Pakistan Journal of Pharmacology
Vol.21, No.2, July 2004, pp.55-63

RELATIONSHIP OF EMG PARAMETERS WITH LOAD APPLIED DURING MUSCULAR ACT

AZEEM, M. A., FARHANA, Z., ARIFA, S., ERUM, A., ANWAR, A. AND SADAF, A.
Neuromuscular Unit, Department of Physiology, University of Karachi
e-mail: azenmu@super.net.pk

ABSTRACT

Relationship between muscle length and active / passive tensions are the established facts in muscle mechanics. Both of these tensions exhibit different mechanical abilities and relation with muscle length. Since electrical activity is followed by mechanical act in muscle, therefore, the present study was carried out to find the relationship of various surface electromyographic (SEMG) parameters with an increase in initial muscle length due to lifted load. For experimental purpose normal subjects of 20-22 years of age group were selected for the recording of SEMG signals from Biceps Brachii (BB) during flexion at elbow with loads of 0-5Kg. The result demonstrated an optimal value of peak amplitudes at an intermediate load of 2Kg. This optimal behavior against load was found similar to active tension against muscle length. In addition, the behavior of number of peaks and SEMG response duration against increasing load was found similar to that of passive tension against muscle length. The results are discussed in terms of load dependent optimal increase in motor unit potentials and change in the recruitment pattern with increase in the initial muscle length due to lifted load.

Key Words: Electromyography, Load, Muscle Length, Motor Unit Potential, Tension generation

INTRODUCTION

When a muscle contract voluntarily against a constant load, the electrical activity in the muscle increases with time and it only maintains by recruitment of additional motor units, so recruitment must take place to compensate for the constantly decreasing force available per fiber (Eason, 1960). During slow flexion of the elbow with or without load, the BB showed considerable activity, and an addition of a weight held in hand increase the muscular activity in the BB (MacConiall, 1949). EMG potentials vary directly with the strength of contraction in a muscle (Bigland and Lippold, 1954a; and Keijo *et al*., 2001). Stalberg *et al*., (1983) and Mark *et al*., (2004) measured the interference pattern, while the load was varied, normal values were influenced by age, gender, muscle and recording electrodes. The increase in electrical activity which occur as a muscle contracts more powerfully has provided an important mean for studying how far different muscles implicated in movements about particular joints (Dempster and Finerty, 1947). Muscle strength is definitely a very complicated function, depending on number of motor units activated and their frequency of contraction. With increasing load, recruitment of motor units is most important until the load becomes heavy; then an increase of the firing rate becomes the most prominent mechanism for the development of force. EMG permit load measurements on single muscle and it may be accomplished by using surface electrodes (Osu *et al*., 2002; Lowery *et al*., 2003; Lapatki *et al*., 2004). EMG does reflect the magnitude of muscle engagement and used to measure the exerted force in percent of the maximal voluntary muscle strength (Hagberg 1981a). Bonnet *et al*. (1991) demonstrated that the stretch associated changes in EMG response and they reported greater facilitation in flexor

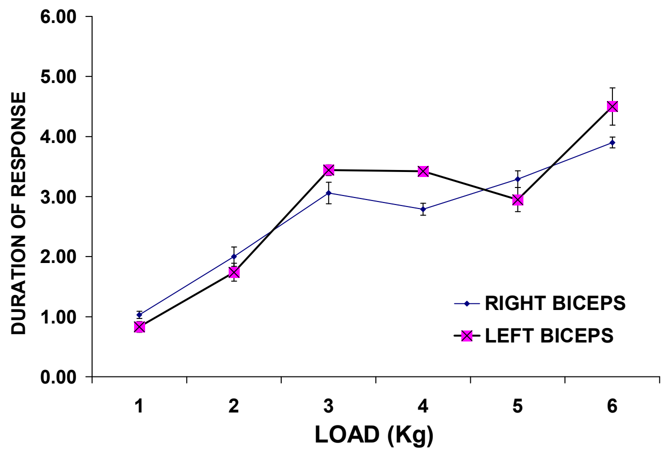

Fig. 1a and b: Effect of load (Duration of Response)

