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Problems Inherent in the Study of the EMG/Isometric Force Relationship

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국문요약

근전도/등척성 힘 관계연구에서 고유의 문제점

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본 연구의 목적은 운동제어/학습 또는 운동역학을 연구하는데 중요한 역할을 하는 근전도의 사용과 근전도와 등척성 수축력과의 관계에 나타나는 문제점과 제안점을 조사하는 것이다. 선행연구를 분석한 결과, 등척성 힘의 증가에 따른 근전도의 증가 관계가 선형적 모양으로 나타나지는 않았다. 또한, 선행연구에서 근전도와 등척성 힘 관계를 연구하는데 몇가지 문제점들이 발견되었다. 이러한 문제점은 선행 연구실험들의 절차상에 차이가 나타났고, 근육의 생리학적인 또는 해부학적인 성질에서 문제점이 논의되었다. 결론적으로, 이러한 문제점들이 해결되지 않는 한 근전도와 등척성 수축력과의 관계는 불분명하게 남아있을 것이다.

핵심단어: 근전도; 등척성 힘; 운동단위; 정량화.

Introduction

Electromyography (EMG) is the study of muscle function through the inquiry of the electrical signal the muscles emanate (Basmajian and DeLuca, 1985). Clinicians have used EMG as a tool to diagnose certain motor disorders and to prescribe and evaluate rehabilitation programs for their patients. Kinesiologists have used EMG to help them understand how muscles function in certain movements and what changes occur as a result of learning. The practical use of the technique in these situations is dependent on a knowledge of the relationship between EMG and certain biomechanical variables. Perhaps the most important of these is the relationship between EMG and force. However, controversy still exists concerning the description of this relationship as research has generated many inconsistent findings (e.g., Basmajian and DeLuca, 1985; Bouisett, 1973; Engelhorn, 1983; Engelhorn, 1987; Rozendal and Meijer, 1982; Woods and Bigland-Ritchie, 1983). Unfortunately, this controversy has serious implications for the use of EMG in understanding human movement as analysis assumes a precise knowledge of the EMG/force relationship.

The purpose of this paper is to examine a select few papers that highlight the inconsistencies in the research and then provide a more detailed discussion of the problems that have caused these inconsistencies. The paper will confine itself to research on the relationship between EMG and isometric tension as the situation is further complicated in an isometric contractions.

How Does EMG Work?

As stated previously, EMG is a study of the electrical activity in muscles. This activity can be picked up and recorded with specialized equipment.

Under normal conditions an action potential propagating down a motorneuron activates all the branches of the motorneuron which in turn activates all the muscle fibers of a motor unit. Muscle tissue conducts electrical potentials similarly to the way in which axons transmit action potentials. Once the post-synaptic membrane of a muscle fiber is depolarized, the depolarization propagates in both directions along the fiber. This depolarization wave generates an electromagnetic field in the vicinity of the muscle fibers. An electrode located in this field will detect the potential (voltage), which is known as an action potential (AP). Because the depolarization of muscle fibers overlap in time, the recorded signal reflects a combination of the individual APs, which is more commonly referred to the motor unit action potential (MUAP). The signal recorded from the whole muscle is known as a muscle action potential (MAP).

Electrodes can generally be divided into two groups: surface or indwelling (intramuscular). Both types of electrodes are influenced by waves that pass by their conducting surfaces as well as waves that pass nearby.

Surface electrodes consist of metal discs (usually silver/silver chloride) about 1 cm in diameter. They detect the average activity of superficial muscles and give more reproducible results than indwelling electrodes (Winter, 1979). Indwelling electrodes are used to record from deep muscles or to investigate fine movements. These can be of two types: needle, fine wire. Needle electrodes are simply hypodermic needles with an insulated conductor inside which is bared to the muscle tissue at the open end of the needle. The needle itself forms the other conductor. In contrast, fine wire electrodes (about the diameter of human hairs) require insertion with a hypodermic needle but then remain in contact with the muscle tissue through their uninsulated ends.

Most EMGs employ a bipolar electrode arrangement where two electrodes are used over the muscle site. Thus, the signal recorded is the difference in potential between the two electrodes. As the human body is a good conductor that will pick up any electromagnetic radiation present, this technique eliminates much of the interference that may influence the recorded signal.

