Electromyography: Its Use and Misuse in Physical Education

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Many of the readers of this column will have encountered a statement such as, "Electromyography would have helped interpret the results." Tucked away in the conclusions or recommendations for further research sections of a paper or text in kinesiology. Just what is the nature of solutions for intractable problems? Is it just a matter of reading the directions on the bottle and using the required dose? Can the poison produce side effects if not used as directed? Breaking with the medical comparison, this article discusses some of the ways in which electromyography can be used in physical education to advantage or vice in a misleading and perhaps undesirable context. Several articles and books containing electromyography have been written for the kinesiologist (1, 2, 3, 4, 5, 6) and this article attempts to supplement these by highlighting some of the current limitations and problems associated with the application of EMG techniques in kinesiology, assuming that the reader is already familiar with some of the above literature. Its intention is to promote a critical appraisal of EMG applications rather than provide a comprehensive survey of the area.

Prerequisites for EMG

One of the principal causes of misuse in electromyography is that simple surface electromyograms (EMGs) can be obtained by anyone with the right equipment and five minutes instruction. Trouble starts when this person, who may have no idea whatsoever about the structure, function, and properties of the tissues lying beneath the electrodes, attempts to interpret the record that he has obtained. It is my firm belief that the student should have a basic understanding of both fundamental electrophysiology and muscle function and mechanics before he has been exposed to electromyography. A logical approach to the study of both the above areas is to begin with the smallest anatomical and electrical elements — the muscle fiber and its properties together with the motor unit action potential (MUAP). If a foundation such as this is developed through basic gross anatomy and an understanding of the origin of an interference pattern (7), the student can approach electromyography with a good chance of understanding its uses and limitations.

The EMG in Perspective

Supposing these prerequisites are accomplished; in which direction and with what equipment should the budding electromyographer proceed? A principle in which I personally believe is that, except in certain restricted situations, the electromyogram in isolation is of little value. The position of the experimenter who has before him a single channel record of an electromyogram and nothing else may be compared to that of the cryptographer who has the code for a single letter yet needs to decipher a complete message. Some of the additional information that is needed for an adequate evaluation of the record includes: What was happening to the muscle at the time the data were collected? Was it shortening, lengthening, or maintaining the same length? Which part of the record corresponds to which part of the movement being performed? How has the equipment being used modified the record obtained? What processing, if any, has been carried out on the EMG? How has the location of the electrodes affected the results? What exercise had the subject performed prior to the collection of the current record?

Need for Other Instrumentation

The questions raised above span many areas ranging from muscle mechanics and instrumentation to fatigue and signal processing. But the major point being made is that other data must be available in a form which can be synchronized with the EMG to allow a more meaningful interpretation of the electromyogram. Geniometry used simultaneously with electromyography provides an excellent source of information for movements of a restricted nature, while high-speed cinematography is useful in more complex movements. At the very least some information which will indicate temporal phases of the movement directly on the EMG record — perhaps from a simple microswitch arrangement — is necessary. All this means, of course, that a single channel oscilloscope or chart recorder is of little value to the electromyographic kinesiologist.

An example of this combination of electromyography with data concerning the motion of limb segments is shown in Figure 1, where surface EMGs from latissimus dorsi and biceps brachii were recorded together with electrogoniograms from the elbow and shoulder (gleno-humeral) joints during the performance of a chin. The record illustrates how the two muscles studied participated in both the pull-up and descent phases of the movement, both probably acting first concentrically and then eccentrically. The slight lessening of activity, particularly in the biceps, just before the descent begins is noticeable, and the similarity of the EMGs in both phases, despite opposite me-

Figure 1: Electrogoniometer traces and raw surface EMGs taken during a chin.
mechanical conditions, emphasizes the value of additional data concerning joint movement. From the gradient of the goniograms it is clear that greater angular velocities were involved in the descent phase.

