ELECTROMYOGRAPHY
SUPPLEMENTUM 1 (AD VOLUMEN 8, 1968)

PROCEEDINGS
OF THE
FIRST INTERNATIONAL CONGRESS
OF
ELECTROMYOGRAPHIC KINESIOLOGY

ORGANIZED BY I.S.E.K.

MONTREAL, AUGUST 1968

EDITOR
N. ROSSELLE
LOUVAIN

PROCEEDINGS
OF THE
FIRST INTERNATIONAL CONGRESS
OF
ELECTROMYOGRAPHIC KINESIOLOGY

COUNCIL OF I.S.E.K. 1968-1972

(International Society of Electromyographic Kinesiology)

PRESIDENT

John V. BASMAJIAN,
Professor, Department of Anatomy, Queen's University, Kingston, Ontario, Canada.

VICE-PRESIDENT

Jack JOSEPH,
Professor, Department of Anatomy, Guy's Hospital Medical School, London S.E.1, England.

SECRETARY

Bengt JONSSON,
Assistant Professor, Department of Anatomy, Medicinaregatan 3, Fack, S-400 33 Göteborg 33, Sweden.

TREASURER

Sven CARLSÖÖ,
Associate Professor, Department of Anatomy, Karolinska Institutet, S-104 01 Stockholm 60, Sweden.

Fritz BUCHTHAL,
Professor, Universitetets Neurofysiologiske Institut, Juliane Mariesvej 36, København, Ø, Denmark.

Vladimir JANDA,
Docent MUDr., Sectio Rehabilitationis, Universitas Carolina-Hospital, Srobarova 50, Praha 10, Czechoslovakia.

John E. PAULY,
Professor, Department of Anatomy, University of Arkansas Medical Center, Little Rock, Arkansas, U.S.A.

Noel E.J. ROSSELLE,
Professor Dr., Department of Physical Medicine and E.M.G.-Laboratory, University Clinic, Rue des Capucins 35, Louvain, Belgium. - **PUBLICATION SECRETARY**

Toshihiko TOKIZANE,
Professor, Institute of Brain Research, School of Medicine, University of Tokyo, 7-3-1 Hongo, Bankyo-ku, Tokyo, Japan.

ELECTROMYOGRAPHY
SUPPLEMENTUM 1 (AD VOLUMEN 8, 1968)

PROCEEDINGS
OF THE
FIRST INTERNATIONAL CONGRESS
OF
ELECTROMYOGRAPHIC KINESIOLOGY

1st

ORGANIZED BY I.S.E.K.

MONTREAL, AUGUST 1968

PROF. DR. N. ROSSELLE
(Dir. Department of Physical Medicine and E.M.G. Laboratory, University of Louvain)
Capucienenvoer 35
LOUVAIN (Belgium)

This edition was supported by grants of

MEDELEC LTD
WOKING — SURREY — GREAT BRITAIN
AND
MEDICO-ELECTRONIC
WILRIJK — ANTWERP — BELGIUM

CONTENTS

THE PRESENT STATUS OF ELECTROMYOGRAPHIC KINESIOLOGY

Dr. J.V. BASMAJIAN

Department of Anatomy
Queen's University
Kingston, Ontario, Canada

When I was invited to give this talk in our Symposium, I agreed quite innocently, thinking I could use the bulk of a paper presented last year to the First International Seminar on Biomechanics at Zurich. Alas, I was too hasty. Mature thought revealed that the material of that talk was aimed at a less sophisticated electromyographic audience than the present one. Here we have gathered some of the most knowledgeable electromyographers in the world. You will be looking to me for more than a broad view of what is going on in this new branch of science.

Unquestionably, electromyography for the study of kinesiology has emerged in the past two decades as an essential research tool. Combined with other techniques, the simultaneous recording of action potentials from various individual muscles and muscle groups has provided the best information on the exact role of muscles in simple and complex movements and postures. As experts in this field, you will agree that these new investigations have often illuminated and supported some classical concepts ; they have also confirmed long-cherished beliefds and – to the chagrin of many – they are in the process of destroying many other beliefs. Certainly they have replaced deduction and inference with solid data. Thus it is fair to say that electromyography now reveals what a muscle actually does rather than what it might do.

Although electromyography has been used for kinesiology ever since its early beginnings, most of the first studies were rather generalized and primitive. In the decades of the Fifties and Sixties, electromyographic kinesiology came of age. This led to the inevitable : the organization of the International Society of Electromyographic Kinesiology in 1965 and thus to the present meeting.

Technology

Probably the most disagreement in electromyography since its beginnings has centered around the techniques used. Many of the earlier studies were rendered useless by inadequate techniques. Because of unavoidable circumstances, many investigators used discarded ECG and EEG equipment. Unfortunately there was too strong a sense of caution in the approach to electrodes and many inappropriate techniques of electrode placement and insertion were employed. We now generally agree that there is a wide selection of different types of electrodes that have their special application ; the good electromyographer employs the whole range.

In the area of electrodes, the most useful recent methodology employs the fine-wire electrodes. Such inserted electrodes are no longer as forbidding to kinesiologist as they once were and they are being widely used everywhere. Certainly for kinesiological studies they are much to be preferred over other types of inserted electrodes. They may be inserted in pairs and in large numbers of pairs. For example in one of our studies we have worked with 14 pairs inserted in different areas around the hip joint for the study of hip kinesiology. In another study, we have placed a great many in the confined regions of the hand, of the tongue, and of the foot.

Bipolar fine-wire electrodes isolate their pick-up either to the whole muscle being studied or to the confines of the compartment within a muscle if it has a multipenate 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 interfering with pick-up from beyond the barrier (such as there always is with surface electrodes). This is not to condemn surface electrodes ; these types of electrodes must be used where a broad or global pick-up of a number of muscles or a large area of muscle is desired. However, in the case of muscles without internal partitions, the fine-wire electrodes reflect the activity of the whole muscle as broadly as the best surface electrodes. Indeed, our investigation of this problem reveals that the surface electrodes will miss deeper potentials which the wire electrodes pick up very well ; on the other hand, the wire electrodes do not miss any of the potentials that the surface electrodes immediately overlying them do miss.

Any type of insulated wire can be used. Our bipolar fine-wire electrodes are made from a nylon-insulated or polyurethane-insulated Karma alloy wire only 25 microns in diameter. Dr. Bengt Jonsson has shown that this small diameter of wire is not suitable for extremely energetic movements because the wire will occasionally break. I would agree with him that for strong exercise one should use a coarser wire instead. Nevertheless, even wires 75 microns in diameter are extremely fine and inpalpable to human subjects.

Apparatus

Electromyographs (either commercial or self-constructed) are high-gain amplifiers with a preference for frequencies from about 10 to several thousand cycles per sec. An upper limit of 1,000 cycles per sec is satisfactory. For kinesiological studies, the best instruments are multi-channel. This leads to difficulties. The multi-channel equipement most readily available to the novice is ink-writing electroencephalographic equipment, but, except for certain special studies, such equipment is not satisfactory. However, some of the newer types have appropriate switching devices for the recording of EMG potentials, i.e., the operator can choose a frequency response with a wider range than that which is standard for EEG's. Even then, the obvious deficiency of ink-writing equipment is that the pens are too slow to record faster frequencies. This is overcome in some laboratories by the integration of potentials (a sort of electronic summation of activity) ; but the use of integrated potentials without concurrent monitoring of raw EMG potentials must be condemned because the integrator does not discriminate against artifacts.

Ideally the recording device should either be photographic or employ electromagnetic tape-recording. With multiple channels, one may photograph a row of cathode-ray traces on photographic film in a variety of ways. Most convenient is the recording of multiple traces from ultra-violet galvanometers on bromide recording papers. Several widely distributed direct recorders are on the market ; one has as many as 36 channels. The miniature galvanometers provide frequency responses suitable for electromyographic and because the special paper requires no developing, there is an immediate display. (Unfortunately this paper darkens with continued exposure to light and the recording is spoiled unless the chemical process is stopped by fixation). In recent years, multi-track tape-recorders have provided a relatively cheap method of storing EMG signals. Elsewhere these matters are discussed in detail (Basmajian, 1967).

General Survey of EMG Kinesiology

In a brief review of this kind, no attempt can be made to touch upon the thousands of studies reported in the literature, especially on the individual actions of specific muscles in specific movements. These have been dealt with in detail elsewhere (Basmajian, 1967). Instead, three special areas will be discussed : locomotion, posture, and motor unit training.

Human Locomotion

Although until recently its contribution has not been as great as it might have been, electromyography has added a new dimention in the latest studies on locomotion. The main reason for this slow start seems to have been that multi-factorial studies are difficult and time-consuming. Only recently has equipment improved to the point where electromyography gives especially useful results. Our recent series of large-scale studies will not be described here but are the source of a number of papers to be published during the present and subsequent years. Limitations of time allows the review of only a few highlights from previously published works.

Excellent multifactorial studies by Radcliffe, by Sutherland, by Murray, and by Liberson have been summarized elsewhere (Basmajian, 1967). Battey and Joseph (1966) in an excellent study using telemetering apparatus have shown that : tibialis anterior is usually bephasic in activity, but sometimes it is active for a short time after the foot is flat on the ground – perhaps "to pull the body over the foot in the early part of the supporting phase".

Soleus begins to contract before it lifts the heel from the ground ; it stops before the great toe leaves the ground. Apparently these are supportive rather than propulsive functions.

Quadriceps femoris contracts as extension of the knee is being completed, not during the earlier part of extension when the action is probably a passive swing. Quadriceps continues to act during the early part of the supporting phase (when the knee is flexed and the centre of gravity falls behind it). Quadriceps activity occurs at the end of the supporting phase to fix the knee in extension, probably counteracting the tendency toward flexion imparted by gastrocnemius.

The hamstrings contract at the end of flexion and during the early extension of the thigh apparently to prevent flexion of the thigh before the heel is on the ground and to assist the movement of the body over the supporting limb. In some persons, the hamstrings also contract a second time in the cycle during the end of the supporting phase ; this may prevent hip flexion.

Gluteus medius and gluteus minimus are active at the time that one would predict, i.e., during the supporting phase ; however, some subjects show activity in the swing phase too.

Gluteus maximus shows activity at the end of the swing and at the beginning of the supporting phase. This is contrary to the general belief that its activity is not needed for ordinary walking. Perhaps gluteus maximus contracts to prevent or to control flexion at the hip joint.

Many other studies in the lower limb have been done in the last few years period. Of some special significance are the studies that have been made at Queen's University which have emphasized the factors which might influence the arch support in the human foot. These studies have reinforced knowledge gained by Joseph and Nightingale and by Basmajian and Bentzon in the 1950's. They not only confirmed the earlier studies but emphasize that muscles are not important in the primary maintenance of the arches of the foot in the plantagrade static foot. However, they are very important during locomotion when the extremes of force are applied to the foot. Apparently the first line of defence against flat feet is a ligamentous one, but the added stresses of walking require special mechanisms.

Trunk Muscles

During Gait. Erector spinae shows two periods of activity, according to Battey and Joseph (as noted before by other investigators). They occur "at intervals of half a stride when the hip is fully flexed and fully extended at the beginning and end of the supporting phase." Apparently the bilateral activity of the erectores spinae prevents falling forward of the body and also rotation and lateral flexion of the thrunk. Sheffield (1962) found the abdominal muscles inactive during walking on a horizontal level.

Trunk musculature received most of the attention of electromyographers in the 1950's. The names of Floyd and Silver, Campbell and Green, and Jones, Beargie and Pauly are well known in this field. Many other investigators also contributed excellent studies on respiration, particularly studies of the intercostal muscles. Perhaps the most significant and largely ignored finding was that of Jones *et al.* (1953) who suggested that the intercostal muscles play a part in posture which is more important than their role in respiration. Their role in respiration seems to be the maintenance of a proper distance between the ribs while the rib cage is actively elevated by the neck muscles (scalenes) during inspiration.

In quiet breathing, the diaphragm is the chief muscle of respiration in man. Recent work by Taylor (1960) seems to suggest that in heavy breathing the old controversy about whether or not inspiration involves only the external intercostals while expiration involves the internals seems to have been resolved with a positive answer. More work is needed in this field.

Upper Limb

In the upper limb, the classic work of Inman, Saunders and Abbott (1944) has been followed by a long series of scattered EMG studies. I cannot in this short talk do justice to all the studies that have been done on the upper limb. Instead I have chosen to emphasize several important concepts that have emerged, particularly some with which I have the greatest familiarity. Bearn's (1961) finding that the activity in the upper fibers of trapezius falls off after a minute or two to disappear completely while the person is upright is especially significant. It is also rather surprising to find that serratus anterior has only slight activity in upright posture.

At the shoulder joint our finding that downward dislocation of the shoulder is resisted by the superior capsule of the shoulder joint and supraspinatus has focussed new attention on this area. This finding has also emphasized that muscle which cross a joint longitudinally are not necessarily active when there is distraction on the joint. Other work on the elbow joint has confirmed this finding. The general principle seems to be that capsules and capsular ligaments are sufficient to prevent distraction except where excessive forces are applied. When muscle is a contributing factor, it often is part of a locking mechanism rather than exerting transarticular forces. On the other hand, during movement such as flexion and extension of a joint, certain muscles are extremely important as a transarticular component to prevent distraction of a joint. Thus, brachioradialis shows little if any activity in maintaining flexed postures even against added loads but is very active in either flexion or extension of the elbow. This is its shunt muscle function, i.e., it acts chiefly during rapid movement along the long axis of the moving bone to provide centripetal force. The whole question of spurt and shunt muscles has been throughly discussed elsewhere. Of course such muscles are not confined to the upper limb and have wide-spread significance in the economy of the body. (See Basmajian, 1967, for a fuller discussion).

Motor Unit Training

Finally, may I take a few moments to describe one of my favorite topics, conscious control of individual motor units by man. Given a clear response of their motor unit activity on a cathode-ray oscilloscope and loudspeaker, and though completely unaware of any movement in the muscle, everyone can achieve notably wilful control over isolated motor-unit contractions in a muscle. Kinesiologist have known for a long time that almost anyone can learn to relax a whole muscle instantly on command. We have found that human subjects can recruit the activity of a single motor unit instantaneously and keep it active for a considerable period of time ; also they can deliberately change the frequency of firing of motor units.

Most persons can be trained to produce specific rhythms on motor unit. It is easy for human subjects to gain control over a number of motor units and consciously switch the activity from one to the other.

These and other findings on motor unit controls have deep significance in kinesiology. Indeed, they underlie the normal control of movement and muscles. This then would indicate that motor unit controls underlie the vary topic of kinesiology itself.

REFERENCES

BASMAJIAN, J.V. (1967) : *Muscles Alive : their Functions Revealed by Electromyography.* Ed. 2. Baltimore, Williams & Wilkins Co.

BATTYE, C.K. and JOSEPH, J. (1966) : An investigation by telemetering of the activity of some muscles in walking. *Med. & Biol. Engng.*, 4 : 125-135.

BEARN, J.G. (1961) : An electromyographic study of the trapezius, deltoid, pectoralis major, biceps and triceps muscles, during static loading of the upper limb. *Anat. Rec.*, 140 : 103-108.

INMAN, V.T., SAUNDERS, J.B. deC.M. and ABBOTT, L.C. (1944) : Observations on the function of the shoulder joint. *J. Bone & Joint Surg.*, 26 : 1-30.

JONES, D.S., BEARGIE, R.J. and PAULY, J.E. (1953) : An electromyographic study of some muscles of costal respiration in man. *Anat. Rec.*, 117 : 17-24.

SHEFFIELD, F.J. (1962) : Electromyographic study of the abdominal muscles in walking and other movements. *Am. J. Phys. Med.*, 41 : 142-147.

TAYLOR, A. (1960) : The contribution of the intercostal muscles to the effort of respiration in man. *J. Physiol.*, 151 : 390-402.

CLINICAL USE OF ELECTROMYOGRAPHIC KINESIOLOGY

J. DESCHUYTERE, H. DECKERS and N. ROSSELLE

Department of Physical Medicine and Laboratory of EMG.
(Dir. Prof. Dr. N. ROSSELLE)
University of LOUVAIN (Belgium)

When kinesiology was starting with the EMG research, the interest was very great and soon the first EMG kinesiological data were used in clinical studies.

But especially the clinical electromyographist could be delighted about these EMG kinesiological studies. So the Isek initiative to bring together and to coordinate the EMG kinesiological research can be acclaimed loudly ; and certainly this first international meeting.

The cooperation all over the world is now a real fact by which EMG kinesiological investigation will be stimulated a great deal.

In that case Isek will be charged very importantly and at the same time a very extensive work is now waiting for them.

There is no doubt about it, that the EMG kinesiology has procured a scientific foundation to the modern rehabilitation, the modern orthopedics, modern transplantation, modern post-traumatic muscle and tendon repair and reconstruction surgery.

We may be convinced that EMG kinesiology and EMG biomechanics with for instance telemetering EMG studies, have furnished the scientific foundation to modern prosthetics and orthotics.

Several other medical disciplines called for EMG kinesiology : for example : EMG studies of extraocular eyemuscles, EMG studies of pharynx muscles, larynx muscles in connection with respiration, deglutition and articulation ; futher EMG studies of the muscles of mastication connected with the problem of orthodontics etc...

In the beginning EMG studies concerned with the function of a single muscle, with the function of antigravity muscles in standing and other positions and with the function of muscle in simple and more complex movements. But very soon attention was paid to the chronological and quantitative EMG activity of different muscles concerned in motion of several joints, and especially the multihead muscles with specific functions in correlation with the gradation of the contraction.

The clinical importance is very clear. If it is definitively stated that m.iliopsoas as a major hipflexor only becomes active after the first 30 degrees of hipflexion this by a sit-up from long lying position (with hip and knees extended) than it is evident that motor revalidation will start after 30 degrees of flexion.

On the other hand, reeducation of the other hipflexors can be accomplished without concurrent activity of the iliopsoas during the first 30 degrees of hipflexion. So surgical treatments will be obliged to deal with these EMG findings.

Quite new data were given by EMG kinesiological studies on muscle coordination as far as the activity of agonists, synergists and antagonists are concerned.

These studies on coordination, and reciprocal innervation by polyelectromyography, were performed to the muscles of the controlateral side. By these investigations for example, it was stated that an abduction of the upper limb, gives results on activation of the controlateral erectors of the spine. So these statements are likely important for treatments of spine deviations, but might be available for aetiologic and pathogenetic investigation of some neuromuscular involvements.

Studies concerned with muscle coordination and reciprocal innervation admitted a better comprehension of programation of human motility in connection with individual innervation patterns with cortical and spinal types. These are new EMG kinesiological notions and data which can be usefull to the clinician.

To illustrate : the studies on the programation of deglutition. Here also we clinicians have in mind the alterations in programation in diseases with retardments of psychomotor development and the late changes in programation in case of reinnervation after intoxications associated with polyneuropathy.

The likely importance for psychotechnical examinations, and for traffic medicine shouldn't be repeated.

It is not possible to consider all the clinical aspects of the EMG kinesiological investigation as far as it is developed today.

Therefore we should think it much more important to deal with those subjects who might be of considerable influence for excellent progress of EMG kinesiology.