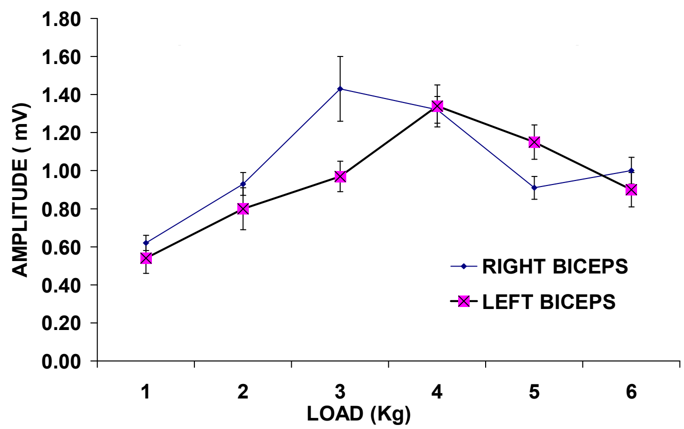

Fig. 2a and b: Effect of load (Peak to Peak amplitude)

muscle than extensor muscle regardless of the degree of stretch. Li & Kazuyoshi (1996) reported that value of maximum voluntary contraction (MVC) in BB depended on contraction level of muscle. The reports regarding the relation of load with various EMG parameters are not available in literature. It was thus planned to determine this relationship by applying different load during flexion of the forearm at elbow while recording the EMG potentials from biceps.

MATERIALS AND METHODS

For all the experiments subjects were selected from the students of M.Sc. (Final), Department of Physiology, University of Karachi, Pakistan, ranging from 20-22 years of age. These subjects were asked to perform flexion of upper limbs at elbow joint for the recording of electromyographic potentials from Biceps Brachii. The experimental setup included three-channel chart recorder

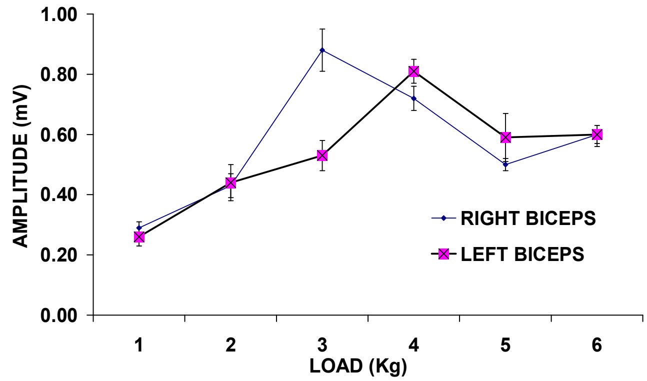

Fig. 3a and b: Effect of load (Maximum Peak Amplitude)

(Lafaytee), amplifier (M-76422T), pre-gelled surface electrodes, earth leads, hand dynamometer (Lafaytee M-76618), weights (1 to 5Kg), razor, sprit and cotton as accessories.

Before recordings, two pre-gelled electrodes were attached on the right arm at the belly of Biceps brachii and one on lateral surface of right arm for reference. The frequency and gain were adjusted while the pen heat was increased to its maximum level. The paper speed was 25mm/Sec. The subject was asked to flex and extend the right arm without load and SEMG signals were recorded from BB at zero load. This process was repeated with 2, 3, 4 and 5Kg loads. The above procedure was repeated for left arm as well. After each experiment the calibration was obtained for 1mv at same gain and frequency levels that were used during experiment. From the recorded signals, number of peaks (NOP), duration of response (DOR), maximum peak amplitude (MPA), peak to peak amplitude (PTPA) and maximum peak duration (MPD) were measured and analyzed using standard statistical tools and student's t-test for data comparison using 0.05 level of significance. Later, the average values of various SEMG parameters were plotted to obtain relationships against various loads.