**Semi-Quantitative Analysis**

No attempt has been made in the record shown in Figure 1 to perform any analysis upon the interference patterns, which are merely presented as "raw" electromyograms. Many investigators have made what might be called a "semi-quantitative" reduction of the raw waveform on the basis of phasing of activity, amplitude, or some other characteristic. Although these judgments are, in general, unrelated to important considerations such as the force produced by the muscle, the results of this grading of activity have proved useful. Figure 2 shows some of the techniques which have been used by various authors to represent their EMG waveforms. Basically they all consist of a determination of when the muscle was "on and off," together with an indication of where the peak amplitude occurred. Studies involving electromyography at various stages of skill learning have used these techniques (4, 8) to advantage, and although the results of the studies cited have been somewhat inconclusive, much work in this area remains to be done and it is likely that future EMG learning studies will contribute to our understanding of the learning process.

A point which needs to be made in relation to this kind of on-off analysis, particularly where movements of short duration are being studied, is that the onset of the EMG is not synchronized in time with the onset of tension development in the muscle. Although the complete details of the time lag which probably varies from muscle to muscle have not yet been elucidated, it is known that in isometric contraction of the biceps brachii, peak force development may follow the peak EMG anywhere from 60 to 100 milliseconds later (9). Thus, in a movement which itself lasts only 100 msec, it may be possible for the EMG to be almost over before movement actually begins.

**Cross-Talk**

In Figure 3, two cross sections of the lower limb are presented (10), one taken approximately 10 cms. above the superior border of the patella and one 15 cms. below the same landmark. At a point on the circumference of each section, a rectangle has been drawn to represent a vertically placed surface electrode pair. In the thigh section it is clear that the vastus lateralis dominates the geography of the area underlying the electrodes and theoretical calculations (11) confirm the fact that even in the presence of simultaneous activity of the same intensity in all the muscles in this section, the EMG from the electrode pair indicated would still be representative of only the vastus medialis. However, in the shank section the situation is very different; it is likely that activity in any or all of the muscles near to the electrodes such as peroneus longus, some of the long extensor group, or tibialis anterior would produce a signal in the electrode pair shown. It would be impossible to ascribe this activity to any of the muscles individually.

The whole limb, indeed the whole human body, acts as a volume conductor, which is of course the basis for the recording of the electrocardiogram. Despite the fact that a muscle group distant from the electrode will only have an effect which is inversely proportional to the square of that distance (11), extreme caution is necessary for the interpretation of EMGs from regions of the body where muscles with different functions are crowded into a small area. It has been suggested (2) that this problem, which is called crosstalk, renders surface electromyography useless in most applications. This is, however, an extreme view and could be stated instead as an encouragement of care in electrode placement and caution in the interpretation of the surface electromyogram.

**Quantitative Electromyography**

The day that most electromyographic kinesiologists are collectively awaiting, with the enthusiasm of Doomsday watchers, is that when they can use some measurement derived from the electromyogram to indicate the force being produced by a muscle group during unrestricted movement of the body. The state of the art in this quantitative area is relatively primitive and research is continuing (12, 13) to try to unravel the complexities which the biological system refuses to divulge! Some facts are well established, however; there appears to be a parabolic relationship between the force produced by a muscle under isometric conditions and a measure known as the full wave rectified
integral (FWRI) of the surface EMG (14, 15). There are "black boxes" available to perform this operation and these can form the basis of informative and valuable laboratory sessions. The FWRI, as shown in Figure 2, can be calculated in small time periods (16) to indicate the nature of a phasic burst of activity. The integral is just one of many ways to quantify the EMG waveform; other techniques such as counting spikes (6) and measuring excursions between turning points (16) have yielded essentially similar results. It must be stressed that the relationship mentioned above exists only under isometric conditions or extremely limited and special conditions of movement (17). Even this relationship is complicated by the fact that most joints in the human body are crossed by muscles that are more than one muscle, which makes the investigation of relationships between force and the electromyogram difficult. It has also been demonstrated (18) that both signal amplitude and the relationship between integrated EMG and tension are dependent upon positioning and separation of electrodes over a given muscle. This factor must be considered in the development of relationships and in the comparison of results between different investigators. As soon as the body begins to move—that is, just at the time a kinesiologist becomes interested—almost all of the relationships that have been identified, particularly those between EMG and force produced, cease to be valid. This is due principally to the fickle properties of skeletal muscle, which is able to exert different forces depending upon its length and the rate at which its length is changing (19, Chap. 13). It is because of this lack of fundamental knowledge concerning the relationship of the electromyography to other important phenomena that misinterpretation occurs and errors are perpetrated.