The introduction of electronic counting devices and the frequency analysers constituted a new period for EMG kinesiology. Studies on auto-and cross-correlation by global EMG have not only a neurophysiological interest, but will certainly be usefull for clinical work.

When systematic EMG studies with electronic devices for integration and for auto- and cross-correlation and for frequency analysing have provided at this moment new acquisitions for better understanding muscle function, in our feeling these EMG kinesiological studies should be directed to the analysis of phasic and tonic motor units according to the techniques of Tokizane ; namely to examine the number and the proportion of these phasic and tonic motor units, and to investigate the chronological and quantitative activity of the phasic and tonic motor units in different muscles in connection with muscle coordination and reciprocal innervation.

Now we are talking about "spurt" and "shunt" muscle : about "fast" and "slow" muscles : that are macroscopical kinesiological notions.

When we should be able to disclose the number and the proportion of these phasic and tonic motor units in different muscles ; when we should be able to reveal how these phasic and tonic motor units are activated chronologicaly and quantitatively, we will obtain microscopical kinesiological notions and details. The more understanding muscle function, the better selective transplantation and repair surgery can be realised.

Many schematical designs are of pratical utility. We use this one (fig. 1).

This scheme only shows neurons and nerve fibers in direct relation with the muscle. Neither sympathic nerve fibers, nor sensory nerve fibers, with origin outside the muscle area, are indicated in this outline.

Bottom left : kinetic and tonic curve of Professer Tokizane.

We are convinced that the differentiation in phasic and tonic motor units is so pronounced, that we couldn't neglect to take it into consideration.

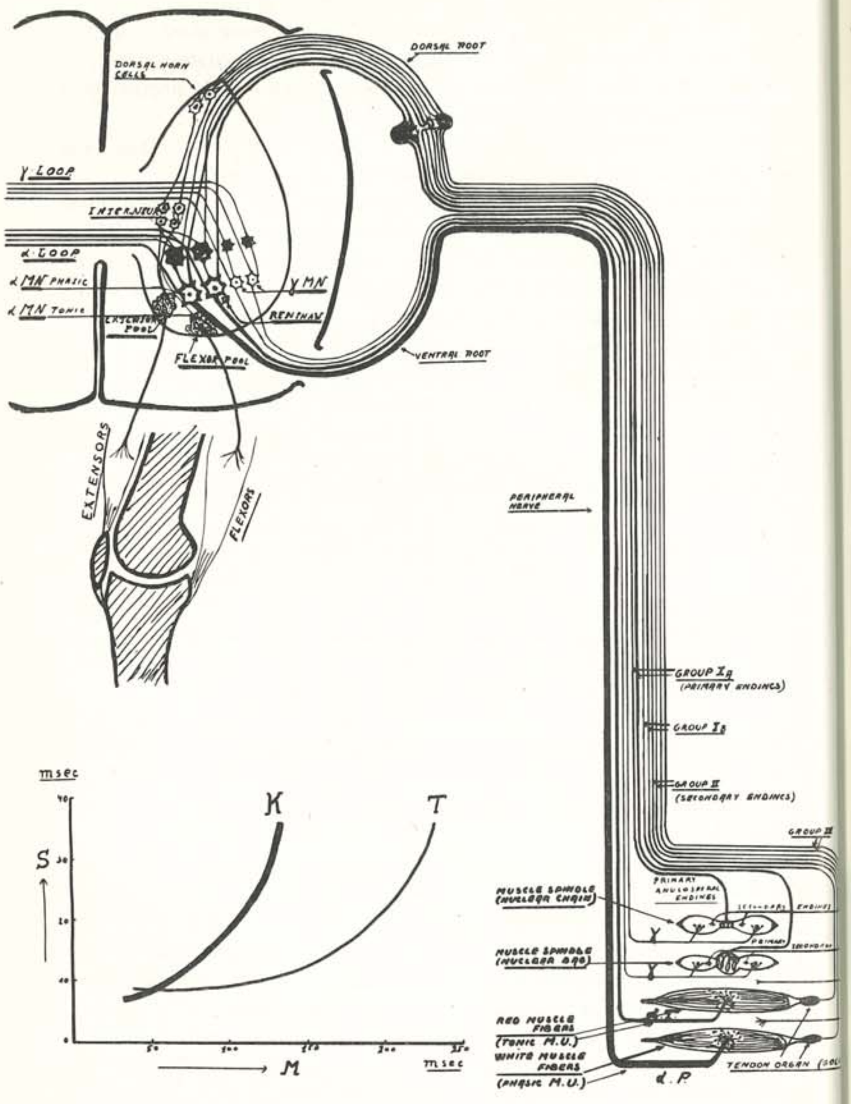
Our knowledge concerning phasic and tonic motoneurons with differences in after- hyperpolarisation following the discharges ; with differences in frequency of firing ; with differences in diameter of the axons, with concommitant differences of the conduction velocity, imposes this view.

Qualitatively muscle fibers themselves do not differ so much, because cross-union of the nerves in an animal limb, even in adult animals, can transform a slow muscle into a fast one and vice versa.

But once the continuity with the axons is established, muscle fibers greatly differ functionally.

Once in possession of the results of the former mentioned topics, a new approach can be made to the problem of muscle fatigue and the problem of reinervated muscle. Substantialy the problem of the reinervated muscle after congenital and neonatal denervations, from which we know that proprioceptive information acquainted during the first weeks after birth, are decisive for coordination and programming of voluntary movements.

Motor patterning, following sensory-motor deprivation, has a different outlook whether performed in a new born or in an adult animal. There is a critical period after which a periferal nerve lesion would no longer produce the same motorpattern defect in the animal. But when the spinal cord and the



higher centers are deprived of a certain amount of information, during maturation, motor patterning and programmation are defective.

It is evident that all clinicians have in mind the investigations in ERBS palsy and in "spina bifida", We need EMG kinesiological data, concerning phasic and tonic motor units to compare the findings with the results of the animal experiments, from which we know that in the newborn all muscles are slow and that differentiation in fast and slow muscles occurs during the first weeks of life, and is greatly affected by neural influences.

It is possible that these studies will help to a better apprehension about the problem of spasticity and rigidity and about the evolution of these pathological states.

A TECHNIQUE FOR EXAMINATION OF LARYNGEAL MUSCLES DURING PHONATION

Thomas SHIPP, Ph.D.

Chief, Speech Research Section
Audiology and Speech Pathology Service
Veterans Administration Hospital
San Francisco, California 94121

Although electromyographic sampling of intrinsic laryngeal muscles during phonation has been conducted for the past 15 to 20 years, this region remains a difficult one for obtaining valid and reliable muscle data, principally because of three factors : 1) movement of laryngeal structures, 2) inaccessibility of the laryngeal muscles and 3) the possibility of altering normal laryngeal function because of EMG procedures used.

The two major movements of the larynx that may interfere with an EMG procedure are swallowing and vocal fold vibration. In adult males the vertical movement of the larynx during swallowing may amount to as much as four centimeters ; thus, implanted electrodes may be displaced from the original site resulting in pickup of spurious signals. When electrodes are placed in the thyroarytenoid muscle they vibrate at the same velocity and frequency as the vocal folds which at the high end of the male vocal range may be upwards of 500 times per second. The resultant microphonic signal can virtually obliterate the EMG signal or so distort it as to make interpretation of the obtained signal impossible. This vertical swallowing and vibratory motion is particularly detrimental when needle electrodes are used because their weight and rigidity prohibit accomodation to the attendant movements.

With the exception of the thyroarytenoid, the location of the other four intrinsic laryngeal muscles makes it difficult to specify with accuracy that the electrodes are indeed placed in the target muscle. Better methods are being developed to validate the site of electrode placement.

With respect to the normality of the desired subject behavior, the EMG procedure must be minimally obtrusive, both in terms of mechanically impeding the cartilage and tissue movement as well as attenuating the psychological anxiety of the subject. Needle electrode EMG, because of the weight and mass of the needle, may well tend to alter the normal movement of the laryngeal structures, particularly during the complex task of phonation.

The Speech Research Laboratory at the Veterans Administration Hospital, San Francisco, has initiated, as the first part in a series of studies on the physiology of phonation, a simultaneous kinesiologic and aerodynamic study of sustained vowel phonation in normal adult males as they vary frequency, intensity and register of voice production. The kinesiologic portion of this study involves sampling simultaneously four intrinsic muscles of the larynx. The muscles, as shown in figure 1, are : the cricothyroid, the posterior cricoarytenoid, interarytenoid and thyroarytenoid. The remaining intrinsic muscle, the lateral cricoarytenoid, was not selected for study because its inaccessibility makes verification of electrode placement difficult.

Each of the adult male volunteer subjects is given a physical examination two days prior to the experimental procedure. It was found in pilot studies that the administration of a mild sedative followed by application of a topical anesthetic throughout the vocal tract was insufficient to allay the anxiety of the subject and to allow him to tolerate the discomfort of the topical and use of a laryngoscope. Different agents were tried until the right combination was found. In our current procedure, one hour before the administration of a topical anesthetic, the subject is given an intramuscular injection comprised

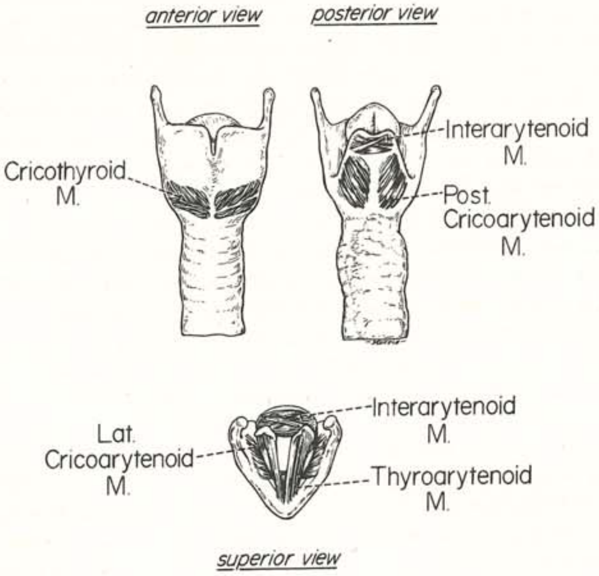


FIG. 1
Three views of the larynx showing the muscles studied electromyographically

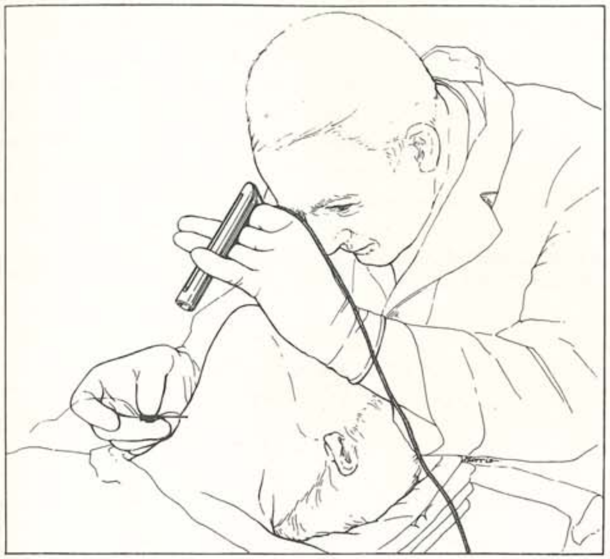


FIG. 2
Experimental arrangement of electrode placement to the thyroarytenoid and interarytenoid muscles. The experimentor guides the needle tip to the muscle site by observing the needle location through a laryngoscope

of 25 mg Demerol(R), 7.5 mg droperidol and 0.5 mg scopolamine. The key agent in this combination is the drug droperidol which acts as a tranquilizer without impairing either complex motor function or mentation. We believe that it is this drug that has been principally responsible for our success in using the techniques to be described.

Each subject is anesthetized topically from the oropharynx to the tracheal bifurcation with a 10 % cocaine solution. This procedure is mandatory for the subject to tolerate the introduction of the laryngoscope and also to desensitize the laryngeal mucosa to prevent coughing during electrode placement.

The electrodes selected for this procedures were of a hooked-wire type inserted for bipolar recording, singly or in pairs, to the muscle site by # 23 or # 25 needles.

Figure 2 shows electrode placement in the thyroarytenoid and the interarytenoid muscles by inserting the electrode-bearing needle through the cricothyroid membrane into the glottis where the experimentor can manipulate the needle tip by observing its location through a laryngoscope.

Figure 3 is an artist's representation of the endoscopic view of the needle tip and electrode after it has penetrated into the subglottic area. In this manner the experimentor can guide the electrode to either the thyromanner the experimentor can guide the electrode to either the thyroarytenoid or interarytenoid muscle sites. Electrode insertion to the posterior cricoarytenoid muscle is accomplished by a peroral approach through the laryngoscope which has been passed down into the subject's hypopharynx to the level of the upper esophageal sphincter. The electrodes are inserted through the anterior pharyngeal wall to the muscle on the posterior cricoid cartilage.

Placement of the electrodes in the cricothyroid muscle is done percutaneously, guided by palpation of the laryngeal cartilages. The cricothyroid muscle, although relatively large in comparison with the other intrinsic muscles of the larynx, nevertheless requires deeper penetration through overlying muscles and connective tissue ; therefore verification of electrode placement is much more difficult than for the other three muscles sampled. In order to verify electrode placement in the cricothyroid muscle a special technique was devised whereby an electrical stimulator is switched into the implanted electrodes. The stimulator, which emits a 30 pulse per second signal at 25 volts, is switched on and off while the subject produces his lowest frequency sustained phonation. When the frequency of the subject's phonation was raised corresponding to the period of stimulation, it was felt that such a change in phonation provided additional verification of the electrode placement in the cricothyroid muscle. The assumption underlying this verification procedure is that biomechanically the cricothyroid muscle has minimal or no activity during a normal subject's lowest sustained phonation and that stimulation of the muscle results in an antero posterior lengthening of the vocal folds, which has been demonstrated to coincide with a rise in vocal fundamental frequency.

FIG. 3

A drawing of the laryngoscopic view of the electrode-bearing needle after it has passed into the larynx below the vocal folds

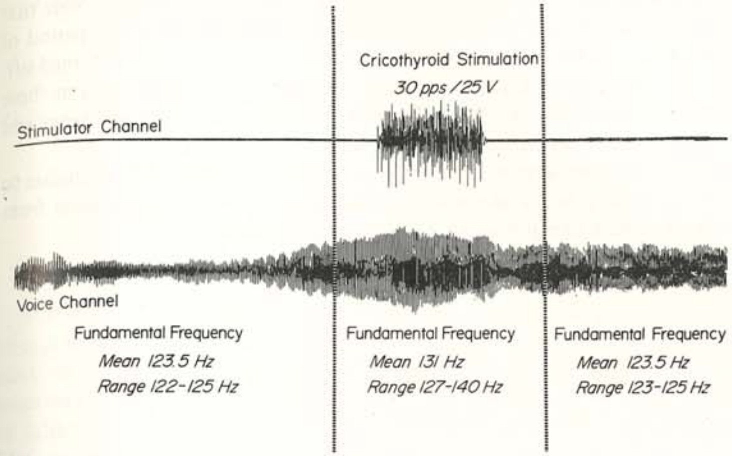


FIG. 4

An oscillographic record of the cricothyroid muscle stimulation channel and the subject's voice channel showing the increase in fundamental frequency (pitch) during electrical stimulation and the return to the pre-stimulation frequency following stimulus termination. Note that the range of voice periods during stimulation do not overlap with the unstimulated voice production

Figure 4 shows an oscillographic write-out of the stimulation channel and the subject's voice signal before, during, and following stimulation. Note that the fundamental frequency of phonation shifts upward during the period of stimulation and returns to its previous level when the stimulator is turned off.

Following electrode placement, the subject produces phonation in three vocal registers at five frequency points within his total phonational range and at two specified intensities at each frequency point.

The techniques described have the potential for allowing future studies to be conducted in the awake subject utilizing simultaneous examination from multiple muscle sites previously thought to be inaccessible.

From the Departement of Human Anatomy, University of Göteborg, Sweden

ELECTRODE PROBLEMS IN ELECTROMYOGRAPHIC KINESIOLOGY

Bengt JONSSON

The demands on electrodes for kinesiologic EMG investigations are in several respects different from those in other electromyographic studies. In electromyographic kinesiologic studies the main interest is usually focused more on estimating the total electric activity than the study of the parameters of different action potentials. Not seldom efforts are made to quantify the EMG activity during a movement or in a specific position. Among the more important demands on EMG electrodes for electromyographic kinesiology are :

1. The activity recorded by the electrodes should be representative for the whole muscle or the part of the muscle under investigation.
2. The activity recorded during a movement or position should be reproducible quantitatively as well as qualitatively during the whole experiment.
3. The electrodes should cause as little discomfort or pain as possible.
4. The electrodes should be easy to handle.

These problems will be discussed in this paper and the advantages and disadvantages of different types of electrodes will be discussed.

Several different types of EMG electrodes have been used in kinesiologic EMG investigations. The most important of these are :

1. Surface electrodes.
2. Needle electrodes. Two types of these are common in kinesiologic studies, namely concentric needle electrodes and unipolar needle electrodes.
3. Wire electrodes.

The demand that the activity recorded by the electrodes should be representative of the whole muscle or part of muscle under investigation means that the electrodes should pick up activity from a relatively large muscle volume. The electrodes should not, however, pick up activity from too large a muscle volume because that would involve a risk of recording activity from muscles other than the desired one. This risk is specially important when small muscles are being studied, or when the electrodes are placed near the surface of the muscle. By pick-up area of the electrode is here meant the muscle volume from which action potentials with an amplitude larger than the noice level are recorded.

Concentric needle electrodes usually pick up activity from a small muscle volume near the tip of the electrode while surface electrodes record EMG activity from a fairly large muscle volume. It seems reasonable to assume that the pick-up area of wire electrodes is larger than that of concentric needle electrodes and smaller than that of surface electrodes.

The demand that the activity recorded during a specific movement or position should be reproducible during the whole experiment, is a condition necessary for making it possible to compare the activity from different movements and positions. It is well known that even a small change of the position of an electrode will give rise to a change of the recorded EMG activity. An unchanged electrode position during the whole experiment is thus necessary for allowing comparisons to be made, unless electrodes with a very large pick-up area are used.

As soon as the position of the muscle in relation to the skin is changed during a muscle contraction the relation of surface electrodes to the muscle is also changed. The large pick-up area of surface electrodes will, however, to a certain degree, diminish the effect of the change in electrode position.

It must be assumed that the EMG recording surfaces of needle electrodes are subject to relatively large displacements during a kinesiologic study.

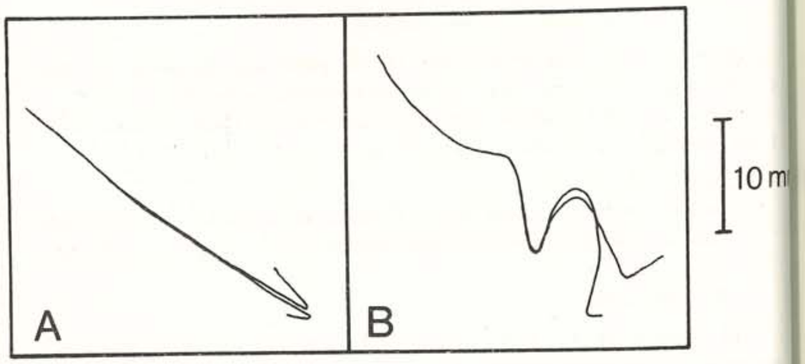


FIG. 1

Wire electrodes located in the flexor carpi ulnaris muscle (A) immediately after the insertion of the wires and (B) after 50 contractions. Drawings from X-ray pictures.