RESULTS

I. *Comparison of Various EMG Parameters Recorded from Right Biceps Brachii with different Loads*

The original records of EMG obtained from right Biceps with different loads have been presented in Table 1. When these average values obtained without load were compared with the average values obtained by using different loads, it was observed that an increase in load was responsible to increase the NOP, DOR, MPA, MPD and PTPA, gradually. This gradual increase in NOP was found to be ranging from 1 fold to 3 folds as load increased from 1Kg to 5Kg. The statistical comparison showed a significant ($P<0.005$) difference when these average values were compared statistically between the average values obtained without load and with load ranging from 1-5Kg. Similarly, DOR showed an increase in its values ranging from 1 fold to 2 folds (Table-1). The statistical comparison also demonstrated a significant ($P<0.005$) difference. The amplitude parameters, i.e., MPA and PTPA have been found to exhibit a similar pattern of rise in their values when compared between without load and with 2-Kg load. These values have been found to de-crease when 3, 4 and 5 Kg loads were applied

(Table-1). Although, these values were still higher than the values obtained without load. The statistical comparison of MPA and PTPA between the average values obtained without load and with 1-5 Kg loads demonstrated a significant ($P<0.005$) difference among them.

II. Comparison of Various EMG Parameters Recorded from Left Biceps Brachii with Different Loads

The average values of all the EMG parameters recorded from the left arm have been shown in Table 2. A comparison of these average values obtained by using different loads and without load, has demonstrated that the NOP, DOR, MPA and PTPA gradually increased due to an expected increase in initial muscle length. This gradual increase in NOP was found to be ranging from 1 fold to 6 folds as load increased from 1 kg to 5 kg (Table 2). The statistical comparison showed a significant ($P<0.005$) difference when these average values were compared statistically between the average values obtained without load and with load ranging from 1-5 kg. Similarly, DOR also showed an increase in its values ranging from 1 fold to 4 folds (Table-2). The statistical comparison also demonstrated a significant ($P<0.005$) difference. The amplitude parameters, i.e., MPA and PTPA have been found to exhibit a similar pattern of rise in their values when compared between without load and with 3 kg load (Table 2). These values have been found to decrease when 4 kg and 5 kg loads were applied. Although, these values were still higher than the values obtained without load. The statistical comparison of MPA and PTPA between the average values obtained without load and with 1-5 kg loads demonstrated a significant ($P<0.05$) difference among them.

III. Comparison of the Effect of Load in Right and Left Biceps Brachii

All the average values of EMG parameters presented in Table 1 and 2 for right and left arms respectively demonstrated that an increase in load results in a gradual increase in all the EMG parameters, i.e., NOP, DOR, MPA, MPD and PTPA. When this effect was compared between right and left Biceps Brachii, it was observed that an increase in load from 0-5Kg resulted in greater increase of EMG parameters recorded from left Biceps. While it resulted in lesser rise in EMG parameters recorded from right Biceps Brachii. The parameters, i.e., DOR and the NOP have exhibited approximately a pattern of gradual rise from 0-5kg. While the amplitude parameters, i.e., MPA and PTPA have exhibited optimal values at 2Kg (right biceps) and 3 kg (left biceps).

DISCUSSION

According to the above described results, it is evident that, as load was increased gradually an increase in initial muscle length is expected due to stretch. It has also increased the SEMG activity in its duration and amplitude. It was found true in both the right and left biceps. A significant difference have been found for all the EMG parameters, between the EMG responses obtained from BB without load and with load, for both the right and left sides.

The NOP showed a marked increase from 1 fold to 3-6 folds, in right and left BB between 1-5 Kg load. This gradual increase showed that motor units (MUs) were recruited to produce required force to lift the load. Muscle strength depends on the number of MUs activated and, the frequency of contraction. When load was increased the muscle produced more and more numbers of spikes to compensate the load (Komi and Vitasalo, 1976). It had been also reported that with slight contraction smaller potentials appear first and as the force/load is increased, larger and larger potentials produced with an increased frequency of firing (Olsen *et al*., 1968; Ashworth *et al*., 1967; Grimby and Hannerz, 1968. 1970, 1974a and b; Hannerz, 1973; Grimby *et al*., 1974). Another evidence is given by Bigland and Lippold (1954a), who showed that number of motor unit potentials

(MUPs) vary directly with the strength of contraction in a muscle. In another study performed by Missiuro, *et al*. (1962a and b), it was demonstrated that the EMG recorded from surface electrodes over Biceps grow steadily during intense physical exertion and SEMG in the final stage of exertion shows evidence of synchronization of MUPs. Further confirmation was given by Norris and Gasteiger (1955) that units producing larger potentials appear later, discharging only at high tensions.

