomechanics of the shoulder (glenohumeral) joint, it was shown that the whole weight of an unloaded arm is counteracted by the upper part of its capsule alone, no muscles being required (*5*). In this area a previously puzzling ligament (the coracohumeral) is very strong; it appears to reinforce the action of the joint capsule in preventing the head of the humerus from sliding downward on the inclined plane formed by the glenoid cavity or shoulder socket. With moderate or heavy loads, a muscle adhering to the capsule (the supraspinatus) is brought into action to reinforce the original tension in the capsule.

Everyone knows that carrying a heavy weight (say, a suitcase) can become a painful experience. It is often assumed that the reactive component which becomes fatigued and exhibits pain is muscular; in fact, the fatigue is chiefly ligamentous. This demonstrates the importance of the inert structures.

Another example of the minimal principle is that of arch support in the human foot. Generations of surgeons have stressed the importance of the muscular tie-beams in the plantigrade foot, yet electromyography has repeatedly pointed to the fundamental importance of plantar ligaments. Indeed, even very heavy loads do not recruit muscular activity in the leg and foot (*5*).

A variety of phenomena that occur with the progressive fatigue of continuous voluntary activity have been described. Some are probably of spinal cord origin and are not well understood. Other phenomena include the synchronization of potentials, an augmentation of the amplitude and duration of potentials, and an increase in polyphasic potentials. An excellent review of these observations has been written by Scherrer and Monod (*12*).

Coordination of Muscle Function

The statement that the brain does not order a muscle to contract, but orders movements of a joint, is true only in part. Under certain circumstances the movement is the result of contraction in only one or two muscles. For example, pronation of the forearm (turning the hand into the palm-down position) is usually produced by one muscle alone, the pronator quadratus, unless there is added resistance to the movement, in which case more muscles are used (*5*). In elbow flexion, the brachialis (not biceps) often suffices (*5*). On the other hand, there are complex movements (such as rotation of the scapula on the chest wall during elevation of the limb) which obviously require groups of cooperating muscles.

It has generally been believed that during the movement of a joint in one direction, muscles that move it in the opposite direction show some sort of antagonism. It has been shown by Sherrington (*13*), however, that the so-called antagonist relaxes completely except perhaps with one exception, at the end of a whiplike motion of a hinge joint (*5*). Sherrington referred to the relaxation of the antagonist as reciprocal inhibition; the term antagonist should thus be replaced by synergist. The activity of muscles in the position of antagonists during a movement may also be a sign of nervous abnormality (for example, in the spasticity of paraplegia), or, in the case of fine movements requiring training, a sign of ineptitude. Indeed, the athlete's continued drill to perfect a skilled movement exhibits a large element of progressively more successful repression of undesired contractions.