Wire electrodes are presumably the type (of the electrodes available today) which have the best chances to avoid displacement during a kinesiologic study. Careful studies of wire electrodes, among other things with roentgenologic techniques, however, have shown that displacement can and often does occur (fig. 1). This displacement may be as much as several millimetres.

It is well known that surface electrodes cause practically no discomfort while needle electrodes frequently cause so much discomfort or pain that the subject's movements are markedly changed. Wire electrodes usually do not cause the subject discomfort in any appreciable degree. They can, however, cause discomfort or pain, definitely affecting movements. This discomfort is conditioned by the insertion needle as well as by the wires, thicker wires eliciting more discomfort than thinner ones.

Wire electrodes

The opinion of the author is that (of the electrodes available today), wire electrodes are the type which are best suited for kinesiologic EMG studies. They are intramuscular and can therefore be used for all skeletal muscles which are available for an insertion needle. They are not, however, perfect and they have some disadvantages which limit their use for electromyographic kinesiology.

The fact that wire electrodes can and often are displaced, during an experiment and that the pick-up area can probably not be diminished beyond 1 millimetre from the uninsulated part of the wires makes it doubtful whether wire electrodes can be used for the study of very small muscles. The frequent occurrence of electrode migration, makes it furthermore doubtful if small differences in the recorded EMG activity during different movements may be interpreted as differences in the muscle's participation in these movements.

Fractures of wire electrodes do occur, especially when the electrodes has been left in the muscle for several days. The wire fragments which are then left within the muscle will probably not cause the subjects any discomfort. It should be pointed out, however, that the electromyographic effect of such a fracture during an experiment can be slight and may be interpreted erroneously as a normal change in the degree of muscular contraction.

We have apparently no perfect electrode for electromyographic kinesiology as yet. Wire electrodes seems to be the best ones, but their limitations should be kept in mind.

From the Departement of Human Anatomy, University of Göteborg,
Sweden

AN ELECTROMYOGRAPHIC STUDY OF CROSS EXERCISE EFFECT IN OCCUPATIONAL THERAPY WITH HEMIPLEGIC PATIENTS

A preliminary report

Boel BROLIN, Bengt JONSSON and Ann-Mari LINDBERG-BROMAN

Introduction

In the spontaneous regress of hemiplegia the recovery of the extensor muscles of the arm usually is slower than that of the flexor muscles. It is thus supposed to be important to train the extensor muscles at an early stage. A commonly used method in the training of the paretic arm of hemiplegics is to let the patients work in occupational therapy with bilateral synchronous movements, e.g. weaving, sawing, sanding on woodwork with resistance added against the extension of the elbow joint.

When using the arm of the unaffected side, there is supposed to be a simultaneous activation of the corresponding muscles of the paretic side. This phenomenon of activation of muscles on the contralateral side has been described as "cross education" (SCRIPTURE et al., 1894, a.o.), "associated movements (reactions)" (WALSHE, 1923), "cross exercise" (DAVIS, 1942), "overflow" (GREGG et al., 1957) and "indirect learning" (HELLEBRANDT and WATERLAND, 1962). In our investigation we will adopt the term "cross exercise effect" as related to the *synchronous activation of homologous muscles* on the contralateral side.

The present study is aimed at testing whether or not a "cross exercise effect" occurs in the triceps brachii muscle of the paretic arm of hemiplegics. The technique involves sanding on an inclined plane : working with the unaffected arm only and also with both arms. In addition we examined healthy subjects with regard to what happens in the contralateral biceps and triceps muscles during unilateral work.

Method and material

The movement studied was sanding on an inclined plane (fig. 1). The

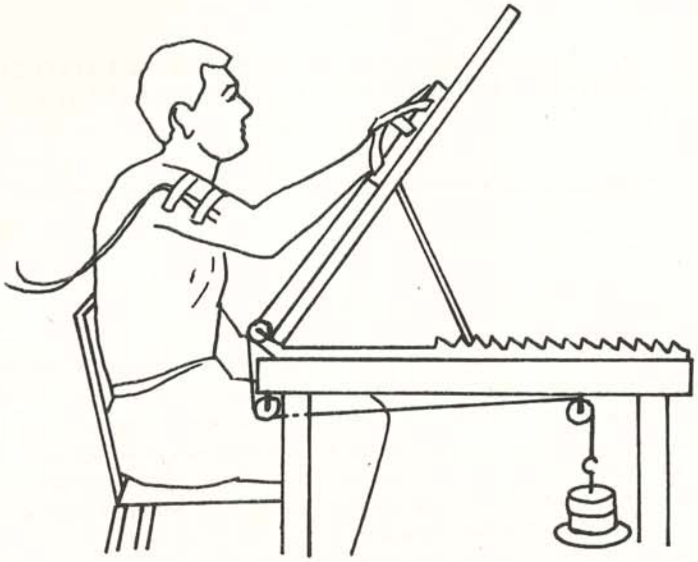


FIG. 1

The subject was seated in front of a table with a surface that could be adjusted step by step at inclinations from the horizontal to the vertical plane.

subject was seated in front of a table with a surface that could be adjusted step by step at inclinations from the horizontal (0°) to the vertical (90°) plane. Our experiments were performed at inclinations of 15° and 60°. One hand was strapped to a wooden block ; the other was either resting on the lap or hanging loosely at the side. When the hemiplegic subject was working with both arms, the affected hand was strapped to the block ; and the other hand was held on the wrist of the diseased arm. Resistance ranging from approximately 0.5 to 5.5 kg was given against the elbow extension through weights attached to the block by a cord running over three pulleys.

The EMG activity was recorded by bipolar wire electrodes connected to an optical three-channel electromyograph, type DISA.

Up to the present we have investigated 9 healthy subjects (unilateral work only) and 4 hemiplegic patients representing different stages of disability (differing in duration and in degree of regress).

Results

Since the number of subjects studied is to small to allow any general conclusions about "cross exercise effect", we will only present some of our findings.

Case 1. Male, aged 47, had a left hemiplegia for 2.5 months. From the clinical point of view the left arm was paralytic. When the patient was working with the unaffected arm as well as in bimanual work, EMG activity was recorded from the biceps muscle on the "paralytic" side, while the triceps muscle on the affected side was almost totally silent.

Case 2. Male, aged 57, had a left hemiparesis for 3 months. He had made a very good recovery and was able to use his arm (but not his hand) voluntarily in an almost normal fashion. In bilateral elbow extension against moderate resistance EMG activity was recorded from both triceps muscles, and with increasing load also from the biceps muscle of the affected arm. In unilateral elbow extension with the unaffected arm there was no activity in the contralateral muscles.

Case 3. Male, aged 50, had a left hemiparesis for 9 months. He had made a good recovery but still had some difficulties in elevating and extending the arm. In bilateral extension of the elbow the biceps muscle of the paretic side was constantly activated earlier and more vigourously than the triceps muscle. The same thing occurred in unilateral work.

Case 4. Female, aged 48, had a right hemiplegia for 1 year with moderate regress. She was able slightly to elevate the arm in the usual flexor synergy but could not voluntarily extend her elbow joint. In bimanual work the biceps as well as the triceps muscles on the paretic side were activated but with domination of the activity in the biceps muscle (fig. 2A). In unilateral work there was a fair amount of activity from the contralateral paretic biceps muscle but none from the triceps (fig. 2B).

In 9 healthy subjects performing unilateral work we found different types of response in the "resting" arm when EMG activity was recorded from the biceps and triceps muscles :

A. No activity whatsoever.
B. Activity in the biceps muscle.
C. Activity in the triceps muscle.

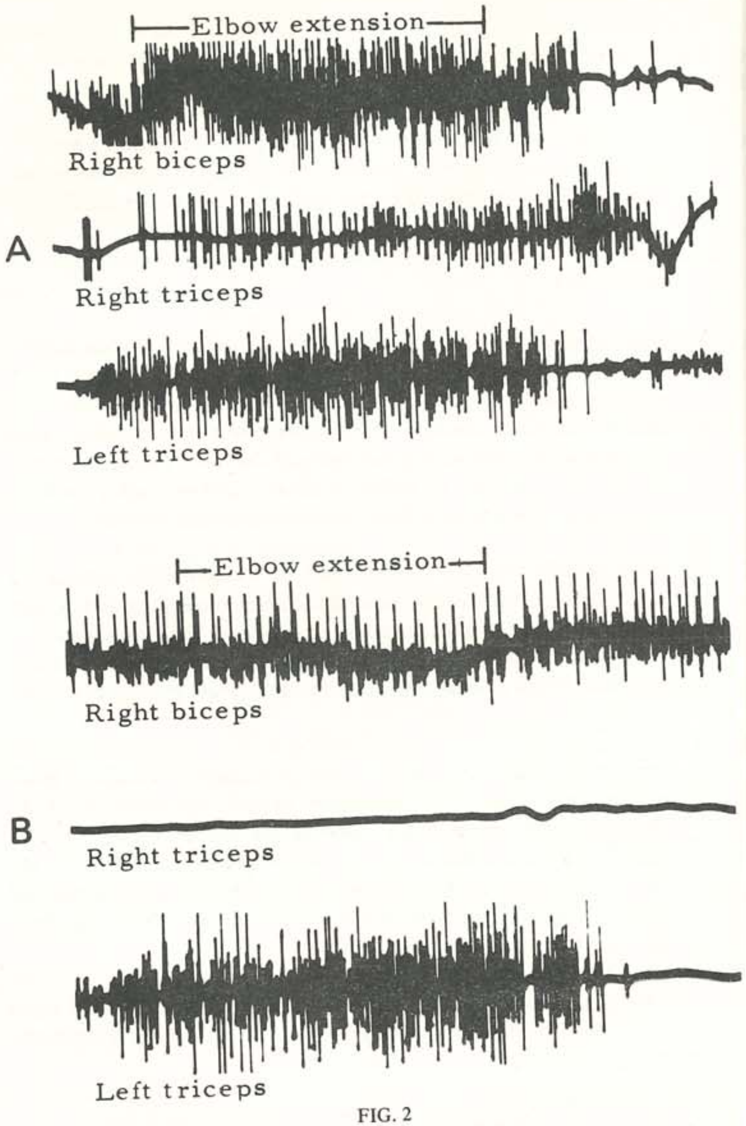


FIG. 2

Case 4 (right hemiplegia) performing (A) bimanual work and (B) work with the unaffected arm. In both cases the elbow extension was resisted by approximately 1.5 kg.

When activity was recorded from the "resting" arm it could be either synchronous or asynchronous with the extension of the elbow joint on the working side. Only occasionally effects occured that could be interpreted as due to "cross exercise effect".

Conclusions

Associated activity is known to exist in normals as well as in hemiplegics. It is, however, doubtful if "cross excercise effect" occurs in normal subjects in the sense of synchronous activation of homologous muscles on the contralateral side. Even in hemiplegic patients we did not find any convincing signs of "cross exercise effect" in this sense. On the contrary we almost constantly recorded EMG activity from the *biceps* muscle of the paretic side in unilateral as well as in bilateral extension of the elbow against resistance. Our material is, however, as yet too small to allow any generalisations.

What can be said to-day is that the training method in question seems to be based on a theory that may not be correct, and that further studies are needed to find out if this method is appropriate for the rehabilitation of hemiplegic patients. It seems clear that many of the methods currently used in occupational and physical therapy ought to be subject to critical analysis.

REFERENCES

DAVIS, R.C. : The pattern of muscular action in simple voluntary movement. *J. Exper. Psychol.*, 31 : 342, 1942.

GREGG, R.A., MASTELLONE, A.F. and CERSTEN, J.W. : Cross exercise – a review of the literature and study utilising electromyographic techniques. *Am. J. Phys. Med.*, 36 : 269, 1957.

HELLEBRANDT, F.A. and WATERLAND, J.C. : Indirect learning. *Am. J. Phys. Med.*, 41 : 45, 1962.

SCRIPTURE, E.W., SMITH, T.L. and BROWN, E.M. : On the education of muscular control and power. *Studies Yale Psychological Laboratory*, 2 : 114, 1894.

WALSHE, F.M.R. : On certain tonic or postural reflexes in hemiplegia, with special reference to the so calles "associated movements". *Brain*, 46 : 1, 1923.

NEUROBIOLOGICAL FEATURES OF MOTOR DRIVING APTITUDE

C. SERRA,

Department of Clinical Neurophysiology,
Traumatologic Orthopaedic Center, Naples, Italy.

P. LAVALLEY,

Department of Psychology, Loyola of Montreal,
Montreal, Canada.

Electromyographic Kinesiology, Applied Anatomy and Psychophysiology have served usefully in the evaluation of muscular-motor activity associated with automobile driving. The activity of the total organism and, the reciprocal relationship between the central and the peripheral processes during motor performance, associated with driving, has been recently studied and evaluated by electrophysiological techniques. The objective of this paper is to briefly review and discuss the literature pertinent to this area of research.

Current electrophysiological instrumentation and methodology has been shown to serve well in the assessment of precise motor activity (Serra, 1968). Innervation of the individual muscles, the co-ordination of all muscles involved in a particular movement, and the temporal relationship of these activities may be determined by their use. It has been found, for example, that during the brief voluntary contraction of a particular muscle the neighbouring muscles may act together synergistically or antagonistically, and innervation is accomplished through various serving muscles (Basmajian, 1965). The central processes may enhance or inhibit this activity. Furthermore, changes in the peripheral motor-mechanics may temporarily alter the development of innervation (Hufschmidt 1959). The general purpose of the antagonistic, and synergistic actions is to stabilize the specific joint.

On the basis of Basmajian's (1965) and Hufschmidt's (1959) contributions concerning reciprocal innervation during any one muscular movement, a certain number of agonistic and antagonistic muscles appear to be activated, exerting either excitatory or inhibitory influences.

For example, when the deltoideus muscle is activated, the ipsilateral sacrospinal muscle appears to be inhibited, whereas the controlateral muscle appears to be activated. A particular motor system has been investigated, in addition, attributing the control of muscular tonus to the spinal alpha motoneurons. These motoneurons can be divided into two types according to their different neurophysiological properties. The first type provides a phasic specialization and, the second type a tonic specialization. This muscular tonus is controlled, in both cases, by the gamma system through the fusal pathways.

In terms of voluntary activity, such as driving, various corticomotor systems are known to be involved ; such as the pyramidal tract with its direct connections to the motor neuron pool and, the gamma system which is involved in the innervation of the muscle spindles. It would appear, therefore, that the inhibition of antagonistic muscles, the individual properties of reciprocal innervation, and the process of central regulation may be evaluated in any particular motor task by means of electrophysiological techniques. A thorough understanding of these activities provides a basis for determining the reaction time in any movement of the body and/or limbs which is necessary to maintain a motor vehicle in its course. The movements required to control a vehicle obviously involve a complex sequence of motor responses and their associated latencies. The latency of a specific response will tend to over-lap with that of another. The temporal evaluation of the gross movement depends, therefore, not only on the latency of individual responses, but also on the degree to which these responses exist in temporal contiguity. This time factor or the latency of response is relevant to the degree of control that any one individual has over his vehicle in an emergency situation. The speed with which a response is made often determines whether or not an accident will occur.

The study of kinesthesis while driving a vehicle has allowed for detailed analysis of the muscular mechanics of individual responses, the behavior of each muscle involved, and of the single heads of the same muscles. The electromyographic study of reciprocal innervation of various muscles can give some information on the so-called habitual driver. In a study on bicep and tricep muscles during the performance of specific movements, for example, it has been shown that reciprocal innervation of antagonistic muscles occurs only as a consequence of extended training. Other EMG investigations have been concerned with the study of mimic muscles during driving (Serra, 1966) ; while others with either respiratory muscles (Serra, 1963 (b)) or, the problem of muscular fatigue during driving under spontaneous conditions (Serra, 1967) or, muscle fatigue after drug administration. From a pathogenic point of view, then, a traffic accident could be attributed to the prevalence in peripheral innervation of the dominant hemisphere, while, and at the same time, a different source of innervation of the homologous muscles of both sides. In addition to what has been stated, and perhaps most importantly, the proprioceptive mechanisms of visual perception during driving are briefly discussed. In general, the visual system appears to be continuously engaged during driving ; either in an absolute or in a relative distance perception, which, in turn, implies the integration of the actual visual perceptual experiences with previous ones. According to Buscaino's neurobiological studies (1946), an important visual contribution must be recognized, (Serra, 1968). That is, both formal and kinesthetic perception, as well as the perception of space, depend largely on the proprioceptive afferents, especially those of the muscles and eyes. Thus, kinesthetic perception can be achieved when there is a harmonious interplay between the proprioceptive mechanisms of the eyes, the semicircular canals and the muscles. A similar importance can be attached to motor and proprioceptive components of visual form perception. The perception of form in both formal and dynamic and stereoscopic reality is closely linked with both the movements of, and the proprioceptive stimuli received from the eye and neck muscles and the semicircular canals. During driving there is a need for a true tonic-kinetic muscular homeostasis. Thus, these proprioceptive phenomena arising in the neck muscles and induced by changes in the position of the head relative to the trunk, play an important role in driving. Throughout the studies previously mentioned, the position of the neck during driving is very important. The influence of the proprioceptive impulses, arising in the neck muscles, in perceptual mechanisms has been studied specifically by Rubino and Santanelli (1950) in their work on the autokinetic phenomenon of the light point (APLP). This phenomenon, besides demonstrating the influence of proprioceptive mechanisms in the eye and neck muscles in kinesthetic perception, is also part of the test for driving aptitude in Italy. The effects of various factors, especially drugs like alcohol, coffee, chloropromazine, and sympathicomimetic amines on muscular tonus and activity have been discussed by Pannain et al. (1936). Drug impairment of the visual, cervicomotor and proprioceptive mechanisms can be detected by the APLP test. This defect, produced by artifically interferring with both the formal and kinesthetic gnostic functions, is a sign of poor driving aptitude. The APLP test will reveal, also, perceptual fatigue from long periods of driving, and will help in evaluating the effects of drugs to overcome this fatigue. In addition to their theoretical value, these findings have important medico-legal applications for traffic accidents that could be caused by a sudden failure in the driver's complex neurobiological mechanisms.

Conclusions : Within the multitude of problems associated with man machine relationships during driving the implications for both neuropsychological and kinesiological research is clearly manifested. The data obtained by means of psychophysiological and neurophysiological techniques could be thoroughly utilized in evaluating the individual psychophysical characteristics of drivers. Through the use of these techniques the basic driving aptitude could be easily assessed in the near future – and the neurobiological mechanisms underlying traffic accidents could be readily determined, making a definite contribution to traffic security.

REFERENCES

BASMAJIAN, J.V. : Man's Posture. *Arch. Phys. Medic. Rehabil.*, 46, 26, 1965.