The duration of EMG responses, i.e., DOR (Fig 1a and b), showed a similar pattern of increase with increasing load magnitude in both the right and left BB. From the above discussion, it is suggested that DOR increases with increasing load also because of increased initial length of muscle and involvement of more and more MUs, which take long time to recruitment for load compensation to produce greater force (Mark *et al*., 2004). Therefore, as load was increased from 0-5 Kg, more and more MUs recruited to compensate this increasing load and ultimately the rate of limb movement decreases. Hence, the response duration was found to increase from 1 fold to 2-4 folds in right and left BB.

Both the relationships for NOP and DOR demonstrated rise in their values with increasing load that is also true for the passive tensions against length. Since application of pre-load resulted in stretch as well as an increase in initial muscle length, therefore it is suggested that the rise in NOP and DOR be related to load as well as initial muscle length. In addition, the passive tensions represent elastic behavior of muscles; therefore, it is further suggested that NOP and DOR are the electrical parameters that probably associate indirectly to influence the elasticity of muscle. It is proposed that those muscles that possess more elasticity may have greater NOP and DOR during their electrical activity.

The amplitude parameters, i.e., MPA and PTPA followed a clear optimal relation with load, in both right & left BB (Fig 2, 3a & b) i.e., both of these parameters showed a clear rise in their values until a certain load and then decline when load was further increased. This pattern can be clearly demonstrated as similar with established length-active tension (L-T) relationship in skeletal muscles. In L-T relation an increase in muscle length, increases active tension generating ability of muscle being maximum at an optimal length of the muscle. When muscle length is increased further the active tension production by the muscle decreases, i.e., beyond the optimal length. Ismail & Ranatunga (1978) clearly demonstrated that human BB muscle operates through a nearly complete length-tension relation with the range of movement. Increase of amplitude with increasing load was also reported by many scientists. A study by Person (1960) clearly demonstrated that the amplitude of MUPs progressively increased as the load is increased. A similar study was performed by Bayer and Flechtenmayer (1950) in which they reported that the mean voltage recorded through surface electrodes over BB was approximately proportional to the force of contraction. Further, Hagberg (1979) reported that amplitude of the myoelectric signals closely reflects the muscular load in non-fatiguing muscular contractions. Norris and Gasteiger (1955) showed that MUPs tend to increase in amplitude with excitation and tension during isometric contraction of normal muscles. In another study it is confirmed that during voluntary contraction muscles most certainly show a direct relationship between force of contraction and EMG voltage, i. e., amplitude (Lippold, 1952; Bigland-Ritchei *et al*., 1953, 1954a and b). Further, Simpson (1965), demonstrated that during voluntary contraction of muscle the number and voltage of muscle fibers contracting per unit of time is related to the tension exerted, i. e., load. Komi and Vitasalo (1976) reported that with change in muscle tension there is a change in amplitude of EMG potentials. Similarly, Zhukov and Zakharyants (1959) studied BB under continuous supporting activity against load, at a certain stage lifting of the load appeared to be subjective and typical changes appear in the EMG, i. e., amplitude of potentials rises, synchronization of potentials appears (Missiuro *et al*., 1962a and b and Currier, 1969).

From the above discussion, it is concluded that load exerts a significant effect on the SEMG activity of the BB in both the limbs. Further that BB follows a length-tension relationship, and the greater values of NOP, durations obtained from BB with load may be suggested due to an increase in the number of involved MUs and association with muscle elasticity. According to Cohen and Brumlik (1976) the number of MUPs depends on strength of contraction, i. e., the number of MUs involved. While the amplitude parameters of SEMG signals showed in the present study that their maximum values at an optimal length of the muscle and showed clear length-active tension type relationship. Thus, the amplitude parameters MPA and PTPA relate with the active tension generation ability of muscle. The decline in the peak amplitudes at higher loads when sarcomeres are stretched beyond optimal length is suggested to be associated with the sensory response produced through muscle spindle (due to stretch) for the reduction in motor unit involvement through spinal cord.