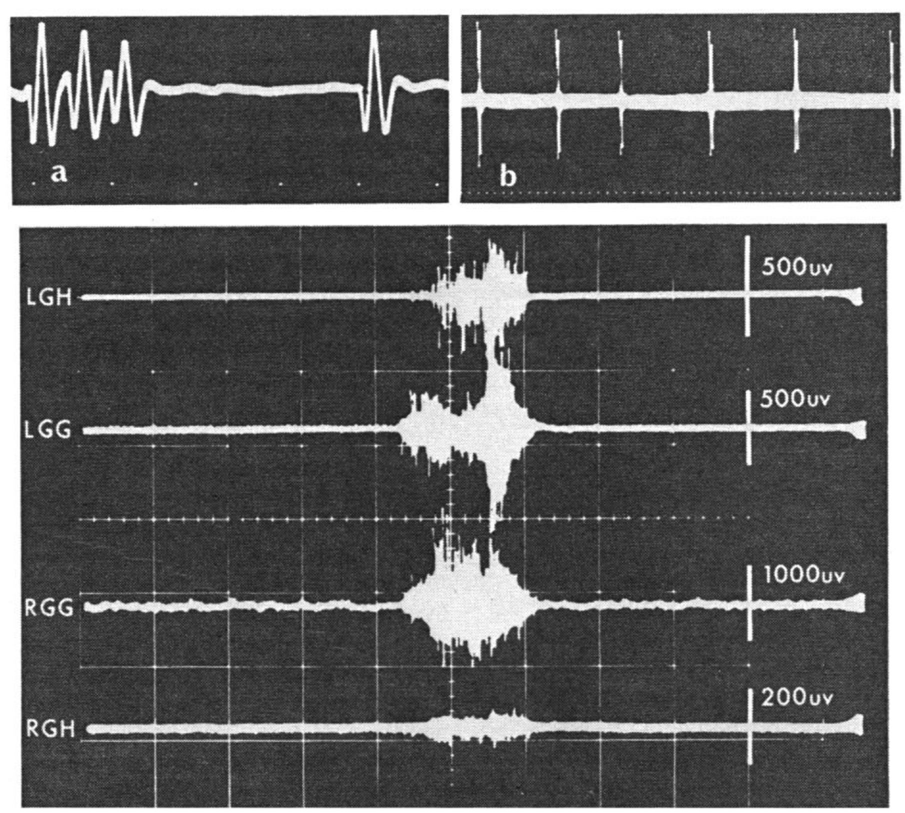

Fig. 3. Potentials demonstrated by electromyography. (a and b) Single motor unit potentials with varying time bases (time scale in each, 10 msec). The lower panel shows simultaneous recordings obtained at slow speeds from muscles in the tongue while the subject was swallowing. (*LGG* and *RGG*, left and right genioglossi; *LGH* and *RGH*, left and right geniohyoids; time scale is 0.5 second per major division.)

Conscious Control and Training of Single Motor Units

A recently developed technique in electromyography, known as motor unit training, offers a useful approach to studies of the conscious control over spinal motoneurons, of the neurophysiological processes underlying proprioception and feedback, and of many related psychophysiological phenomena. Although in the 1930's Smith (*14*) and Lindsley (*15*) gave brief accounts of man's ability to discharge single motor units and to vary their rates, electromyographers tended to take this phenomenon for granted and performed no systematic studies of it until the early 1960's (*7, 16*). Advances in the development of intramuscular electrodes then permitted rapid progress. In man it is much easier to place an electrode in or near the muscle fibers rather than in the spinal cord; thus, electromyography provides a simple way to record the activity of the motoneurons.

Human subjects undergoing motor unit training are given auditory and visual displays of their individual myoelectric potentials recorded by means of intramuscular electrodes. The cues provide the subjects with an awareness of the twitching of individual motor units. They learn in a few minutes to control this activity and can give many bizarre responses with only the feedback cues as a guide (*7*).

Subjects are invariably amazed at the responsiveness of the loudspeaker and cathode-ray tube to their slightest efforts, and they accept these as a new form of proprioception without difficulty. It is not necessary for them to have any knowledge of electromyography. After being given a general explanation of the procedure they need only to concentrate their attention on the response of the electromyograph. Even the most naive subject is soon able to maintain various levels of activity in a muscle on the sensory basis provided by the monitors. Indeed, the actions that are required of him generally demand such gentle contractions that his only awareness of them is through the apparatus. After a period of orientation, the subject can be put through increasingly difficult tasks for many hours.

After acquiring good control of the first motor unit—that is, being able to fire it in isolation, speed it up, slow it down, and turn it "off" and "on" in various set patterns, most subjects can

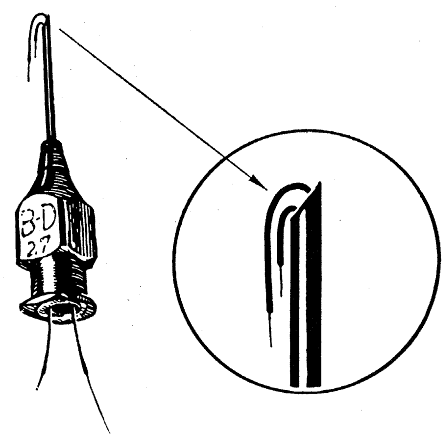

Fig. 4. Bipolar fine-wire electrode (top) greatly magnified in the carrier needle (bottom). The carrier needle will be withdrawn after insertion, leaving the hooked wires in the muscle.

isolate a second unit with which they then learn the same tasks; then a third, and so on. In a serial procedure, the next task may be to recruit, unerringly and in isolation, the several units over which he has gained the best control. The best subjects (about 1 in 20) can learn to maintain the activity of specific motor units in the absence of either one or both of the visual and auditory feedbacks. That is, as the monitors are gradually turned off the subjects must try to maintain or recall a well-learned unit without the artificial "proprioception" provided earlier.