Surface electrodes automatically record longer duration MAPs than indwelling electrodes because of the larger surface area over which they record. However, for a given set of electrodes the duration of the MAPs is a function of the velocity of the propagating wavefront. Normal individuals usually have a propagation velocity of about 4 m/sec. The faster the velocity the shorter the duration of the MAP. Velocity may be affected by certain myopathies and by fatigue. Fatigue causes biochemical changes in the muscle which may affect its filtering property

The factors affecting the amplitude of the action potential are slightly more complex than those affecting the duration. These include: the diameter of the muscle fiber; the distance between the active muscle fiber and the detection site; and the filtering properties of the electrode (e.g., size of detection surfaces, distance between contacts, and chemical properties of the metal-electrolyte interface). These factors will be discussed in more detail in the final section of this paper.

Studies on the EMG/Isometric Force Relationship

This section looks at three studies that are representative of the general trend in the research on the EMG/force relationship. A comparison of the three highlights the in consistencies in the area and the problems researchers must confront if they are to come up with a definition of the relationship.

Early studies on the relationship suggested that, for isometric contractions, the amplitude of the EMG signal should increase as the square root of the force generated by the muscle when the motor units are activated independently (Basmajian and DeLuca, 1985). However, the majority of investigators report either a linear or non-linear increase in EMG as force increases.

One of the first studies on the relation between EMG and force was conducted by Lippold (1952). Lippold (1952) studied the gastrocnemius-soleus muscle group during plantar flexion of the foot. Action potentials were recorded from thirty different subjects during isometric contractions at ten different strengths ranging from 4.5 to 45 kg on a dynamometer strain guage. The results showed a linear relationship between the EMG and the tension produced by the voluntary isometric contractions. This relation ship held across the full range of the contraction strengths. Lippold (1952) believed hese results reflected a spatially random recruitment of motor units as well as either random increments of discharge frequencies or smooth increments once the units had been activated.

Zuniga and Simons (1969) studied the relationship between EMG activity in the biceps brachii and isometric tension generated by a steadily increasing voluntary isometric flexion. The averaged plots of the results of one subject and from nine subjects together showed a non-linear relationship between the averaged EMG and tension. Their results were obviously in contrast to those of Lippold (1952). Zuniga and Simons (1969) believed their results arose from an increase in the synchronization of motor unit activity which caused an increase in the amplitude of the EMG pattern above 20% of maximum voluntary contraction (MVC).

A different approach to the problem was taken by Woods and Bigland-Ritchie (1983). They studied the adductor pollicis, soleus, biceps brachii, and triceps brachii of 20 subjects. Subjects made brief contractions at various submaximal force levels, ranging from 10~90% of maximal voluntary contraction. Results indicated a linear relationship for the adductor pollicis and soleus, but a non-linear relationship for the biceps brachii and triceps brachii. They concluded that the differences observed were a manifestation of the compositional differences of the muscles tested (i.e., relative percentage of fast-twitch vs, slow-twitch fibers). Procedural differences were discounted as a possible confounder of the results as procedural variations (changes in electrode placement, recording configuration, and limb position) did not affect the observed relationship.

These three studies provide a good introduction and overview of the state of research in the area. It is already apparent that there are a number of problems that make comparisons among studies and replication of studies very challenging.

Problems Associated With the Study of the EMG/Force Relationship

Now that the inconsistencies in the research have been highlighted it is important to try to understand what has caused them. Basically, these inconsistencies stem from procedural differences among studies as well as physiological and/or anatomical differences of motor unit organization in the various muscle groups studied. Before each of these problems is dealt with independently it would be beneficial to consider some general methodological problems inherent in the use of EMGs.

According to Rozendal and Meijer (1982), human kinesiological EMG suffers from four major methodological problems: localization, cross-talk, mechanical context, and quantification. Localization requires a knowledge of the muscle(s) from which the signals are generated. As the signal is the sum total of the activities of several muscles (cross-talk problem), localization is a difficult problem to overcome.

Experimenters must rely heavily on an excellent knowledge of kinesiological anatomy and anthropometry in order to determine if they are recording from the muscles under investigation. Rozendal and Meijer (1982) assert that this has led to a logical circularity as the testing procedure is often derived from the hypothesis under investigation. For example, if a researcher wants to test if a muscle has a particular function, then in order to determine if the electrode is in, or recording from, the muscle the subject must perform the function under investigation. Ironically, this means that if a researcher wants to determine the function of a particular muscle through EMG he must already know its function. This problem is further compounded because it is necessary to determine if there is activity or no activity in a muscle. This assumes a knowledge of a particular threshold under which it may be concluded that no activity appears and above which something is going on.

The mechanical context problem relates to the potential function of a muscle. Potential function refers to the type of contraction, which may be concentric, static, or eccentric. In many situations it is difficult to determine which type of contraction is occurring. The situation is further complicated when it is considered that muscles can also act as neutralizers or stabilizers.