In addition, some differences have been found between the right and left BBs SEMG responses, i.e., higher values obtained from left BB for all the SEMG parameters than right BB. This difference is probably due to hand dominance. Since, all the subjects were right handed, therefore lifting of load was easier for right BB than left BB. It is therefore suggested that relatively less numbers of MUs involved in right BB than left and thus higher values obtained for left as compare to right one.

REFERENCES

Ashworth, B., Grimby, L. and Kugelberg, E. (1967). Comparison of voluntary and reflex activation of motor units: functional organization of motor neurones. *J. Neurol. Neursurg. Psychiat.,* **30**: 91-98.

Bayer, H. and Flechtenmayer, C. (1950). Ermuding and Aktionspannung bei der isometrischen Muskelkontraktion des Menschen. *Arbeitsphysiologie.* **14**: 261.

Bigland-Ritchie, B. and Lippold, O.C.J. (1954a). The relation between force, velocity and integrated electrical activity in human muscles. *J. Physiol. (Lond.).* **123**: 214-224

Bigland-Ritchie, B. and Lippold, O.C.J. (1954b). Motor unit activity in the voluntary contraction of human muscle. *J. Physiol.* **125**: 322-335.

Bigland-Ritchie, B., Lippold, O.C.J. and Wrench, A. (1953). The electrical activity in isotonic contractions of human calf muscle. Proc. of the Physiol. Society, 20-21 March, *J. Physiol.* **120**: 40p-419.

Bonnet, M., Requin J. and Stelmach G.E. (1991). Changes in electromyographic responses to muscle stretch, related to the programming of movement parameters. *Electroencephlogr. Clin. Neurophysiol.* **81**: 135-151.

Cohen, H.L. and Brumlik, J. (1976). Electro-diagnosis. *In "Manual of Electroneuro-myography*". 2nd Ed., Harper and Row, Hagerstown, Maryland, N.Y.

Currier, D.P. (1969). Measurment of muscle fatigue. *J. Am. Physiol. Th. Assoc.* **49**: 724-730.

Dempster, W. T. and Finerty, J.C. (1947). The relative activity of wrist-moving muscles in static support of the wrist joint; an electromyographic study. *Amer. J. Physiol.* (Lond.). **150**: 596.

Eason, R.G. (1960). Electromyographic study of local and generalized muscular impairment. *J. Appl. Physiol*. **15**: 479-482.

Grimby, L. and Hannerz, J. (1968). Recruitment order of motor units on voluntary contraction: changes induced by proprioceptive afferent activity. *J. Neurol. Neurosurg. Psychiat.,* **31**: 565-573.

Grimby, L. and Hannerz, J. (1970). Differences in recruitment order of motor units in phasic and tonic flexion reflex in 'spinal man'. *J. Neurol. Neurosurg. Psychiat.* **33**: 562-570.

Grimby, L. and Hannerz, J. (1974a). Differences in recruitment order and discharge pattern of motor units in the early and late flexion reflex components in man. *Acta Physiol. Scandinavi.* **90**: 555-564.

Grimby, L. and Hannerz, J. (1974b). Disturbances in the voluntary recruitment order of anterior tibial motor units in bradykinesia of Parkinsonism. *J. Neurol. Neurosurg. Psychiat.* **37**: 47-54.

Grimby, L., Hannerz, J. and Ranlund, T. (1974). Disturbances in the voluntary recruitment order of anterior tibial motor units in spastic paraparesis upon fatigue. *J. Neurol. Neurosurg. Psychiat.* **37**: 40-46.

Hagberg, M. (1979). The amplitude distribution of surface EMG in static and intermittent static muscular performance. *Eur J Appl Physiol Occup Physiol* **40**(4): 265-272.