Any skeletal muscle may be selected for motor unit training. In my laboratory we usually select the abductor pollicis brevis, abductor digiti minimi, tibialis anterior, biceps brachii and brachialis, and the extensors of the arm and forearm. But we have also successfully trained motor units in back muscles, shoulder and neck muscles, tongue muscles, and others; there appears to be no limit.

Factors Influencing Motor Unit Training

Almost all subjects (among many hundreds tested) have been able to produce well-isolated contractions of at least one motor unit, turning it off and on without any interference from neighboring units. Only a few people fail completely to perform this basic task. Analysis of subjects that perform poorly and very poorly reveals no common characteristic that separates them from subjects that perform well. Most people are able to isolate and master one or two units readily; some can isolate and master three units, four units, and even six units or many more. This last level of control is of the highest order, for the subject must be able to give an instant response to an order to produce contractions of a specified unit without the interference of neighboring units; he also must be able to turn the unit off and on at will.

Once a person has gained control of a spinal motoneuron, it is possible for him to learn to vary its rate of firing. This rate can be deliberately changed in immediate response to a command. The lowest limit of the range of frequencies is zero—that is, one can start from neuromuscular silence and then give single isolated contractions at regular rates as low as one per second and at increasingly faster rates. When the more able subjects are asked to produce special repetitive rhythms and imitations of drum beats, almost all are successful (some strikingly so) in producing subtle shades and coloring of internal rhythms.

Some persons can be trained to gain control of isolated motor units to such a degree that, with both visual and aural cues shut off, they can recall any one of three favorite units on command and in any sequence. They can keep such units firing without any conscious awareness other than the assurance (after the fact) that they have succeeded. In spite of considerable introspection, they cannot explain their success except to state they thought about a motor unit as though they had seen and heard it personally. This type of training may underlie some facets of the development of ordinary motor skills.

We have found no distinct personal characteristics that reveal reasons for the quality of performance. The best subjects are of various ages, either sex, and may be either manually skilled or unskilled, educated or uneducated, bright or dull personalities [see (*17*)]. Some nervous persons do not perform well—but neither do some very calm persons.

In a recent study (*18*) we set out to discover whether previous training in special skills is a factor in the time it takes to achieve control over the first motor unit. We used the time required for training the motor units in one of the hand muscles as the criterion.

The time required to train most of the manually skilled subjects was above the median, although one might expect the opposite. Henderson (*19*) has suggested that the constant repetition of a specific motor skill increases the probability of its correct recurrence by the learning and consolidation of an optimal anticipatory tension. Perhaps this depends on an increase in the background activity of the gamma motoneurons regulating the sensitivity of the muscle spindles of the muscles used in performing that skill. Wilkins (*20*) postulated that the acquisition of a new motor skill leads to the learning of a certain "position memory" for it. If anticipatory tensions and position memory, or both, are learned, regardless of whether they are integrated at the cerebral level, the spinal level, or both, these or some other cerebral or spinal mechanisms may be acting temporarily to block the initial learning of new skills. It may be that some neuromuscular pathways acquire a habit of responding in certain ways, and it is not until that habit is broken that a new skill can be learned.

When a large number of subjects were studied on two occasions using a different hand each time, Powers (*21*) found that they always isolated a unit more quickly in the second hand. Isolation was twice as rapid when the second hand was the preferred (dominant) hand; it was almost five times as rapid when the second hand was the nonpreferred one. The time required to train a subject to control a previously isolated unit was shortened significantly only when the preferred hand was the second hand.

Any changes in the action potentials of trained motor units as a result of electrical stimulation of the motor nerve supplying the whole muscle must reflect neurophysiologic changes of the single neuron supplying the motor unit. Therefore, Scully and I investigated the influence of causing strong contractions in a muscle to compete with a discrete motor unit in it which was being driven consciously (*22*). Each of a series of subjects sat with his forearm resting comfortably on a table top. The stimulator cathode was applied to the region of the ulnar nerve above the elbow. The effective stimuli were 0.1-millisecond square-wave pulses of 70 to 100 volts, delivered at a frequency of 90 per minute. Because stimuli of this order are not maximal, all axons in the ulnar nerve were not shocked and slight variation must have existed in axons actually stimulated by each successive shock (Fig. 5).