Quantification refers to the quantities derived from the raw data to represent the amplitude of the EMG signal. There are several techniques that can be used. It is beyond the scope of this paper to deal with these techniques, except to note that there is no consistent use of just one technique and the technique employed is usually dictated by the purpose of the study. According to Basmajian and DeLuca (1985), the lack of a proper description of the EMG signal is probably the biggest single factor that has hampered the development of EMG into a precise discipline.

Different methods of quantification are just one of the procedural variables that make it difficult to compare studies. There are a multitude of others that only need to be considered briefly to gain a taste of the size of the problem they represent.

Procedural Problems

Many variations in detection and data processing techniques have been used by researchers. It has already been mentioned that detection site, electrode type, electrode configuration (monopolar vs. bipolar), skin preparation, and amplifier and filter specifications can affect the amplitude of the EMG signal. These differences are compounded by the lack of a consistent use of one parameter measure of amplitude and further compounded by variations in data processing techniques. For example, some investigators have averaged their data (masking subject differences such as age, gender, onset of fatigue, and level of physical conditioning) while others have presented data from individual subjects. Data analysis has also shown considerable variation. Zuniga and Simons (1969) noted that a number of researchers have examined their data for linear regression but made no mention of testing them for non-linear fit. A final important procedural difference is the use of either continuous or interrupted, serial measurements of force and EMG.

Physiological and/or Anatomical Problems

Physiological and/or anatomical properties of the muscles tested contribute to the inconsistencies within the research. Several muscle dependent phenomenon may contribute to the EMG/force relationship. These include: motor unit recruitment and firing rate properties; relative location of the fast twitch fibers within a muscle and with respect to the detection electrodes; cross-talk from signals originating in adjacent muscles; and, agonist-antagonist muscle interaction.

There is clear evidence that the firing rate and recruitment properties of relatively large and small muscles differ distinctly (Basmajian and DeLuca, 1985). In smaller muscles the firing rates of motor units reach relatively higher values than the firing rates of motor units in larger muscles. Furthermore, firing rate at recruitment is much more variable among motor units in different muscles than among motor units within a muscle. Motor unit recruitment is typically a function of size in steadily increasing contractions, with the smaller motor units recruited initially followed by the larger units. Small muscles recruit all their motor units well below 50% of MVC while larger muscles recruit motor units throughout the full range of voluntary force. As a result, smaller muscles rely more on firing rate to increase force above 50% of MVC. Larger muscles recruit motor units at least to 90% of MVC and possibly higher. Their firing rates peak earlier, then plateau.

Motor units are not evenly distributed within the muscle so that the relative location of slow-twitch and fast-twitch fiber is an important consideration. The amplitude of the action potential is proportional to the fibre diameter. Fast-twitch fiber are generally larger in diameter and therefore generate a larger amplitude action potential. This higher action potential may also be a result of a higher resting membrane potential and a greater density of sodium channels in fast-twitch fiber. The amplitude of the signal is also a function of the distance between the active fiber and the detection electrode. As the larger motor units are recruited at higher force levels, the relative location of the fast-twitch fiber within the muscle and with respect to the recording electrodes determines how the signal from the motor units affects the surface EMG signal. According to Woods and Bigland-Ritchie (1983), the low threshold units, which are recruited during low force contractions, predominate in the deeper layers of muscles of mixed fiber type. They propose that the non-linear EMG/force relation, often observed over the lower force range, may result from an attenuation of the signal from the low threshold units so that the EMG per unit force is reduced. This situation changes as force increases and the more superficial high threshold units are recruited.

Cross-talk from signals originating in adjacent muscles is primarily a function of the agonist-antagonist muscle interaction. In various situations there is a need to stiffen the joint and the antagonist(s) may be active. As force increases it is assumed to be directly related to the agonist. However, this relationship may be altered by such things as joint angle, limb position, and pain sensation. In addition to the antagonist, it is almost impossible to determine the extent to which synergist muscles contribute to the stiffness of the joint as force increases. With respect to the previous information it seems clear that the EMG signal can be affected by a combination of these variables, especially as force increases.

Conclusion

The relationship between EMG and force is clearly a tenuous one. EMG seems to increase proportionally with force but it is unclear whether this relationship is linear or non-linear. To date research has generated inconsistent findings. It has been proposed that these inconsistencies can be attributed to either procedural differences among studies or physiological and/or anatomical properties of the different muscles studied. Procedural differences result from variations in detection, quantification, and data processing and analysis. Physiological and/or anatomical differences are due to motor unit recruitment and firing rate properties; relative location of fast-and slow-twitch fiber; cross-talk from adjacent muscles; and agonist-antagonist muscle interactions. Unless these problems are dealt with adequately, the EMG/force relationship will remain obscure.

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