BUSCAINO, V.M. : *Neurobiologia delle percezioni.* Ediz. Scient. Ital., Napoli, 1946.

HUFSCHMIDT, H.J. : Zur funktionellen Organization der motorischen Einheiten eines Muskels. *Dtsch. Z. Nervenheilk.*, 175, 583, 1959.

PANNAIN, B., SPANTANELLI, R., SERRA, C. : *The influence of various drugs on proprioceptive mechanisms of visual perception during driving.* Excerpta Med. Intern. Congr. Series No 80, 22, 1963.

RUBINO, A., SANTANELLI, R. : Il fenomeno autocinetico del punto luminoso. *Acta Neurol.*, 5, 481, 1950.

SANTANELLI, R., SERRA, C. : *Meccanismi propriocettivi della percezione visiva durante la guida.* Atti I Congr. Medic. Traffico, San Remo, 846, 1960.

SERRA, C. : *Meccanismi neurobiologici degli infortuni stradali.* Atti I Congr. Med. Infort. Traffico, Roma, 150, 1963.

SERRA, C. : *Meccanismi regolatori della motricita'umana durante la guida.* XX Confer. Traffico Circolaz., Stresa, sett. 1963.

SERRA, C. : *Le indicazioni extraneurologiche dell'elettromiografia.* XXIII Quad. di *Acta Neurol.*, Napoli., 1946.

SERRA, C. : *Il fattore uomo nell' infortunio stradale.* XXIV Confer. Traffico Circol., Stresa, sett. 1967.

SERRA, C. : *Motor driving aptitude evaluation. An EMG contribution.* Internat. Meeting on E.M.G., Glasgow, June 1967 in *Europe Med. Phys.*, 4, I, 1968.

COMPARISON OF GAIT ON TREADMILL AND FLOOR WALKING

Drs. H. VISSER and Drs. H. BERNTSEN

In the present study experiments being carried out to compare ordinary gait and gait on a tread mill. Based on the possibility to put forth a signal by the test-person himself, by which the capability exists to record gait patterns in comparison with EMG signals ; this experiment has been carried out.

Electromyographic Foot Contact Registration

The tread of the electric tread mill was covered by strips of anti-slipping profiled aluminum plate (slide 1).

An electric-conducting floor was constructed in this way. The plate consists of a manganese-aluminum alloy, with a good wear-out solidity and conducting capacity.

On the sole and heel of the footwear (basketball shoe) (slide 2) two series of conducting brass blocks were assembled. These series are connected with each other in the sole, imitating the effect of two continued strips and maintaining the natural flexability of the footwear.

By means of a better-box containing a potentiometer, a voltage of 5 mV is put on the EMG channals of choice. This voltage is short-circuited when both brass strips touch the conducting walking strip.

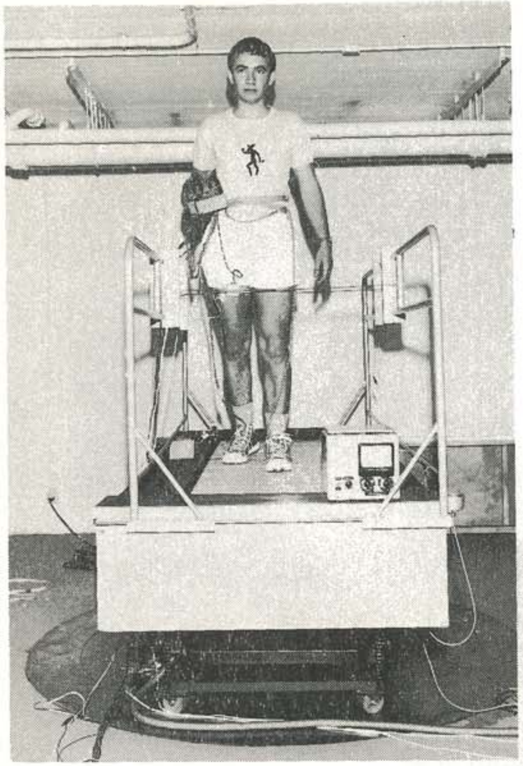
On the EM-graph this is recorded as a positive peak. In leaving the walking strip the contact is cut off and this results in a negative peak (slide 3).

Heal and sole contacts are recorded separately.

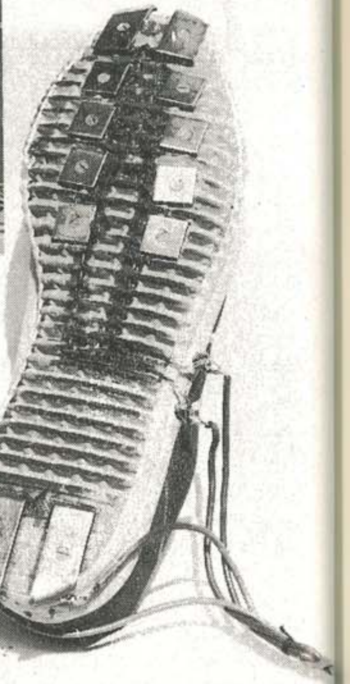
In the same way step-marking can be obtained in floor walking by passing a steel plate in the walking circuit.

The Speed of the Tread Mill is registered on the Electromyograph as speed indication on the tread mill apparatus seems not exactly enough and, therefore, unreliable.

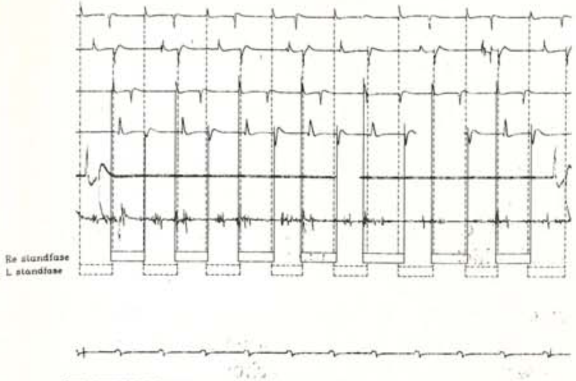
Therefore, the tread mill floor turns round a wheel of known circumference. In the wheel are drilled two openings, opposite each other, and through the openings falls the light of a foto-cell. In this way, each half-turning of the wheel causes a pulse. These pulses are registered on the EMG, while on the EMG a time marking is also fixed up.

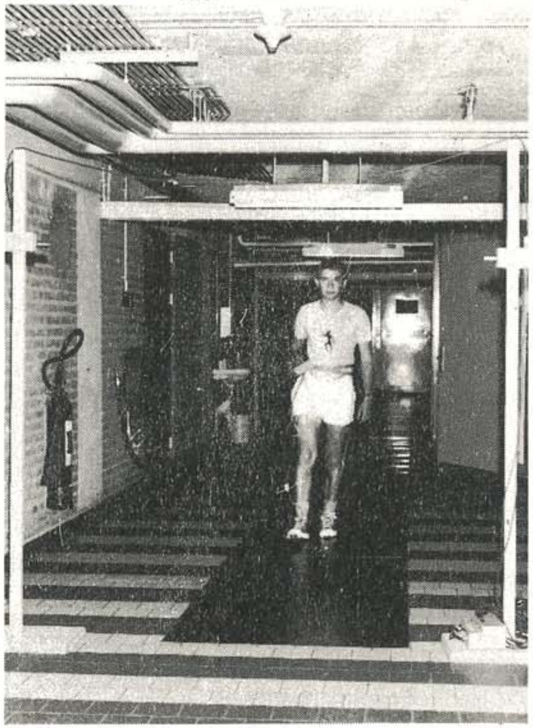


SLIDE 1



SLIDE 2





SLIDE 4

The Speed of the Test-person in Floor-walking (slide 4) has been calculated as follows :

The test-person makes his way in a corridor, crossing a steel plate 10 meters in length. At the beginning and the end of the steel floor, foto-cells are placed. Cutting of the light beam by the walking person is registered on the EMG. Using the time marking, spead is calculated.

A forced speed can be put on a person by letting him walk after an "artificial hare", which can be adjusted in several speeds.

Also *Frequency of steps* can be forced on a person in both circumstances, by adjusting a metronome (0-200 - sound/min) to which one the test-person can adapt his walking rhythm and so can choose his own spead. To make this applicable on a tread mill a variator has been placed, which enables us to give the walking strip speeds 1-9 km/hour. This variator is fed by signals of two switches. The test-person walks on the mill between two wires in front and behind him. When for a particular forced frequency the speed of the tread mill-walking is too high, the test-person touches the wire in front of him and this turns the switch, and speed is decreased automatically.

Muscle-Potentials are picked up by skin electrods. The actionpotentials were amplified and registered on a 8-channal ELTHER EMG.

Test-Persons were 14 students, healthy young people, 20 to 25 years of age, 12 well trained and 2 uuntrained in walking on a tread mill and behind the artificial hare, wearing basketball shoes, especially made for this experiment.

Results

a. Relation between forced speed and step length.

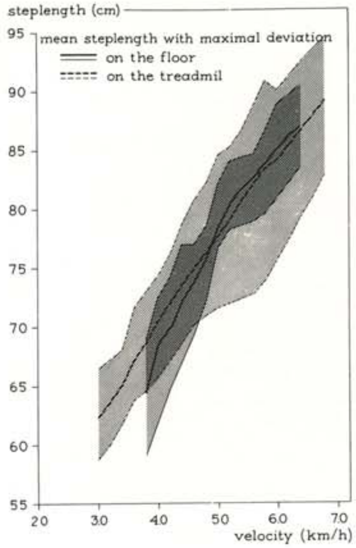
The walking patterns, in trained subjects, walking normally and on tread mill seems to be rather similar.

The average step lengths according to comparable speeds are not significantly different in the two ways of walking (slide 5).

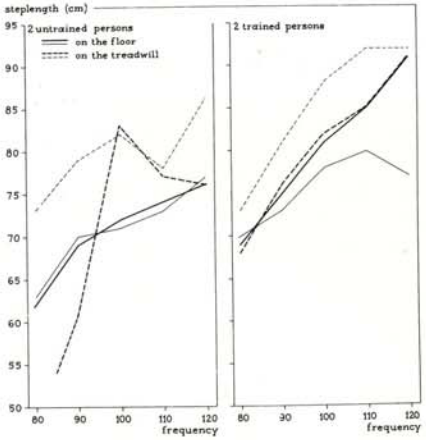
On the contrary, the variation in floor-walking, especially in higher speeds, is obviously greater than in tread mill walking. This suggests a certain influence of the mill upon the step length of the individual test-persons. However, this is not expressed in the average value.

b. Relation forced step-frequency and step-length.

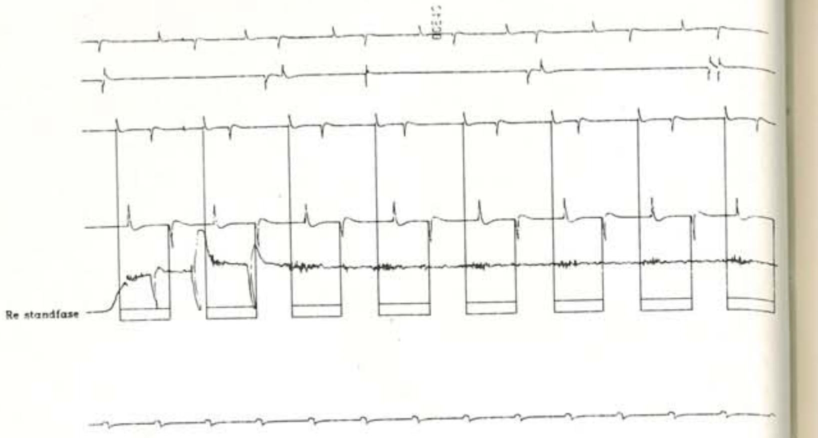
In this situation there appears to be a difference in trained persons and other ones.



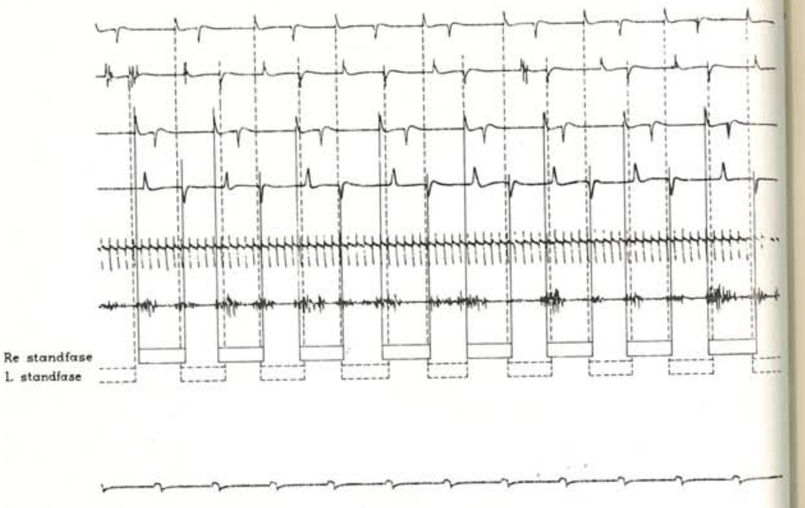
SLIDE 5



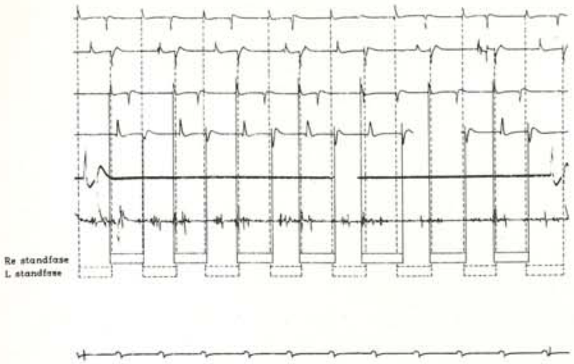
SLIDE 6



SLIDE 7



SLIDE 8



SLIDE 9

Only slight difference in the two ways of walking is seen in trained persons. In *floor-walking* there are no differences in 2 untrained subjects, but in walking on the tread-mill with forced step frequency, step length is very variable (slide 6).

c. Comparison of the EMG recordings.

The activity of the right M rectus femoris in subjects walking normally and on the tread mill is compared.

Also other muscles have been examined. These results will be published.

In ordinary gait the activity of the rectus femoris muscle starts at the end of the swinging-phase and ends in the stance-phase when the heel leaves the floor. After that activity there is in the trained test-person hardly activity until the end of the next swing-phase (slide 7).

In tread mill-walking the muscle of a well-trained test-person is active from the end of the swinging-phase until half the stance-phase, and a new but lower peak of activity appears towards the end of the stance-phase until about one-third of the swinging-phase (slide 8).

But an untrained test-person, who is walking normally, (slide 9) exhibits EMG recordings comparable with the EMG of a trained test-person walking normally, as well as on the tread mill. The EMG of an untrained person on the tread mill is very irregular and the gait is unpredictable.

Conclusions

In trained subjects walking normally and on a tread mill the M rectus femoris displays different patterns of activity. In ordinary gait the muscle is only active at the end of the swinging-phase and ends in the stance-phase to monophasic.

In the tread mill-walking of a trained test-person, the activity of the M rectus femoris is biphasic.

In untrained subjects, walking normally and on a tread mill, the M rectus femoris displays different patterns of activity too.

Thus, the patterns of activity in the EM gram are dependent on the training-state of the test-person and of experimental conditions namely floor-walking and tread mill-walking.

To explain the difference in muscle activity during the two ways of walking step-length-variation can be cancelled.

To explain it in another way, for example by biomechanical difference in gait, more information is needed about other muscles of the leg.

Summary

Gait on the floor is compared with gait on tread mill.

The average step length at comparable speeds is not different. However, the variation at normal gait is greater.

At a forced speed there is a difference in steplength at gait on the tread mill between trained and untrained subjects.

The Electromyogram shows at trained subjects a monophasic activity of the M rectus femoris at normal gait and a biphasic activity at gait on tread mill.

Supported by a grant of the Netherlands Sport Federation, The Hague.

Zusammenfassung

Das Gehen auf den Boden wird vergleicht mit dem Gehen auf dem laufenden Band.

Die durchschnittliche Schrittlänge bei vergleichbare Geschwindigkeit ist nicht verschieden.

Die Streuung ist aber beim normalen Gehen grösser.

Bei einer aufgedrängte Geschwindigkeit gibt es ein Unterschied in Schrittlänge beim Gehen auf dem laufenden Band zwischen trainierten und nicht-trainierten Probe-Personen.

Das Elektromyogram zeigt bei trainierten Probe–Personen eine monophasische Aktivität der M rectus femoris beim normalen Gehen und eine biphasische Aktivität beim Gehen auf dem laufenden Band.

Unterstützt von der Niederländische Sport Federation, Den Haag.

ELECTROMYOGRAPHY OF THE FLEXOR POLLICIS BREVIS AND ADDUCTOR POLLICIS IN TWENTY HANDS

A Preliminary Report[1]

W.J. FORREST, M.D., M. Sc. (Med.),

Assisant Professor, Department
of Anatomy, Queen's University, Kingston,
Ontario, Canada.

M.A. KHAN, M.B., B.S.

Colombo Plan Fellow, Department
of Anatomy, Queen's University, Kingston,
Ontario, Canada.

The human hand owes much of its efficiency and multiplicity of function to its key member, the thumb and to the mobility, strength and precision of movement that the thumb possesses. A recent gross morphological and electromyographic study in this laboratory centred upon four of the intrinsic muscles of the thumb – the superficial and deep heads of flexor pollicis brevis (1, 2) (as described by Cruveilhier) (3) and the oblique and transverse heads of adductor pollicis (1) – which, when taken together, comprise an important, multi-functional motor of the thumb. Fan-shaped in appearance, this band of muscles arises in the midline of the palm and converges laterally to insert into the base of the proximal phalanx of the thumb.

In the past, the description of the flexor pollicis brevis has been confusing. Wood Jones (4), and later, Day and Napier (2) showed that previously, anatomists not only gave parts of the short flexor different names but also disagreed as to what parts made up the muscle. Moreover, the confused description extended to the oblique head of the adductor pollicis. The latter was considered by some to be part of the flexor pollicis brevis (2, 4) ; others indeed named it the oblique head of the adductor pollicis but included with it the deep part of the flexor pollicis brevis (5, 6).

The recent morphological study carried out on 45 hands in our dissection laboratory confirmed for us that the deep flexor brevis and oblique adductor are distinctively separate muscles in terms of origins, insertions and direction of fibres. Furthermore, it was felt that because of certain key differences in the direction of fibres and insertions of all four muscles, each ought to show

---

[1] Supported by a grant from the Medical Research Council of Canada.