Contrary to expectation, when the massive contraction of a muscle was superimposed on the contraction of only one of its motor units, the regular conscious firing of that motor unit was not significantly changed. Our experiments leave little if any doubt that well-trained motor units are not blocked in most persons. Even the coinciding of the motor unit potential with elements of the electrically induced massive contraction would not abolish the motor unit potential.

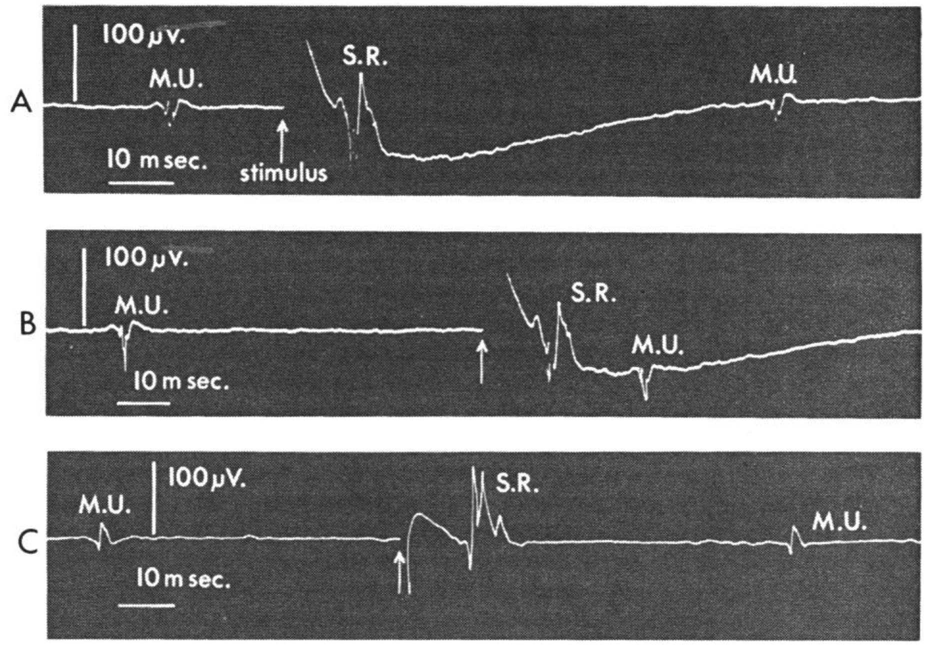

Fig. 5. Undisturbed firing of trained isolated motor units in the abductor digiti minimi of three different subjects, A, B, and C. Arrows indicate application of stimuli (0.1-msec square-wave pulses of 70 to 100 volts) to other axons in the same muscle. Each such stimulus is followed by a massive response (*S.R.*) while the isolated motor units continue to fire uninterruptedly (*M.U.*).

Subjects asked to move a neighboring joint while a motor unit is firing find such a request distracting, but can usually achieve the task in spite of the distraction (*23*). Carlsöö and Edfeldt (*24*) concluded that proprioception can be assisted greatly by exteroceptive auxiliary stimuli in achieving motor precision. Some persons can be trained to maintain the isolated activity of a motor unit regardless of changes in the position of various joints of a limb. In order to maintain or recall a motor unit at different positions, the subject must keep the motor unit active during the performance of the movements; and, therefore, preliminary training is necessary.

Applications of Motor Unit Training

In the search for new models of the learning process, motor unit training emerges as an important technique demanding widespread exploration. In addition to providing a model for neuromuscular training and operant conditioning, it also has practical applications in such fields as rehabilitation and the design of myoelectric artificial aids for the physically handicapped. Normal persons can adequately control several motor units connected electronically to electric motors. With motors having several steps or rates, the strength of contraction can be made variable. Many practical problems in designing such equipment must be overcome, but there is no question of the feasibility of using individual motor units to act as switches for separate channels of mechanical devices (*25*).