Some Abuses

Just because the amplitude of the EMG from a muscle during movement is greater under certain conditions, it is not possible with existing knowledge to imply that the force being produced is greater. Another common mistake occurs when two independent EMGs from different muscles are available. It is easy to imply, as some investigators have implied, that because the amplitude, integral, or some other measure of muscle A is greater than the corresponding measure from muscle B, then muscle A is producing more force than muscle B. This situation is complicated by many factors ranging from the size of the actual muscle fibers to the nature of the interface between the skin and electrodes. This point is well illustrated by the simple experiment shown in Figure 4, in which a subject is maintaining a 40 lb. barbell in a static position. If we can assume that there is symmetry in the attachment of the left and right biceps to the skeleton and that the various muscles having a flexor action at the elbow are used in similar proportions on the left and right sides, it is then possible to say that equal force is being exerted by the left and right biceps brachii muscles. The interference patterns from surface electrodes over the left and right biceps are shown in the lower part of Figure 4 together with a one millivolt 60Hz calibration signal. The considerable difference in the amplitudes of the two electromyograms is apparent despite the similarity of the posture and of the equipment used to collect the signals. Differences such as these have been suggested as a basis for evaluating the functional state of muscle (20), and further investigation is needed in this promising area. Although the example presented here is not from isometric conditions, the limitation of comparisons between two muscles is even more restricting in the dynamic situation.

Recordings from Single Motor Units

Another important area of study in electromyography concerns the recording and recognition of action potentials from single motor units (SMUs). Research in recent years has shown that an amazing apparent "over design" exists in the human nervous system whereby small numbers of muscle fibers from the millions at our disposal can be controlled voluntarily after a period of training (3). An example of this control is shown in Figure 5, where after a brief period of training, the subject is "counting up to ten"—the first 3 counts being visible on the scope face—with a motor unit from the abductor digitii minimi. Work with SMUs in physical education has been relatively limited because it is usually, though not always (21), necessary to use intramuscular electrodes which are inserted through the skin. It is essential that any experimenter who uses these methods be thoroughly trained both in human anatomy and in the techniques of preparation and insertion of the electrodes. The dangers of infection and serious damage to nervous tissues are too great to feel that these techniques are freely available to anyone who has the inclination to try them. However, in well trained hands, the study of SMUs provides extremely valuable insight into the operation of the individual units of the nervous system. The electromyography of SMUs is certain to make a great contribution in the future, particularly in the area of neuromuscular mechanisms of learning, and has already proved useful in the rehabilitation of injuries to the nervous system.

In Conclusion

This has been somewhat of a whistle-stop tour of an expansive area, and consequently many important aspects have been omitted. These include the effect of fatigue upon the electromyogram (22), the problems of day-to-day reliability of EMG measures (20), the influence of movement artifact and electrode construction upon EMG signals (23), the use of EMG to differentiate between slow and fast muscle fibers (24), and the advantages of bipolar or unipolar electrode systems (20). Also the uses of EMG in the training of relaxation and in dance education, sometimes termed "biofeedback," techniques, have not been discussed. Despite the fact that many limitations of electro-
myography have been mentioned, the author does not hold a pessimistic view of the role of electromyography in physical education. It is an indispensable tool in kinesiology and biomechanics and the limitations are stressed merely so that these valuable techniques can be more effectively used.

References