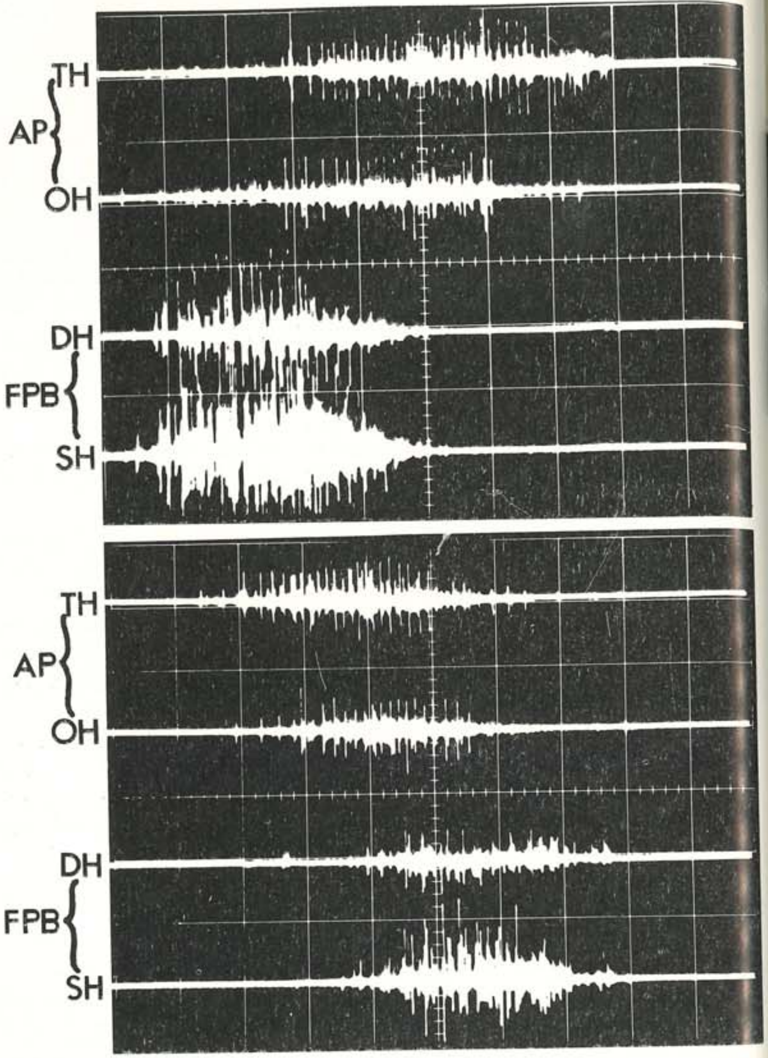


FIG. 1

The upper set of four tracings was recorded during slow circumduction of the thumb. Moving from its starting (rest) position, the thumb extends, abducts, flexes, opposes, then moves radially across the palm to return to its starting position. The lower set of four tracings was recorded during reverse circumduction.

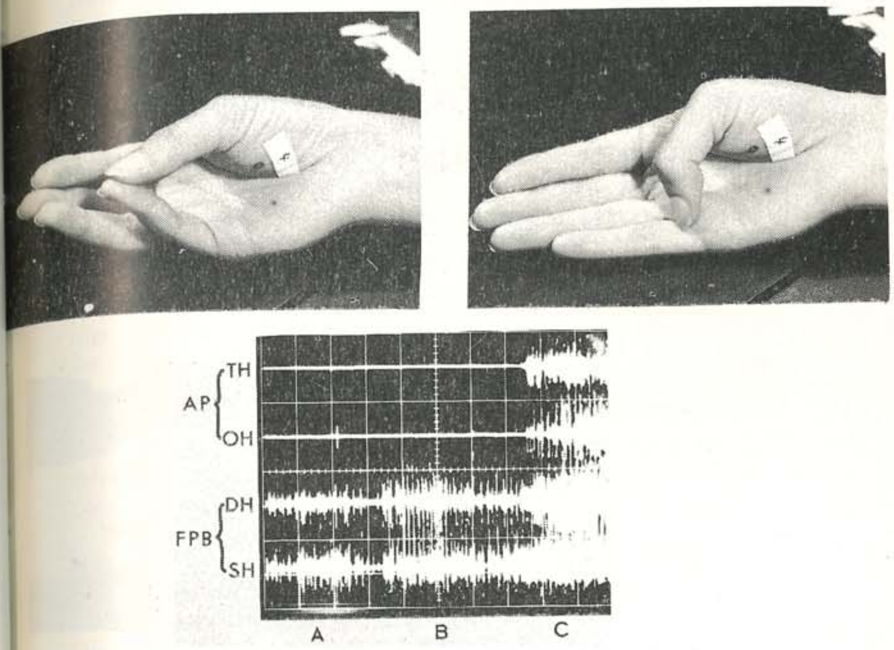


FIG. 2

The thumb moves slowly from its starting (rest) position through abduction, flexion and opposition to touch lightly first the tip of the little finger ("A"), then the base of the little finger ("B"). Finally, the thumb presses firmly against the base of the little finger ("C"). (Note : several subjects also showed slight or moderate activity in the oblique adductor beginning at "B" ; however, activity in the transverse adductor in most subjects did not occur until "C", as shown above).

All tracings (figures 1 to 4) were photographed from the face of a Tektronix type 564 storage oscilloscope using a sweep speed of 0.2 sec. per cm.

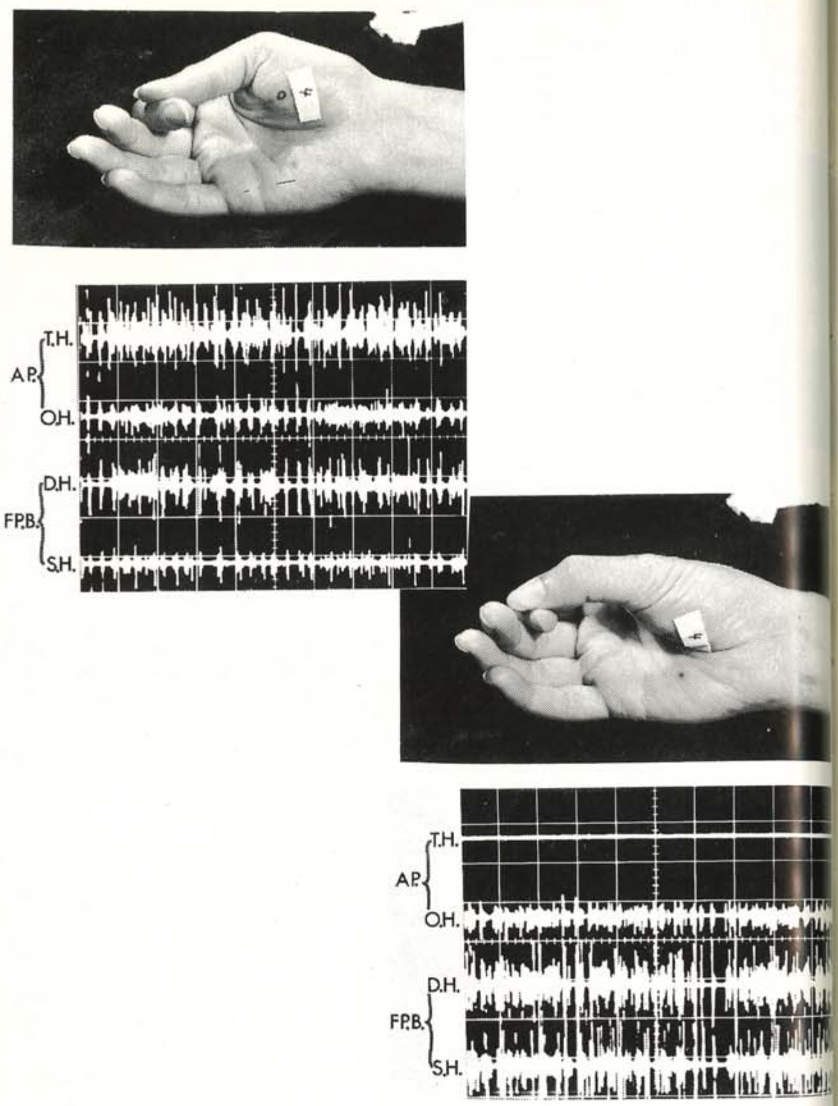


FIG. 3 & 4

The thumb, placed in a lateral pinch position angainst the distal phalanx of the index finger, is rolled in a proximal direction (i.e. lateral rotation of the thumb, fig. 3), then (in fig. 4) is rolled in a distal direction (i.e. medial rotation of the thumb).

its own characteristic pattern of function during various movements and postures of the thumb.

Electromyography using bipolar Karma fine-wire electrodes (7, 8) implanted into the right hands of 20 young adult subjects was employed to investigate functional anatomy. EMG recordings from the four muscles showed that although at times significant activity occurred simultaneously in all four muscles during a particular movement or position of the thumb, the onset, duration and degree of activity in each muscle often was different (fig. 1 & 3). Patterns of activity and inactivity in each muscle during the series of movements and positions soon were recognized and became predictable in most (but not all) of the 20 hands.

As might be expected the pattern of activity in the superficial flexor brevis was clearly different from that in the transverse head of the adductor (figs. 3, 4). Interestingly, activity in the deep flexor usually resembled that in the superficial flexor ; similarly, activity in the oblique adductor usually resembled that in the transverse adductor. Yet, acitivities in the adjacent deep flexor and oblique adductor at times were significantly different (figs. 1, 2). These findings tend to support the view that the deep flexor pollicis brevis is indeed a "flexor" and oblique adductor pollicis an "adductor", and that the two are separate muscles functionally.

The electromyographic study (to be described in more detail in a future publication) complemented the morphological study and revealed a picture of distinctiveness of function even in closely adjacent muscles. Not only is each part of this flexor-adductor complex a separate entity morphologically, but functionally as well, with each having its own precise influence and stabilizing effect upon the thumb.

BIBLIOGRAPHY

1. GRAY, H. : *Anatomy ; descriptive and applied.* 34th ed., edited by Davis, D.V. and Coupland, R.E., Longmans, Green & Co. Inc., London, p. 687, 1967.
2. DAY, M.H. and NAPIER, J.R. : The two heads of flexor pollicis brevis. *J. Anat.*, 95 : p. 123, 1961.
3. CRUVEILHIER, J. : *Anatomie descriptive.* Bechet jeune, Paris, 1834.
4. WOOD JONES, F. : *The principles of anatomy as seen in the hand.* 2nd ed. (reprint), Baillière, Tindall and Cox Ltd., London, 1949.
5. CUNNINGHAM, D.J. : *Textbook of Anatomy.* 6th ed., edited by Robinson, A., Oxford University Press, London, p. 462, 1931.
6. PIERSON, G.A. : *Humain Anatomy.* 9th ed., vol 1, edited by Huber, C.G., J.B. Lippincott Co., Philadelphia, p. 610, 1936.
7. BASMAJIAN, J.V., and STECKO, G. : A new bipolar electrode for electromyography. *J. Applied Physiol.*, 17 : p. 849, 1962.
8. BASMAJIAN, J.V., FORREST, W.J., and SHINE, G. : A simple connector for fine-wire electrodes. *J. Appl. Physiol.*, 21 : p. 1680, 1966.

TELEMETERING ELECTROMYOGRAPHY OF WOMEN WALKING ON HIGH HEELS

J. JOSEPH

Guy's Hospital Medical School, London.

When walking on high heels, women show comparatively little change in the activity of the muscles investigated. The tibialis anterior contracts continuously during the stance phase, but much less markedly than when walking on low heels. The soleus contracts more strongly during the stance phase, and the quadriceps femoris contracts more strongly and during most of the stance phase as compared with walking on low heels. There are no obvious changes in the activity of the hamstrings, flexors of the hip, gluteus medius and maximus and erector spinae.

ELECTROMYOGRAPHY OF POSTURAL MUSCLES IN RELATION TO VISUAL ATTENTION

A. LAVILLE and A. WISNER

Laboratoire de Physiologie du Travail du
Conservatoire National des Arts & Métiers[1]

Abstract

The whole activity of the nape muscles is related to the performance speed and duration of a precise work.

When the work load (performance speed) is great, the average distance between the eyes and the work plane is small and the head movements are not numerous. At the same time, a high level of electric activity is recorded in the nape muscles.

When the experiment is long (2 hours), neither the performance, nor the posture changes, but clear electromyographic evidences of muscle fatigue appear progressively.

Recording the electromyographic activity of the nape muscles can be an index of the visual attention required for such a precise work.

Résumé

L'activité électrique globale des muscles de la nuque est en relation avec la vitesse d'exécution et la durée d'une tâche de précision.

Quand la charge de travail (Vitesse d'exécution) est grande, la distance moyenne entre les yeux et le plan de travail est faible et les mouvements de la tête sont peu nombreux. On note simultanément un niveau élevé d'activité électrique des muscles de la nuque.

Quand l'expérience se prolonge (2 heures) il n'y a pas de variations de la performance ni de la posture, mais il apparaît progressivement des signes électromyographiques nets de fatigue musculaire.

L'enregistrement de l'activité électrique des muscles de la nuque peut être un indice de l'attention visuelle exigée par un travail de précision.

---

[1] 41, Rue Gay-Lussac – Paris V^{e}.

LES CONTREREACTIONS MUSCULAIRES D'EQUILIBRATION AU COURS DE LA MARCHE BIPODALE ET MONOPODALE

P. RABISCHONG et E. PERUCHON

Résumé de la Communication

L'étude de ces contreréactions a été faite au moyen d'une plate-forme dynamométrique équipée de 4 capteurs, à jauges électriques explorant chacun une direction. Les informations sont recueillies sur un enregistreur à plume et en même temps sont coordonnées selon les 2 axes sur un oscilloscope à 2 voies. Cette méthode permet de matérialiser le centre de gravité et ses déplacements et permet également de chiffrer la surcharge effectuée sur chacun des capteurs. Elle fait partie d'une méthode décrite par nous sous le nom d'électropodographie statique. Conjointement sont enregistrées les réactions musculaires au moyen d'électrodes cutanées placés sur les muscles responsables des contre-réactions d'équilibration. Les enregistrements montrent que les réactions musculaires ont leur maximum d'intensité au maximum de déséquilibre et semblent être induites par des informations sensorielles multiples. Notre but a été de déterminer la part qui revient à chacun des niveaux. On peut considérer en effet qu'il existe 4 niveaux de régulation correspondant à 4 types de bouclage de régulation par un "feed back" :

1°) un niveau labyrinthique. Il nous est apparu que ce niveau joue un rôle excessivement faible dans les phénomènes d'équilibration statique et que le rôle en particulier de l'otolithe chez l'homme est extrêmement réduit. Il nous a été donné en effet d'examiner des malades labyrinthectomisés bilatèralement (de causes chimiothérapiques) et de n'observer chez eux aucun trouble de l'équilibre statique, les yeux ouverts ou les yeux fermés.

2°) Le niveau proprioceptif. Nous entendons par là un niveau de régulation qui permet l'ajustement des muscles agonistes et antagonistes à l'existence des proprirécepteurs fuseaux neuromusculaires, et organes de Golgi essentiellement.

3°) Le niveau extéroceptif. Ce niveau est un niveau de contrôle final et nous semble jouer un rôle capital en tout cas beaucoup plus important qu'il n'est convenu d'admettre. Il représente essentiellement par les récepteurs sensoriels du tact placé dans la couche profonde de la peau de la face plantaire du pied. Le comportement de ces récepteurs est d'ailleurs sensiblement identique à celui de nos capteurs, ils transmettent des informations de déséquilibre avec une notion réactionnelle qui permet les ajustements posturaux. Ce "feed back" de régulation envoie également une information vers le cortex conscient qui permet non seulement la régulation posturale, mais encore la conscience de l'état de déséquilibre.

4°) Le niveau visuel. C'est également un niveau de contrôle final. On sait que l'oeil est capable de pallier toutes les déficiences sensorielles de régulation. Aussi la suppression de ce contrôle visuel entraine toujours des contre-réactions d'équilibre beaucoup plus instables déterminant un phénomène de pompage surtout visible dans la station monopodale.

Notre objectif est donc d'une part de déterminer la part exacte qui revient à chacun des niveaux de régulation, et d'autre part d'envisager à l'avenir la constitution d'un système automatique de stabilisation des prothèses de membre inférieur basées sur le principe des informations de déséquilibre nées à partir de capteurs plantaires pouvant induire des contre-réactions d'équilibre.

INFORMATION PROCESSING OF THE MYOELECTRIC SIGNAL FROM SKELETAL MUSCLE

William D. McLEOD, Ph.D.
Carlo J. DE LUCA M.Sc.

The field of electromyographic kinesiology has gained impetus during the last few years. By its own title, study within this field is not limited to cases with existing neuromuscular pathology. As I view the important work to be done within the field, it is necessary to have a good background of work done on normal systems. Unfortunately, the field of electromyography was originally developed only for clinical diagnosis and has not been primarily concerned with the requirements of electromyographic kinesiology. Traditionally, electrophysiological signals used for clinical purposes have been read by medically trained people who accomplish the analysis of the signal based on past experience. This mode of operation does not force quantitative measurement. Any means of simplifying the output trace will suffice.

Any processing that has been done on the myoelectric signal has been primarily that most easily done with equipment that the suppliers are willing to provide. If indeed we are to approach this problem from a rational standpoint, we must set goals for the information extraction from the myoelectric signal that are realistic when the requirements of electromyographic kinesiology are kept in mind. In addition, it would be desirable to develop a quantitative measurement.

The primary objectives of this research were to attempt a fairly extensive study of the myoelectric signal from the biceps brachii in order to determine parameters that varied linearally with output load and possibly elbow angle. The minor objectives were to gain some background experience in order to start development of a realistic model that would allow the use of the myoelectric signal to predict the load and angle of the joint. It is relatively simple to measure the load output from the joint as well as the joint angle. In addition, the myoelectric signal is relatively easy to obtain. One must remember, however, that when measuring the load output external to the body there is a joint efficiency factor that would be one of the unknowns. At this stage in the experimentation, this factor was considered negligible.

One other main point of interest in the research was to establish the validity of a single sample of the myoelectric output from the muscle. Since a muscle consists of many fibers, it is probable that in some muscles a single sample of the myoelectric output is not sufficient to establish the function of that muscle. The trapezius muscle would be an example wherein the muscle attachment is not simple. With a muscle of this kind, it might be necessary in the long run to take more than one sample of the muscular output in order to predict joint functions. The short head of the biceps brachii is a good example of a muscle that has a simple attachment and will allow the validating of a single sample from the muscle.

At the present time there are several standard techniques used to reduce the raw myoelectric signal to some form that is manageable. These techniques can be broken up into two rough classifications : the first being time domain, and the second frequency domain. With all standard techniques, the physical amplitude of the myoelectric signal plays a major role.

The time domain techniques can be separated into several sub-classifications. The simplest is to view the raw myoelectric signal through a fairly narrow window and assess some rough levels of quantization which would then allow a person to visually assign a number to the signal. This technique is very subjective and not readily suited to any good scientific analysis.

Secondly, one can rectify the myoelectric signal and put it through a smoothing filter. This will provide a given level of output from the muscle which is still fairly raw in nature unless the smoothing filters' time constants are very large, in which case it is only a guess at the average output of the signal at any given time.

The third technique that fits closely whith the above two is to integrate the electromyographic signal. It is important to recognize that seldom is pure integration used. In all cases, it will be pseudo-integration which, in the extreme, simply provides the envelope of the electromyographic signal.

All of the above methods can be done with equipment normally supplied by the manufacturers.