Motor unit training has also been used in the retraining of muscles in physical therapy and in teaching patients to relax specific muscles. Jacobs and Felton (*26*) have shown patients with painful traumatic neck spasms how to relax the affected muscle, thus effecting relief from the pain. Hardyk *et al.* (*27*) have used similar techniques to abolish laryngeal muscular activity in certain types of reading problems where the speed of silent reading is impeded by subvocalization. There is no limit to the novel applications in research and technology that are possible from the basic knowledge that, given electronic feedbacks, man can consciously control individual motoneurons with extreme precision.

Electromyographic Kinesiology

Much literature has already accumulated on the role of various muscles as revealed by electromyography. Most of it is only of interest to specialists with a clinical interest and to groups such as athletes, musicians, and dancers that are directly concerned with human physical performance. Most investigations have been centered on man, but comparative studies with other mammals are attracting growing interest among biologists. Here I shall describe some of the studies that have the greatest potential for stimulating increased interest.

Many of the widely held beliefs on human posture—and to a lesser extent, human gait—are based on teleology and metaphysics. Many are not borne out by electromyography. It has long been thought that man has had a complicated evolution and that his posture and locomotion are second-rate adaptations. Adaptations they certainly must be, but electromyography has demonstrated their superb functional efficiencies. Man's upright posture is extremely economical in energy expenditure, and there is no clear evidence that his back and lower limbs are hurt more often than those of quadrupeds. The large "antigravity" muscles in man permit the powerful movements necessary for the major changes from lying, to sitting, to standing, and thus cannot be equated with the antigravity muscles of animals that habitually stand on flexed joints.

To stand erect, most human subjects require very slight activity and some intermittent reflex activity of the intrinsic muscles of the back (*5*). During forward flexion there is marked activity until flexion is extreme, at which time the ligamentous structures assume the load and the muscles become silent. In the extreme-flexed position of the back, the erector spinae remain relaxed in the initial stages of lifting heavy weights (*28*).

Asmussen and Klausen (*29*) concluded that the force of gravity is counteracted by one set of muscles only, usually the back muscles, but in 20 to 25 percent of subjects, by means of the abdominal muscles. The line of gravity passes very close to the axis of movement of the fourth lumbar vertebra and does not intersect with the curves of the spine as is often postulated. Klausen (*30*), investigating the effect of changes in the curve of the spine, the line of gravity in relation to the fourth lumbar vertebra and ankle joints, and the activity of the muscles of the trunk, concluded that the short, deep intrinsic muscles of the back must play an important role in stabilizing the individual intervertebral joints. The long intrinsic muscles and the abdominal muscles stabilize the spine as a whole.

A load placed high on the back automatically causes the trunk to lean slightly forward. The increased pull of gravity is counteracted by an increased activity in the lower back muscles. A load placed low on the back reduces the activity of the back muscles (*31*). There is increased activity when a load is held in front of the thighs. Thus, the position of the load—either back or front—either aids the muscles or by reflex action calls upon their activity to prevent forward imbalance.

While some investigators believe that the vertebral part of the psoas major (a large hip flexor which lies on the side of the spine) acts on the spine, I have found with Greenlaw (*32*) that this muscle shows only slight activity during standing. Even strong attempts to increase the natural lumbar lordosis (the hollow of the back) which is said to be a function of psoas in man, recruits little activity in the muscle.

Multifactorial studies are difficult and time consuming, and only recently has equipment improved to the point where electromyography gives especially useful results. In walking there is a very fine sequence of activity in various groups of muscles in the lower limb. As the heel strikes the ground the hamstrings and pretibial muscles reach their peak of activity. Thereafter the quadriceps, the large muscle mass which extends the knee, increases in activity as the torso is carried forward over the limb, apparently to maintain stability of the knee. As the heel lifts off the ground, the calf group of muscles build up a crescendo of activity which ceases as the toe leaves the ground, although the quadriceps and sometimes the hamstrings reach another (but smaller) peak of activity (*5*).