Hagberg, M. (1981a). On evaluation of local muscular load and fatigue by Electromyography, Arbete och Halsa, Vetenskaplig Skriftserie. 1981: 24, Arbetarskyddsverket, Stockholm, Sweden.

Hannerz, J. (1973). Discharge properties of motor units in man. *Experientia.* **29**: 45-46.

Ismail, H. M. and K. W. Ranatunga (1978). Isometric tension development in a human skeletal muscle in relation to its working range of movements: The length-tension relation of biceps brachii muscle. *Exp Neurol* **62**(3): 595-604.

Keijo, H., Arto, P., William, J.K., Arja, H., Heli, V., and Markku, A. (2001). Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J. Appl. Phyiol. 91(2):* 569-580.

Komi, P. and Vitasalo, J.H.T. (1976). Signal characteristics of EMG at different levels of muscle tension. *Acta. Physiol. Scand.* **96**: 267-276.

Lapatki, B.G., J.P. van Dijk, I.E. Jonas, M.J. Zwarts, and D.F. Stegeman (2004). A thin, flexible multi-electrode grid for high-density surface EMG. *J. Appl. Physiol.* **96**: 327-336.

Lowery, M.M., N.S. Stoykov, and T.A. Kuiken (2003). Asimulation study to examine the use of cross-corelation as an estimate of surface EMG cross talk. *J. Appl. Phsiol.* **94**(4): 1324-1334

Li, Weiqiang and Kazuyoshi, S. (1996). Distribution of muscle fiber conduction velocity of M. biceps brachii during voluntary isometric contraction with use of surface array electrodes. *Applied Human Science* **15**(1): 41-53.

Lippold, O. C. J. (1952). The relation between integerated action potentials in a human muscle and its isometric tension. *J. Physiol.* **117**: 492-99.

MacConiall, M.A. (1949). The movements of bones and joints. 2. Function of the musculature. *J. Bone and Joint Surg.* **31-B**: 100-104.

Mark, B.S., Gerald L.G., and Daniel M.C. (2004). EMG responses to an unexpected load in fast movements are delayed with an increase in the expected movement time. *J. Neurophysiol.* **91**: 2135-2147.

Missiuro, W., Kirschner, H., and Kozlowshi, S. (1962a). Electromyographic manifesttation of fatigue during work of different intensity. *Acta. Physiol. Polon.* **13**: 11-23.

Missiuro, W., Kirchner, H. and Kozlowski, S. (1962b). Contribution a etude de la fatigue au cours de travaux muscularies d' intensites differentes. *J. Physiol. (Paris)* **54**: 717-727.

Norris, F.H. Jr. and Gasteiger, E.L. (1955). Action potentials of single motor units in normal muscle. *Electroenceph. Clin. Neurophysiol.* **7**: 115.

Olsen, C.B., Carpenter, D.O. and Henneman, E. (1968). Orderly recruitment of muscle action potentials: motor unit threshold and EMG amlpitude. *Arch. Neurol.* **19**: 591-597.

Osu, R., D.W. Franklin, H., Kato, H., Gomi, K. Domen, T. Yoshioka, and M. Kawato (2002). Short- and Long- Term changes in joint co-contraction associated with motor learning as revealed from Surface EMG. *J. Neurophysiol,* **88**: 991-1004.

Person, R.S. (1960). Electrophysiological study of the activity of the motor apparatus of man in fatigue. *Fiziol. Z. (Mosk.),* **36**: 810.

Simpson, J.A. (1965). Electromyographic evidence on central and peripheral factors in control of muscle contraction in the human. *Proc. 6th. Internat. Cong. E. E. G. and Clin. Neurophysiol.,* 601-603.

Stalberg, E., Chu, J., Bril, V., Nandedkar, S., Stalberg, S. and Ericsson, M. (1983). Automatic analysis of the EMG interference pattern. *Electroencephalogr Clin Neurophysiol,* **56**(6): 672.

Zhukov, E.K. and Zakharyants, J.Z. (1959). Electrophysiological data concerning certain mechanisms of overcoming fatigue. *J. Physiol. (U.S.S.R.)* **46**: 819-827.