One further time domain technique is the use of correlation functions. This, of course, relies heavily on extensive computational capabilities and does not seem to provide any useful information. The most useful parameter that can be obtained from the correlation functions is the dominant frequency in the signal. I have not as yet seen any effective use made of the auto-correlation function.

Within the frequency domain there are basically two techniques that have been used. The first is, of course, counting the number of times the myoelectric signal crosses the 0 axis. There seems to be no sound basis for doing this other than that it is a different method. The second technique is the power density spectra. To date this technique has been used simply to obtain the main frequency component within the myoelectric signal. There have been many people producing power density spectra, but no effective use has been made of this technique to date.

All of the above techniques are highly dependent on the amplitude of the myoelectric signal. This is a bad parameter since the amplitude of the myoelectric signal is highly dependent on the number of motor units monitored by a given electrode. If the fine wire karma electrodes are being used, the amplitude of the output is then highly dependent upon the de-insulated area at the tip of the electrode. On the other hand, if surface electrodes are being used, the amplitude is highly dependent upont the amount of skin and fat that exists between the electrodes and the muscle. Surface electrodes do not allow discrimination between muscles that are adjacent to one another. It is my opinion that the fine wire karma electrodes provide the best means of isolating individual muscles but can influence any amplitude dependent analysis technique being used. Since it seems obvious that any parameter providing the most dependable information about the muscle behaviour must not be dependent upon amplitude, the authors were primarily concerned with investigation into the frequency domain.

One important point, when investigating the frequency properties of the myoelectric signal, is to cover a broad enough frequency band to be certain that no information is lost by filtering at either the high frequency end or the low frequency end. The results in this paper are based on an analysis of the signal where the low frequency cutoff point was 8 hz, and the high frequency cutoff was approximately 400 hz. A preliminary study showed that there is no significant energy above 350 hz.

Two basic experiments were performed. The first was to determine muscle or joint output loading and the corresponding myoelectric signal. Is was hoped that this experiment would provide us with a means of assessing the various parameters that can be extracted from the myoelectric signal. The second experiment was performed to gain some insight into the normal innervation of skeletal muscle for the purpose of developing a reasonable model which would provide an ultimately good signal processing means.

In the first experiments, two independent signals were extracted from the same muscle (the short head of the biceps brachii). This experiment was aimed at attempting to determine if a single sample of the myoelectric ouput from the muscle was a valid representation of that muscle output. Several interesting results were obtained. In the power density spectra of the muscles there is a well defined energy peak at approximately 11 hz which has been termed the tremor frequency. This frequency varies linearally with the output load from the joint. The variation is over a fairly narrow frequency band covering about 1.5 to 2.0 cycles per second. The majority of the literature quoting power density spectra does not show this energy as an independent peak. This could be due to several reasons. One of the primary causes is that most of the work is done with a low cutoff point of around 20 cycles per second eliminating this information from the signal. One other point worth mentioning is that unless one very carefully observes the power density spectrum of the myoelectric signal, this peak could be well hidden since the power density spectra has a fairly large standard deviation and normally requires much smoothing in order to determine average values. If any smoothing is applied to this signal, the information at the tremor frequency is lost. One other observation is that the frequency of the maximum power point of the myoelectric signal varies linearally with elbow angle.

The investigation of the signal from both sites within the muscle gave the same information, allowing the conclusion that a single sample from the short head of the human biceps brachii is a valid representation of that muscle function.

The second experiment, aimed at increasing the basic information on muscle innervation, provided some interesting information. A set of bi-polar electrodes were installed in the short head of the biceps brachii, and the subject was asked to isolate a single motor unit. When this was accomplished, he was asked to attempt to increase the firing rate of this motor unit and to keep increasing this rate irrespective of the recruitment of additional motor units. Due to the nature of the myoelectric signal, it is almost impossible to track a single motor unit in a contraction showing several. With very careful study, we were able to keep track of the firing rates of the motor units up to the point where there were seven different motor units firing.

The results of this experiment showed that the firing rate of the motor unit would increase to a point somewhere between 11 and 15 pulses per second, at wich time another unit was recruited. Instead of increasing the rate of firing of this motor unit, more units were recruited all of them firing at approximately the same rate. Since there is evidence in the literature that a single motor unit can fire up to approximately 50 per second, it would seem that the first function that occurs in an increasing muscle contraction is the recruitment of motor units rather than the increase in firing rate. A valid model under this condition would be to assume that the motor units were all recruited prior to an increase in firing rate above this basic 11 to 15 pulses per second. Some of our records, when plotting an amplitude-dependent parameter versus the load output, indicate that up to a given load the relationship was linear, and at that point a discontinuity occurred with a change in slope. It would seem valid to speculate that this is the point at which the motor units increase in their firing rate and that up to this point all that was happening was the recruitment of additional motor units.

This paper has presented a parameter (the tremor frequency) that apparently varies linearally with output loading. It is a very simple parameter to extract and should not be disturbed too greatly by motion artfact. The second parameter, the frequency of the maximum power peak, varies with joint angle and, again, is a relatively simple parameter to extract. Neither of these parameters is dependent upon amplitude and allows any type of electrode to be used.

BIBLIOGRAPHY

BUCHTHAL, F. : The General Concept of the Motor Unit. *Neuromuscular Disorders.* Vol. 34, No 3, pp. 3-30, 1961.

BIGLAND, B. and LIPPOLD, O.C.J. : The Relation Between Force, Velocity and Integrated Electrical Activity in Human Muscles. *J. Physiol.* Vol. 123, pp. 214-224, 1954.

PEARCE, K.I. and SHAW, J.C. : Activity Measurement Using the Integrating and Cross-Over Counters. *Med. Elect. Biol. Engrg.,* Vol. 3, pp. 189-198, 1965.

BENDAT, J.S. and PIERSOL, A.G. : *Measurement and Analysis of Random Data.* John Wiley and Sons, New York, 1966.

LIPPOLD, O.C.J., REDFEARN, J.W.T. and VUVO, J. : The Rhythmical Activity of Groups of Motor Units in the Voluntary Contraction of Muscle. *J. Physiol,* Vol. 137, pp. 473-487, 1957.

LEE, Y.W. : *Statistical Theory of Communication.* John Wiley and Sons, New York, 1960.

AN ELECTROMYOGRAPHIC-CENIMATOGRAPHIC STUDY OF THE THIGH MUSCLES USING M.E.R.D. (MUSCLE ELECTRONIC RECORDING DEVICE) I.

Bruce R. BRANDELL, Phd.,

Assistant Professor of Anatomy, Department
of Anatomy, University of Saskatchewan.

Garnet J. HUFF,

Assistant Professor of Electrical Engineering,
Department of Electrical Engineering,
University of Saskatchewan.

George J. SPARK, B.E.,

Assitant Professor of Electrical Engineering,
Department of Electrical Engineering,
University of Saskatchewan.

Introduction

This paper is a preliminary report of a study intended to determine the significance of thigh muscle activity patterns by correlating them with phases of the stride during various forms of locomotion, and ultimately with different types and degrees of training. While a respectable number of earlier studies have reported relationships between the lower limb muscles and walking, for example Radcliffe, Liberson, Battye and Joseph, and Elftman (1-4), none seems to have been made to determine the effect on this relationship of "warm up" or fatigue during prolonged continuous walking, or of muscle activity patterns during running. Such studies require relatively long uninterrupted periods of recorded locomotion under natural untethered conditions, and would be necessary if the effect of training were to be meaningfully accessed. Therefore, a small portable Muscle Electronic Recording Device was built, which can be worn by a performing subject without appreciably interferring with his performance, and which records and replays EMG with a high degree of fidelity. In addition to numerous successful preliminary walking and trotting trials of three to four minutes duration, one combined electromyographic-cinematographic test has been made, and is reported here in some detail.

This project was supported by a grant from the fitness and Amateur Sport Directorate, Department of National Health and Welfare, Canada.

Equipment and Methods

M E R D - 1

A device for recording EMG from ambulatory subjects.

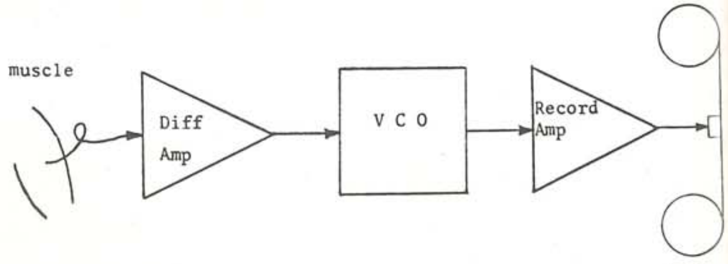
General Description :

MERD- (Mio-Electric Recording Device) is a small (5cm × 15cm × 20cm), lightweight (2 Kg) tape recorder wich is rugged enough to withstand the rigors of strenuous exercise and is capable of recording two channels of EMG from ambulatory subjects.

Recorder :

The tape transport is an adaptation of a commercial cassettype tape recorder. The tape speed has been increased (approximately two times) and the single channel head replaced by a two channel model.

A block diagram of the Record Electronics is shown in Fig. 1. Both channels are indentical. The EMG signal (0-2 MV, 100-1,000 Hz) is picked up with a two-wire-plus-ground system of electrodes and amplified by an integrated circuit Differential Amplifier with a gain of about 5,000. This output which has an amplitude of several volts is used to vary the frequency of a Voltage Controlled Oscillator. The VCO has a center frequency of 4 kHz and a deviation of ± 50 %. This technique of recording (Frequency Modulation) is used to overcome the problem of tape dropout and thus enables accurate amplitude data to be obtained. The output of the VCO is amplified and shaped before being applied to the head for recording on tape.



TAPE

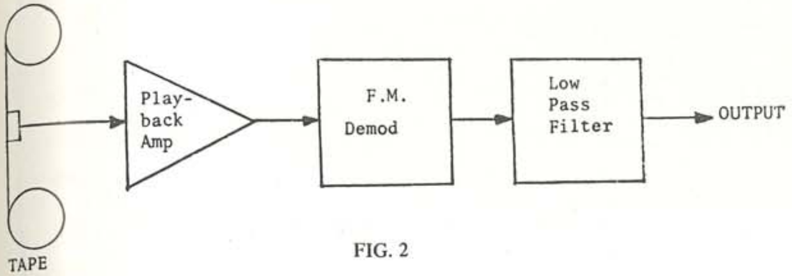
FIG. 1

Record

Playback Unit :

The Playback Unit changes the small FM signals which are read off the tape to a replica of the original EMG. A block diagram of this part of the system is shown in Fig. 2.

The signal from the tape is amplified and shaped by the Playback Amplifier and then converted from a frequency modulated carrier to the EMG signal by the FM Demodulator and the Low Pass Filter. This output can be further processed by a Band Pass Filter to remove low frequency base line jitter and high frequency noise before being viewed on an oscilloscope.



TAPE

FIG. 2

Playback

Auxiliaries :

Provisions are made for identification and sychronization of the tape with motion pictures of the same activity. A hand switch is used to produce a mark signal on the tape and to activate a lamp mounted on the recorder. This allows tape-picture synchronization. A foot switch is used to identify individual steps in the activity.

Electrodes :

Two .0011″ insulated wire electrodes were inserted into each muscle to be tested by means of a $1\frac{1}{2}''$, 26g. hypodermic needle, which was withdrawn before the experiment, leaving the bared and barbed ends of the wires in the muscle. This allowed the subject complete freedom of movement without pain or discomfort. The *muscles* tested in this trial were the right vastus medialis, a major extensor of the knee, and the right semimembranosus, which flexes the knee and extends the thigh. The outer ends of the electrode wires were bared, and connected to shielded lead wires by means of small clamps. Each pair of clamps was, in turn, firmly cemented to the floor of a small plastic box with a removable lid. This arrangement protected and stabilized the lead wire connections, and helped to reduce low frequency mechanical disturbance. Also small plastic covers protected the points of electrode wire insertion. The electrode lead wires passed through a copper ground plate, and were plugged into the side of the MERD, which was strapped on the back with a simple harness arrangement.

Foot Switch :

A two inch piece of contact switch tape was taped into the ball of the right foot in a position, which resulted in its firing almost exactly in the middle of the flat foot part of the stride, which enabled correlation between the motion picture and a marker signal on the upper beam of the EMG recording.

Photography :

Black and white motion pictures were taken of each test trial at a speed of 124 frames/second. Because it was feared that the light marker signal would be too small to be identified in the motion picture, each trial was started from a standstill to make certain identification of each stride.

Four trials were made outdoors on the university stadium track :
one walking trial of seventeen complete strides (thirty-four steps),
two trotting trials of twelve strides each, and one sprinting test of nineteen strides.

Experimental Results

Technical Performance of the MERD I

Preliminary results indicate that the sensitivity and time stability of the unit are quite satisfactory due largely to the stability of the tape transport and the use of FM recording. The use of a two channel four track head has proved to produce marginal playback signal so that a four channel recorder would probably not be satisfactory. A precision tape transport would overcome this problem.

Correlation of EMG (Right Semimembranosus and Vastus Medialis) and Stride Phases Walking (Figures 3 and 4). The periods of semimembranosus and vastus medialis activity alternated with each other. Semimembranosus

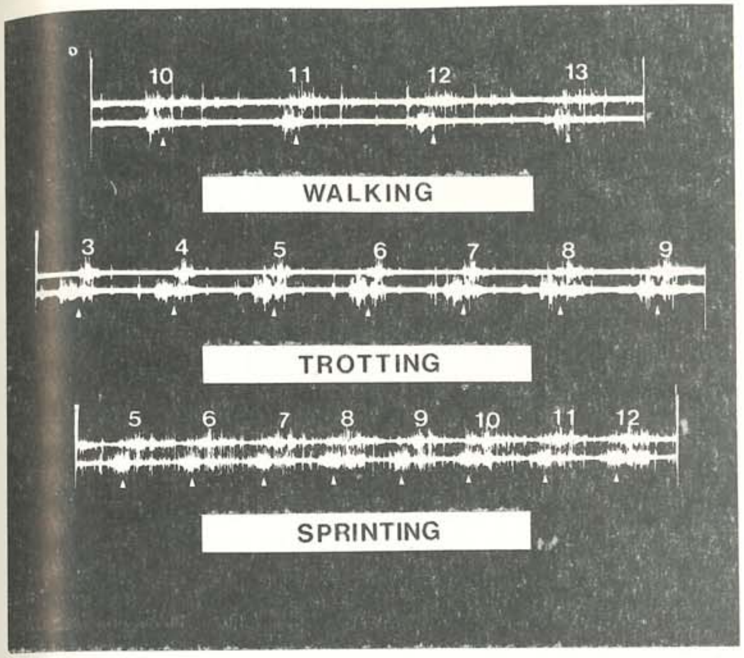


FIG. 3

Upper beam – vastus medialis ; lower beam – semimembranosus. The nummerals represent the number of full strides taken from a complete standstill.

became active just past mid-swing phase with the knee and hip joints slightly flexed, and it continued during knee and hip extension to end just at, or slightly after, heel contact. Vastus medialis usually began weakly at about the same time as semimembranosus, but became strongly active only after the latter's activity had ended. Its EMG terminated early in the flat foot phase of the stride. These findings agree substantially with those of Radcliff (4) and Liberson (3). However, the former indicates consistent quadriceps, and inconsistent hamstring activity during early swing phase, and the latter depicts activity for the right hamstrings during left toe push off (before right toe contact). These periods of activity were entirely absent in the seventeen walking paces reported here, but the first was consistently present during sprinting, and the second during both trotting and sprinting trials.

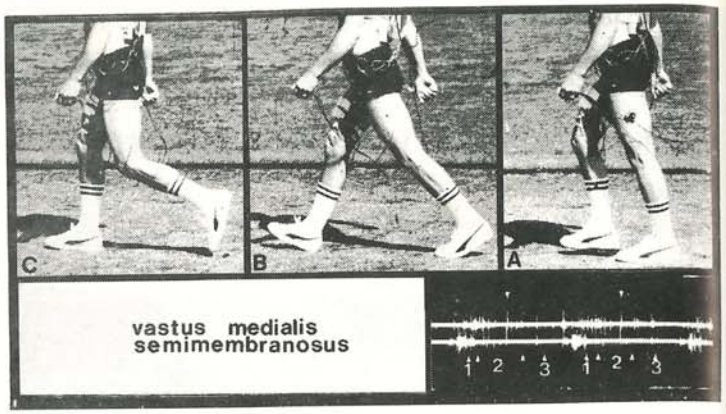


FIG. 4

Walking, strides 11 and 12. A – start of semimembranosus, B – end of semimembranosus, C – end of vastus medialis. 1 – heel strike, 2 – flat foot, 3 – toe off.

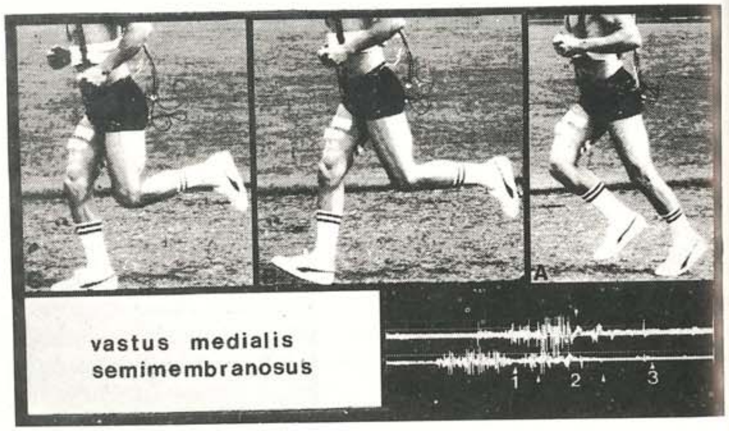


FIG. 5

Trotting, stride 6. A – start of first phase of semimembranosus, B – start of second phase of semimembranosus, C – end of vastus medialis.

Trotting (Figures 3 and 5). The activity of semimembranosus was clearly divided into two parts. 1). The first part was entirely before the vastus medialis activity. It began just past mid-swing phase with the knee and hip joints markedly flexed, and the left toe pushing off, and continued during knee and thigh extension, i.e. limb straightening, until the moment of heel strike. 2). The last part, which was entirely absent during walking, usually began after a slight interruption of activity after the heel was well planted, but before the foot was completely flat. It continued during a brief period of knee flexion and thigh extension, and ended as the foot was brought flat onto the ground. The vastus medialis activity generally corresponded to the last part of semimembranosus, but began slightly before and ended shortly after it. The first trotting trial recording is reproduced in Figure 3, and the strides of the second trial were very similar.