Conclusions

Among the many studies being made of groups of muscles in human beings, there is one that I shall describe briefly because of its novelty. With a group of music professors, I have been recording the activity of the lip and cheek muscles of wind-instrument players possessing various levels of proficiency. We have found evidence of very clear differences between performers. We have demonstrated a relation between the skill of players and specific electromyographic patterns which requires extensive exploration. Since one purpose of these studies is to establish methods for improving performance, some efforts are being made to apply feedback techniques based on motor unit training. Subjects with multiple electrodes in the muscle of the cheek (buccinator) and lips can selectively activate local areas of these muscles quite easily. This finding provides a firm beginning for many applied studies of performance and its direct modification.

Another study that Tuttle and I began recently (*33*) is concerned with the posture and locomotion of apes with an emphasis on evolutionary theory. Initially, we are examining the "knuckle-walk" of gorillas by means of videotapes and multichannel electromyography from muscles of the hand and forearm. We hope to determine whether man's direct ancestry included a knuckle-walking stage. As the reader can imagine, electromyography in apes is more difficult—and much more hazardous—for the investigator. Our techniques have allowed extensive electromyographic exploration of muscles throughout the forelimb in one gorilla and limited studies in others. In recent months we have also succeeded in recording the concurrent muscular activity in muscles of the hip and thigh regions, of great interest to anthropologists attempting to explain the erect posture of man. The synchronized videotape record displays both the spontaneous behavior of the unrestricted animal and five channels of electromyography from intramuscular electrodes. To extend this work to a larger population without further increasing the risk to the investigators, future work will make increasing use of telemetering by means of multiple transmitters implanted surgically.

Electromyography promises to make significant contributions to a host of biological sciences. Zoologists and psychophysiologists have not taken full advantage of the technique until recently, but this picture seems to be changing. The electronic and recording equipment now available is both better and cheaper than it was formerly, and is improving rapidly. Almost 200 years since Galvani described animal electricity, this branch of science is finally coming into its own.

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On the Impact of the Computer on Society

How does one insult a machine?

Joseph Weizenbaum

The structure of the typical essay on "The impact of computers on society" is as follows: First there is an "on the one hand" statement. It tells all the good things computers have already done for society and often even attempts to argue that the social order would already have collapsed were it not for the "computer revolution." This is usually followed by an "on the other hand" caution which tells of certain problems the introduction of computers brings in its wake. The threat posed to individual privacy by large data banks and the danger of large-scale unemployment induced by industrial automation are usually mentioned. Finally, the glorious present and prospective achievements of the computer are applauded, while the dangers alluded to in the second part are shown to be capable of being alleviated by sophisticated technological fixes. The closing paragraph consists of a plea for generous societal support for more, and more large-scale, computer research and development. This is usually coupled to the more or less subtle assertion that only computer science, hence only the computer scientist, can guard the world against the admittedly hazardous fallout of applied computer technology.

In fact, the computer has had very considerably less societal impact than the mass media would lead us to believe. Certainly, there are enterprises like space travel that could not have been undertaken without computers. Certainly the computer industry, and with it the computer education industry, has grown to enormous proportions. But much of the industry is self-serving. It is rather like an island economy in which the natives make a living by taking in each other's laundry. The part that is not self-serving is largely supported by government agencies and other gigantic enterprises that know the value of everything but the price of nothing, that is, that know the short-range utility of computer systems but have no idea of their ultimate social cost. In any case, airline reservation systems and computerized hospitals serve only a tiny, largely the most affluent, fraction of society. Such things cannot be said to have an impact on society generally.

Side Effects of Technology

The more important reason that I dismiss the argument which I have caricatured is that the direct societal effects of any pervasive new technology are as nothing compared to its much more subtle and ultimately much more important side effects. In that sense, the societal impact of the computer has not yet been felt.

To help firmly fix the idea of the importance of subtle indirect effects of technology, consider the impact on society of the invention of the microscope. When it was invented in the middle of the 17th century, the dominant commonsense theory of disease was fundamentally that disease was a punishment visited upon an individual by God. The sinner's body was thought to be inhabited by various so-called humors brought into disequilibrium in accordance with divine justice. The cure for disease was therefore to be found first in penance and second in the balancing of humors as, for example, by bleeding. Bleeding was, after all, both painful, hence punishment and penance, and potentially balancing

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