Sprinting (Figures 3 and 6). The analysis of muscle activity-stride correlation for this trial must be considered with some caution, since the foot contact switch made multiple firings, and its marks could not be used for analysis. However, the hand light switch was signaled between the ninth and tenth strides, and identification of the corresponding deviations of the lower beam made possible the following analysis of these strides. In the ninth stride semimembranosus begins just past mid-swing phase, as in walking and

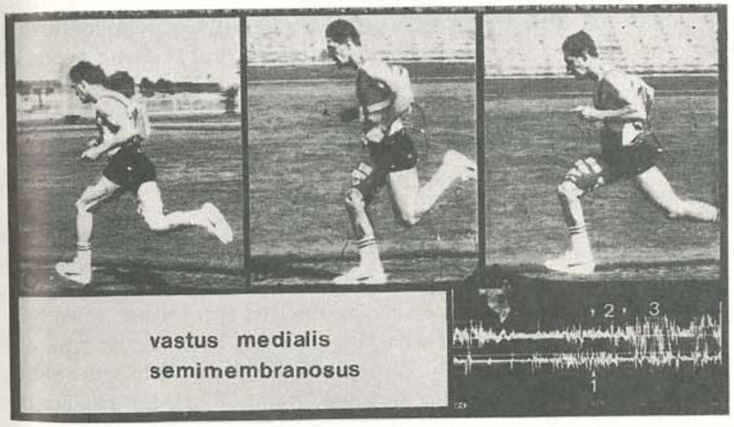


FIG. 6

Sprinting, stride 9. A – start of first phase of semimembranosus, B – end of first phase of semimembranosus, C – end of vastus medialis. 1 – heel strike, 2 – flat foot, 3 – toe off.

trotting, although both feet were completely off the ground at this moment in the sprint stride. Its EMG continued without interruption until the foot was flat on the ground in midstance, during both limb straightening and early knee bending. This span of activity included both parts of semimembranosus activity during trotting. An additional weaker, but still prominent, active period corresponded to the strongest vastus action and extended from near the end of the stance phase, as the right toe pushed off, to the early part of the swing phase with the foot far back and the knee somewhat flexed, i.e. during knee flexion and thigh extension.

Substantial vastus medialis activity began earlier, as the foot raised onto the toes, but it was entirely displaced in this stride, as compared to trotting, where it was related to the flat foot part of the stance phase. Stride ten was very similar, but also had vastus medialis activity during flat footed stance. Strides 6-15 were all similar in pattern, but the first four strides (during acceleration) and the last four strides (during deceleration) presented the same pattern as during trotting.

Discussion

The MERD I has proven to be an excellent two channel portable recorder, during the preliminary walking, trotting and sprinting trials reported here. The patterns of EMG were clearly defined and could be replayed with a remarkably low level of noise. The movements of a subject over a period of several minutes could be readily recalled by identifying EMG patterns recorded during walking, running and climbing stairs. Some difficulty was experienced with multiple firings of the foot switch during sprinting, and it now appears desirable to have an external signal correlate switch firing more exactly with the stride phase.

The role of the semimembranosus and vastus medialis in locomotion seems to be, to a large extent, out of phase with the obvious functions of these muscles during free movement of the knee and hip joint. That is, the semimembranosus was primarily active during the later swing phase, when both the knee and hip joints were extending, although it flexes the knee and extends the hip of the free limb. Vastus medialis was primarily active during the early stance phase, when the knee was flexing, although it extends the knee of the free limb. Therefore, it must be assumed that these muscles are performing breaking functions: the semimembranosus to prevent over extension of the knee, and vastus medialis to prevent collapse of the knee joint as the limb assumes the full weight of the body.

During trotting a second phase of semimembranosus activity came into play, which matched that of vastus medialis during the early stance phase, and appeared to bring the foot more firmly onto the ground by strengthening knee flexion between initial heel and initial toe strike.

Sprinting appears to present a modified trotting pattern. It added a third EMG phase coincidental with strong vastus medialis activity, which corresponded to hip extension and knee flexion, as the right toe left the ground in early swing phase. This is the free limb function of semimembranosus, and is made use of to pull the limb up and backwards during this more vigorous form of locomotion. Vastus medialis acting at the same time would seem to be helping to control the magnitude of knee flexion. The ocassional absence of vastus medialis in its "usual" place during the early stance phase may be related to the very short duration of flat footed stance, as compared to walking and trotting-ratios of about 2:3:6.

Summary

A preliminary study to correlate thigh muscle EMG patterns and the characteristics of the stride during different types of locomotion has been made with the use of an especially constructed Muscle Electronic Recording Device (MERD I), and high speed motion picture photography. MERD I consists of a small portable two channel tape recorder for recording EMG from ambulatory subjects, and was constructed from a commercial tape transport with the use of integrated circuits and transistors to keep a small size and low weight. Beam deviations were fired by hand and foot switches to provide identification and synchronization with the motion pictures.

Distinct EMG patterns of the semimembranosus and vastus medialis were correlated with the stride phases of walking, trotting and sprinting. In general it was found that the activity of the two muscles alternated between late swing and early stance phases during walking, semimembranosus extended to the early stance phase during trotting, and that both muscles added a third early swing phase activity period during sprinting.

Acknowledgements

We wish to acknowledge with thanks the superb photographic support given this project by Hans Dommasch, head photographer, University of Saskatchewan, and the cheerful willingness of Robert M. Kurtz, physical education major, to perform as our subject.

REFERENCES

1. BATTYE, C.K. and JOSEPH, J. An investigation by telemetering of the activity of some muscles in walking. *Med. Biol. Eng.*, 4, 125, 1966.
2. ELFTMAN, H. : Biomechanics of muscle : with particular application to studies of gait. *J. Bone. Jt. Surg.*, 48 A, 363, 1966.
3. LIBERSON, W.T. : Biomechanics of gait : a method of study. *Arch. Phys. Med.*, 46, 37-48, 1965.
4. RADCLIFFE, C.W. : The biomechanics of below-knee prostheses in normal, level, bipedal walking. *Artif. Limbs.*, 6, 16, 1962.

KINESIOLOGIC STUDIES IN CRANIOFACIAL MALFORMATIONS

Samuel PRUZANSKY, D.D.S.

Center of Craniofacial Anomalies
University of Illinois at the Medical Center
P. O. Box 6998, Chicago, Illinois 60612

Introduction

The purpose of this report is to call attention to the array of natural experiments available to the investigator that permits insight into mechanisms controlling posture and movements of the head, jaws and tongue. So far, only a small number of such cases have been studied by means of electromyography.

Earlier studies in this laboratory focused on electromyography of the temporalis, masseter and hyoid musculature in normal and pathologic conditions in man. The results revealed adaptive patterns of muscle behavior that compensated for abnormalities in form and function. (1-7) More recent x-ray studies on a larger variety of congenital and acquired defects of the mandible and associated structures suggest interesting opportunities for the kinesiologist. Of particular interest is the role of the muscles converging on the hyoid bone and their relationship to the posture and movements of the mandible.

The Infrahyoid Muscles

The infrahyoid muscles have been excluded from electromyographic kinesiologic studies on the movements of the mandible. In considering the muscles that contribute to the depression of the mandible, the external pterygoid has been identified as the prime mover, with secondary roles assigned to the anterior belly of the digastric and the mylohyoid muscles.

The infrahyoids, as part of the anterior cervical chain, are connected to the hyoid bone and are in series with the depressors of the mandible. As such, one might expect the infrahyoids to reflect the behavior of the mandible and the interplay of muscle forces converging about the hyoid bone. Visual

Supported by grants from the Children's Bureau and the National Institutes of Health (HD DE 01153),
Department of Health, Education, and Welfare

observation of patients with ankylosed temporomandibular joints indicated compensatory hyperactivity of the supra-and infrahyoid muscles. In the normal individual, depression of the mandible against external resistance also elicited active contraction through the supra- and infrahyoid chain. All the more reason it seemed to investigate the readily accessible infrahyoid muscles.

At the time these investigations were conducted, needle electrodes that chould be autoclaved were not readily available. This precluded the study of the external pterygoid and restricted most of our kinesiologic work to the utilization of surface electrodes. Accordingly, paired surface electrodes were attached to each of the readily palpable sternohyoid muscles (Figure 1).

When the subject was sitting upright in a relaxed position, the sternohyoid muscles were electrically silent. With deep inspiration, pronounced symmetrical activity was elicited and upon expiration, equally symmetrical decay of electrical response was recorded from the two leads (Figure 2).

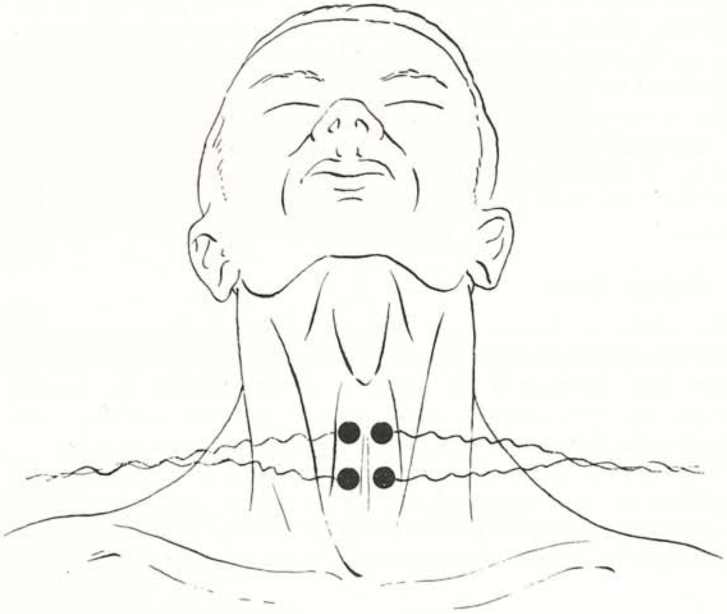


FIG. 1

Disposition of paired surface electrodes over the Sternohyoid muscles.

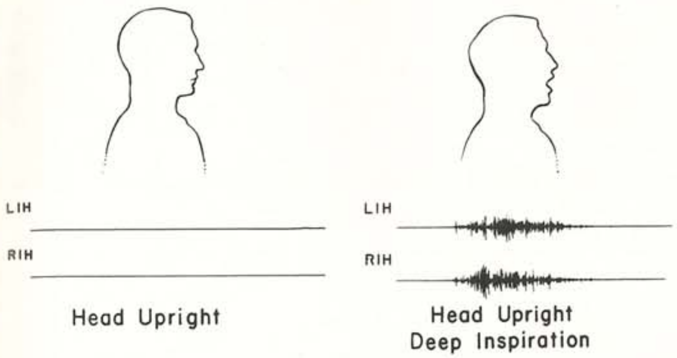


FIG. 2

LIH indicates left infrahyoid group or more accurately left sternohyoid. RIH devotes the right sternohyoid

Mandibular depression evoked an equal response from both sides. When the movement was slow, the activity became evident beyond the mid-range of opening. With rapid jaw opening, the recorded activity was of greater magnitude and apparently of earlier onset (Figure 3).

With the head held in extension, the sternohyoids were electrically silent. Even when the posture was maintained against resistance, no activity was evoked. Holding the head in flexion produced low amplitude discharges which were markedly increased when flexion was performed against external resistance (Figure 4).

Sitting upright in a chair with the head rotated toward the right, activity was evoked in the left sternohyoid muscle but not the right. The reverse pattern was obtained with rotation toward the opposite side. When the rotations were repeated against resistance, activity was registered from both leads,

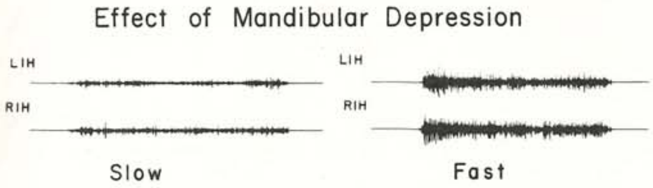
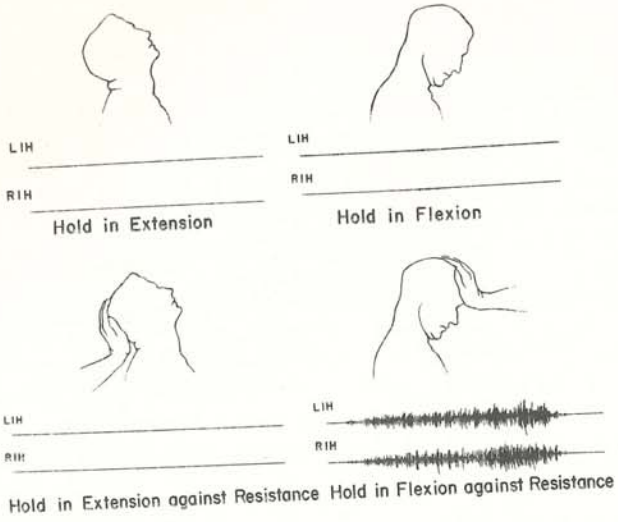


FIG. 3

Slow movement elicited activity as the mandible progressed beyond the mid-range of opening. Fast movement seemed to evoke a more immediate and rapid onset of activity

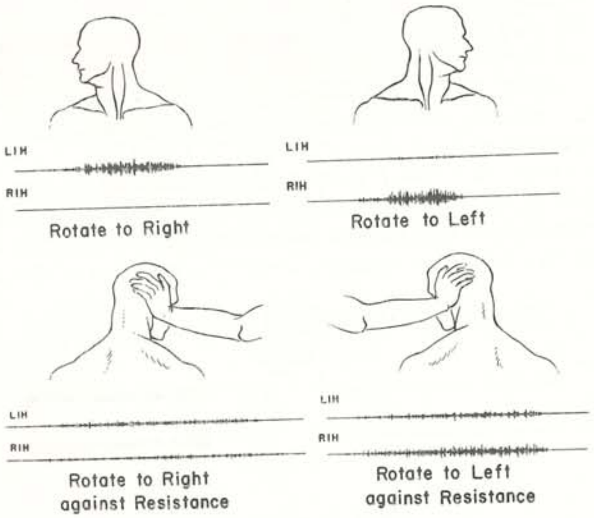


Hold in Extension Hold in Flexion

Hold in Extension against Resistance Hold in Flexion against Resistance

FIG. 4

External manual resistance is provided by a technician



Rotate to Right Rotate to Left

Rotate to Right against Resistance Rotate to Left against Resistance

FIG. 5

Effect of head rotation on the activity of the sternohyoid muscles

FIG. 6

Patient with marked arrest of condylar growth on the right, deviation of the menton toward the affected side, and retrognathia

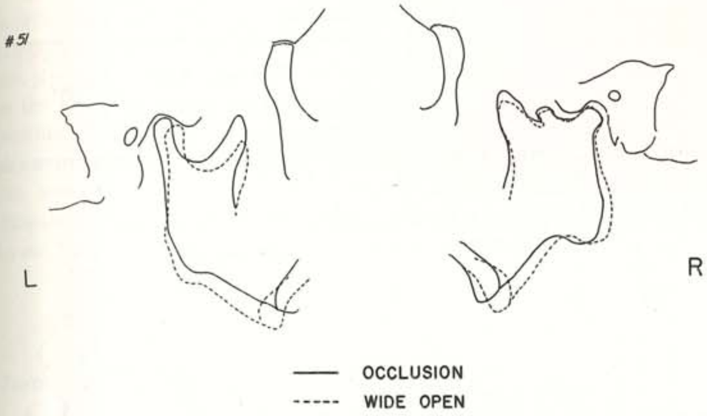


FIG. 7

Tracings of oriented laminagraphic x-rays revealed marked deformity on right side with motion restricted to hinge-like rotations. Translatory movement was recorded on the opposite side

FIG. 8

Patient in figure 6 following surgical reconstruction

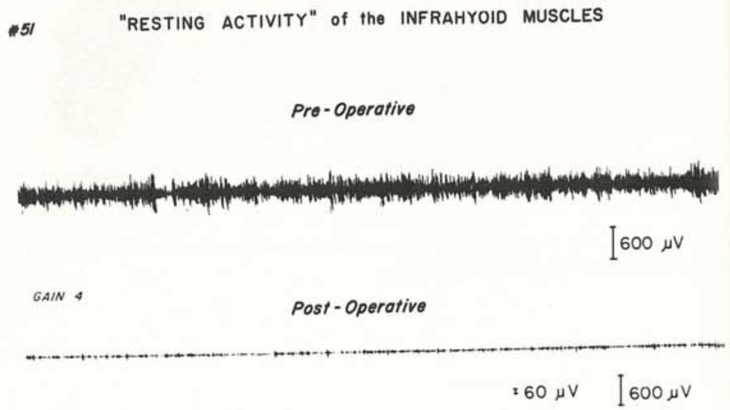


FIG. 9

Electromyographic activity of the sternohyoid muscles in the patient illustrated in figures 6 and 8, before and after surgery

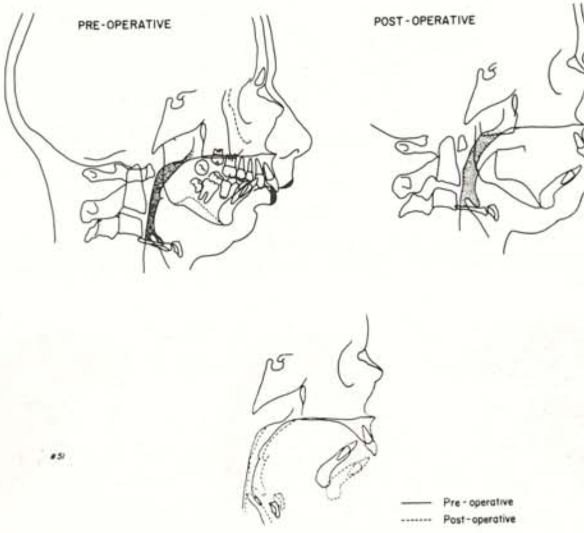


FIG. 10

Tracings of cephalometric x-rays of patient illustrated in figures 6 and 8, before and after surgery

though with a slightly greater amplitude on the contralateral side (Figure 5).

In the course of these investigations, an opportunity was presented to study a young lady with a marked unilateral arrest of condylar growth and retrognathia (Figures 6 and 7). As a result of the surgical reconstruction, her mandible was repositioned in a more forward and median position (Figure 8).

The electromyograms of the sternohyoid muscles were recorded both before and after the operation (Figure 9). Because of the pronounced activity recorded "at rest" prior to surgery, special care was taken to insure the reliability of this observation. Although some activity was evident following surgery, the difference was quite pronounced.

The interpretation of this finding was not clear until the cephalometric x-rays were traced and superimposed (Figure 10). The airway, indicated by stippling, was relatively narrow prior to surgery and expanded as a result of the jaw repositioning. Similarly, the epiglottis, the base of the tongue, as well as the hyoid bone were positioned forward and upward by the change in jaw position. The retrognathia presented prior to surgery affected the posture of the retromandibular organs and particularly, imposed on the dimensions of the airway. The hyperactivity of the sternohyoid muscles suggested an adaptive reflex mechanism providing continuous downward traction on the hyoid bone and tongue to maintain the patency of the airway.

Torticollis

It was reasoned that any postural deviation of the head would demand some compensatory mechanism to maintain congruent mandible to maxilla relationships. For these reasons, torticollis attracted our interest as a natural experiment for the extension of our previous studies.

In all cases of torticollis that came within our purview, the midline relationships between the maxillary and mandibular arches were found to be essentially symmetrical with the mandible at rest despite the prevailing asymmetric forces tugging upon the lower jaw. Although not fully illustrated in the text, a consistent pattern of muscle activity was noted at rest. The posterior fibers of the temporalis, on the side contralateral to the abormal sternocleidomastoid muscle, exhibited continuous low grade discharge at rest. On the side ipsilateral to the abnormal sternocleidomastoid muscle, all of the leads from the temporal is showed continuous and nearly equivalent activity. Activity from the sternohyoid muscle was recorded only on the side of active sternocleidomastoid muscle. Thus, it seemed as if the posterior fibers of the temporalis on one side were opposing the action of the sternohyoid muscle

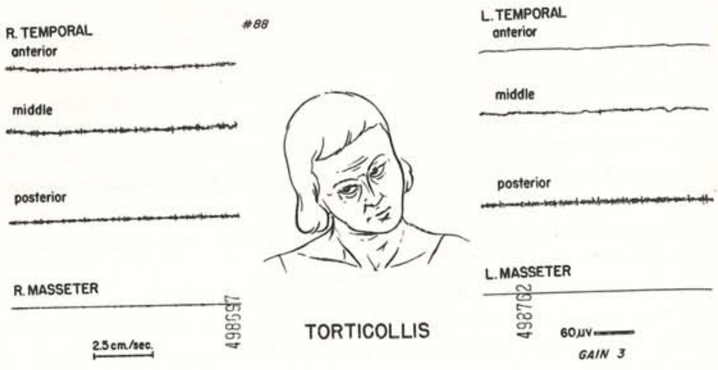


FIG. 11

Neurogenic torticollis. At rest, the posterior fibers of the temporalis muscle, on the side contralateral to the contracted sternocleidomastoid, demonstrated continuous discharge. On the opposite side, all three leads from the temporalis muscle revealed low amplitude discharge

FIG. 12

The pattern demonstrated in figure 11 was accentuated when the patient assumed a position of comfort through self-induced resistance to the involuntary rotation of the head

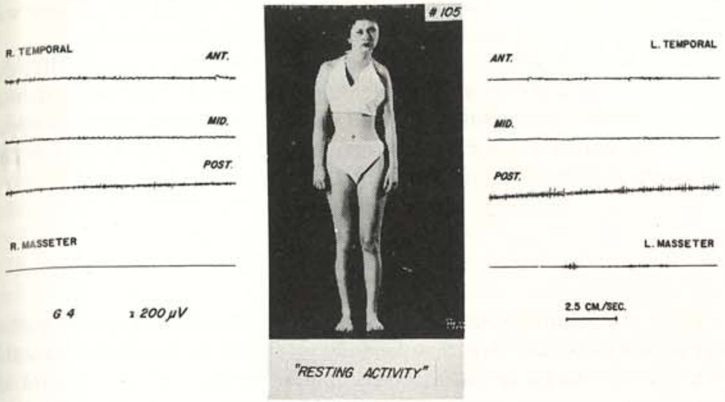


FIG. 13

Congenital torticollis

FIG. 14

Ocular torticollis

on the opposite side. As a result of this interplay, mandibular posture was maintained in a symmetrical relationship to the upper jaw and face.

This pattern of activity at rest in the cases of torticollis was not unlike the pattern elicited in the normal upon rotation of the head. Thus the compensatory mechanisms that control the relationship of the lower jaw to the upper jaw in the normal subject during rotation of the head, are operant in the pathologic state at rest.

Discussion

From our investigations on normal subjects and a wide variety of pathological conditions, it is clear that the infrahyoid chain, or more accurately the sternohyoid muscles as measured herein, contribute to the control of mandibular movement. Most importantly, the infrahyoid muscles participate in the interplay of forces on the hyoid bone and appended organs in a manner that integrates their position in relation to the displacing actions of changing jaw position in the course of physiologic functions. When the mandible is displaced by pathologic conditions, compensatory and adaptive reactions were evident in the activity of the sternohyoid muscles, as well as other muscles, to maintain a state of equilibrium. This function is particularly critical in the defense of the airway.

There are a number of clinical entities, either of congenital or acquired origin, that produce postural changes in the retromandibular structures that are threatening to the maintenance of the airway. Why some infants and children adapt and compensate, while others do not, is not altogether clear. The availability of serial roentgencephalometric data on a large series of such cases provide some insights previously unavailable. For example, the micrognathia in the Pierre Robin syndrome may produce severe glossoptosis with respiratory embarrassment. Yet the equally severe micrognathias in the syndromes of mandibulofacial dysostosis and otomandibulo dysostosis do not produce the same difficulty in the retromandibular area.

The child with Still's disease and severe retrognathia protects his airway by extension of the head upon the neck and hyperactivity of the sternohyoid muscles. Thereby, the diameter between the cervical vertebrae and the hyoid bone are maintained at a constant sufficient to retain a patent airway.

What is required for the further elucidation of the factors governing the posture of the mandible is a multi-dimensional study of normal and abnormal conditions making use, if possible, of simultaneous cinefluoroscopic and electromyographic methodologies.

Summary

The sternohyoid muscles were studied by paired surface electrodes which permitted analysis of their symmetric and asymmetric behavior.

Based on the results of studies on normal and abnormal subjects, it was evident that the infrahyoid muscles play an important role in the integrated movements of the hyoid bone and its appended organs as they relate to the posture and movements of the mandible. This interplay of muscle activity may be critical in the maintenance of a patent airway.

The wide spectrum of congenital and acquired malformations of the mandible provide unusual experiments of nature for investigation by the kinesiologist who can combine radiographic and electromyographic methodologies. Such investigations may contribute not only to the treatment of the patients, but should also provide fundamental information regarding the postural mechanisms that govern a vital area.

BIBLIOGRAPHY

1. PRUZANSKY, S., et al : Cephalometric, Electromyography and Laminagraphic Analysis of Two Cases of Bilateral Subcondylar Oseotomy. *Am. J. Ortho.*, 36:474, 1950.
2. PRUZANSKY, S. : The Application of Electromyography to Dental Research. *J.A.D.A.*, 44:49-68, 1952.
3. PRUZANSKY, S. : Electromyographic Measurement of the Function of the Muscles of Mastication in Man. *Proc. of Institute of Medicine of Chicago*, 19:315-316, 1953.
4. PRUZANSKY, S. : The Control of the Posture of the Mandibile During Rotation of the Head. *J. Dent. Res.*, 34:720, 1955.
5. CURTIN, J.W., GREELEY, P.W. : Osteochondroma of the Mandibular Condyle (with EMG and Cephalometric Analysis by S. Pruzansky). *Plast. & Reconstr. Surg.*, 24:511, 1959.
6. PRUZANSKY, S. : Applicability of Electromyographic procedures as a Clinical Aid in the Detection of Occlusal Disharmony. *Dental Clinics of No. Amer.*, W.B. Saunders Co., Philadelphia, 1960, pp. 117-130.
7. PRUZANSKY, S. : Contributions of Roentgenographic Cephalometry to Study of Congenital and Acquired Malformations of Face. *Dental Clinics of No. Amer.*, W.B. Saunders Co., Philadelphia, July 1960, pp. 395-417.

E.M.G. FINDINGS IN ROTATION OF THE KNEE

J.C. JANSEN

Department of Anatomy, University of Amsterdam,
The Netherlands, Head of Department :
Prof. Dr. J. van Limborgh

Introduction

General and specific aspects of the rotatory movements in the knee joint have been dealt with by many authors and investigators. (Fick, 1910, Benninghoff, 1964, Barnett, 1961, Mac Conaill, 1949, 1950).

As to the function of muscles in regard to these movements, most standard textbooks are in accordance. (Gray, 1962, Morris-Schaeffer, 1953, Cunningham, 1951) However, there seems to be only scarce information on the role of the musculature based on experiments, i.e. electromyographic analysis. (Jonsson, 1966, Carlsoo, 1966, Basmajian, 1954)

Therefore, an investigation was undertaken into the behaviour of all muscles crossing the knee joint (except the popliteus muscle) which has been carried out as part of a larger research project concerning all superficial hip-thigh and knee muscles, of which the results will be published separately.

Methods and Materials

An eight-channel Offner T.C. electroencephalograph, specially modified for e.m.g. analysis, was used, which was connected to a standard Dynograph write-out unit, equipped with a seven speed drive and a signal eventmarker, as well as to a 502A type Tectroni double-beam oscilloscope for visual control. Beckman bioelectric skin electrodes were applied to the skin over the muscle to be investigated. The skin was shaved, scraped gently with fine sandpaper and cleansed with alcohol. Normal electrode jelly was used. Electrode resistance could be measured directly.

All experiments were carried out in a specially screened e.m.g. room in order to reduce any possible interference. Subjects who volunteered for the investigations were 15 male, healthy students in the age-group 18-30. All subjects were tested physically as to foot, knee, hip – or back lesions.

The muscles investigated were (1) tensor fasciae latae, (2) biceps femoris, (3) sartorius, (4) gracilis, (5) semitendinosus, (6) quadriceps femoris, (7) gastrocnemius muscles.

All muscles were properly identified by palpation. The pairs of electrodes were placed on the muscle bellies, 2 cm. apart and widely spaced from each other pair in use. Electrode cables were fixed to the skin, so as not to cause any movement artefacts. During the experiments lowest and highest amplifications were alternated to obtain the maximum reliability of results.

The subject was asked to perform rotation of the semiflexed knee, both medial and lateral, in sitting and supine position, at first without and afterwards with resistance to obtain the "normal" and the strongest contractions. Control recordings were made of the subject in a fully relaxed position.

Results

Fully relaxed position : Using the highest amplification obtainable (highest sensitivity 10 micro. V./cm) all muscles could be relaxed into the electrical-rest state. In this situation a clear e.c.g. could be detected over the muscles originating in the hip region especially across the tensor fasciae latae muscle. This is in accordance with previous investigations of others in this field. (Basmajian, 1966, Campbell, 1958, Joseph, 1960) Deliberately touching and manipulating the electrodes only caused an occasional deflection of the baseline (fig. 1). Fixation of the electrodes by special adhesive fixation discs proved to be highly reliable. Only if and when electrodes were torn off the skin movement artefacts appeared as described elsewhere (Campbell, 1958, Jonsson, 1966) The noise level proved to be in the order of 1-2 micro V. Because of the chosen recording technique it was apparently impossible to obtain any continuous information on frequencies beyond 150 cycles/sec.

To be able to give at least some quantitative standards for discussion the following approach has been sought :

0-10 micro. V:	no activity :	–
10-20 micro. V :	slight activity :	±
20-50 micro. V :	small activity :	+
50-100 micro. V :	fair activity :	++
100-300 micro. V :	strong activity :	+++
300micro. V : and beyond :	very strong activity :	++++

This was mainly necessary because movements against strong resistance were investigated as well, although reliable quantitative measurements in e.m.g. analysis are still impossible due to different, well known causes. (Campbell, 1958, Ralston, 1961)

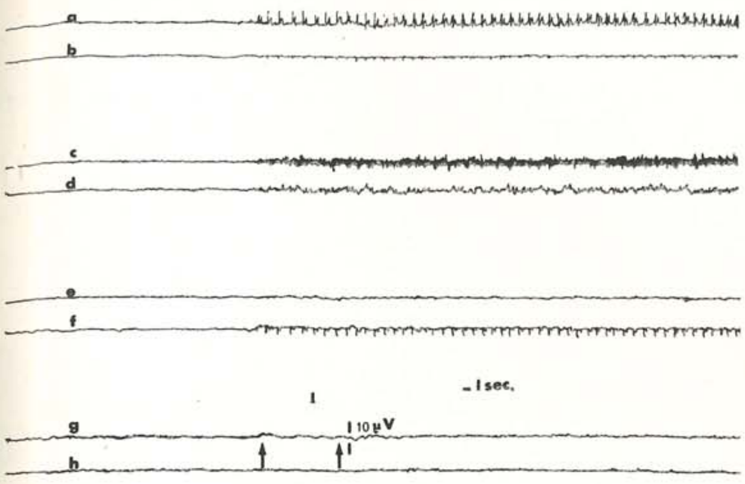


FIG. 1

Experimental set-up ; highest sensitivity 10 μV/cm.

a – gluteus medius muscle
b – gluteus maximus muscle
c – gracilis
d – sartorius
e – vastus lateralis muscle
f – tensor fasciae latae muscle
g – biceps femoris (short head)
h – semitendinosus.

A clear e.e.g. signal is present over the gluteal muscles ; there is a noise signal over the gracilis (loose electrode) ; touching of the electrodes over the biceps causes only slight deflections.

Medial Rotation of the Knee (fig. 2)

(1) Tensor fasciae latae : All subjects showed no activity at all during either unresisted or resisted medial rotation.

(2) Biceps femoris : Similar results were obtained in all 15 subjects. All subjects eventually showed some "burst" activity when the knee was involuntarily flexed during resisted medial rotation.

(3) Sartorius : 13 Subjects showed no activity, 2 only slight activity during the unresisted movement, but even with resistance only 7 subjects showed a slight activity.

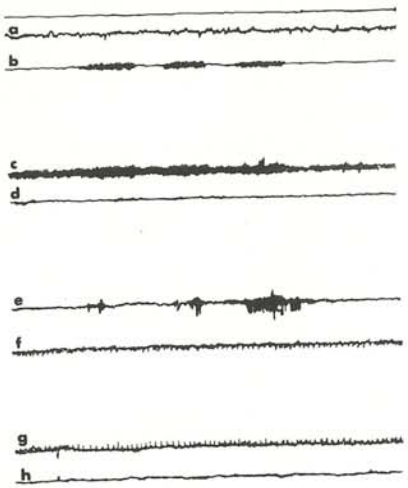


FIG. 2

Medial rotation of the knee

a – gracilis
b – vastus medialis muscle
c – semitendinosus
d – rectus femoris muscle

e – vastus lateralis muscle
f – tensor fasciae latae muscle
g – gluteus medius muscle
h – biceps femoris (short head)

(4) Gracilis : 11 Subjects showed slight activity, 4 small activity during unresisted medial rotation. The general pattern did not alter during resisted medial rotation, although there might be decided upon an increase of activity, but the increase was within limits of the afore mentioned table.

(5) Semitendinosus : All 15 subjects showed no, respectively slight, activity during either the unresisted movement or the resisted. Although occasional "bursts" could be seen, these were clearly attributable to the flexion movement described above.

(6) Quadriceps femoris : Of this muscle vastus lateralis, rectus femoris and vastus medialis were investigated separately. Rectus femoris showed no activity in any phase of movement. The activities of both vasti were interrelated in a peculiar way. All subjects showed a slight activity in vastus lateralis and a small one in vastus medialis during unresisted medial rotation. During resisted medial rotation, however, 12 subjects showed a fair acitivity in the vastus medialis muscle while there still was a slight activity in the lateral vastus. This situation proved to be almost reciprocal in lateral rotation of the knee. It was a very well marked in 4 subjects.

(7) Gastrocnemius : Both heads of the muscle were investigated separately. In 12 subjects there was a slight activity in both heads during unresisted rotation, either medial or lateral, in 3 a small activity. During resisted rotation the activity rose to a fair amount in 8 subjects, but the two muscleheads did not reveal the same clear interrelationship as the vasti.

Lateral Rotation of the Knee, (fig. 3)

(1) Tensor fasciae latae : In 14 subjects there was no activity unless resistance was applied, in which case all subjects showed a fair activity. 1 Subject showed small activity during unresisted lateral rotation.

(2) Biceps Femoris : All subjects showed fair to strong activity during unresisted or resisted lateral rotation.

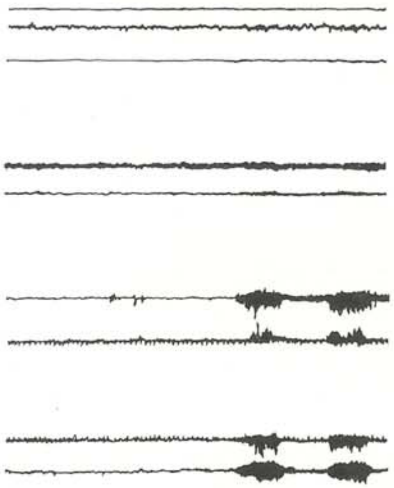


FIG. 3

Lateral rotation of the knee.

Same muscles, same amplification as depicted in fig. 2. Gains set at the highest sensitivity (see fig. 1).

(3) Sartorius : (4) Gracilis : (5) Semitendinosus, never showed any activities during any form of lateral rotation in any subject. As to the activities of Quadriceps femoris and Gastrocnemius, the reader is referred to the descriptio of the results of medial rotation experiments.

Discussion

The recordings over the muscles studied in these investigations are surprisingly not in accordance with the ascribed functions of these mucles in most standard textbooks (Gray, Braus, Cunningham), although in respect of the gracilis they are similar to the findings of the others (Jonsson, 1966).

This investigation seems to point out that rotation of the knee (in semiflexed position) is only a very secondary movement, at least in so far as muscle activity is concerned.

Furthermore it underscores the role of the quadriceps, the biceps femoris and, indirectly, the popliteus muscles in rotation of the knee. Of all the muscles investigated only the monoarticular ones seem to play some role in rotation of the knee joint, if the biceps femoris activity might be attributed to the short head.

Last but not least, there is a striking difference in activity of all the muscles investigated in flexion or extension movements as compared with rotation movements. This goes for the qaudr-ceps femoris and biceps femoris too. Evidentally one can easily resist free rotation of the knee. The activity of the gastronemius seems to be related to movements of the foot, especially during resisted movements.

How far these results demonstrate modern concepts of rotatory movements in condylar joints remains to be seen (Mac Conaill a.o. 1961).

Summary

(1) Electromyographic studies have been made on tensor fasciae latae, biceps femoris, sartorius, gracilis, semitendinosus, quadriceps femoris and gastrocnemius muscles during several forms of movements of the knee in 15 male subjects aged 18-30 years.s,

(2) Results obtained in medial and lateral rotation of the knee are described.

(3) The differential activities of the muscles mentioned during unresisted and resisted rotatory movements discussed in view of the discrepancies between the results of this investigation and general descriptions.

I wish to thank Dr. W.J.M. Hootsman for all help and good advice and for giving me an opportunity to continue my work in the E.M.G. room of the Wilhelmina Gasthuis in Amsterdam.

LITERATURE

BARNETT, C.H., DAVIES, D.V. and MacCONAIL, M.A., (1961) : *Synovial Joinst, Their structure and mechanics.* Longmans, Green & Co., London.

BASMAJIAN, J.V. and BENTSON, J.W. (1954) : An e.m.g. study of certain muscles of the legand foot in the standing position. *Surg. Gynec. Obstet.* 98, 662.

BENNINGHOFF, A. and GOERTTLER, K. (1964) : *Lehrbuch der Anatomie des Menschen.* Band I, q. Aufl. Urban & Schwarsenberg, Munchen, Berlin.

BASMAJIAN, J.V. (1962) : *Mucles alive, their functions revealed by electromyography.* The Williams and Wilkins Co., Baltimore.

BRAUS, H. (1954) : *Anatomie des Menschen,* Band I, 3 Aufl. Springer Verlag, Berlin.

CAMPBELL, E.J.M. (1958) : *The respiratory muscles.* Lloyd-Luke Books, London.

CARLSOO, S and MOLBECH, S. (1966) : The functions of certain two-joint muscles in a closed muscular chain. *Acta Morph. Neerl. Scand.* Vol. VI, no. 4, 379.

CUNNINGHAM (1951) : *Textbook of Anatomy.* 9th ed. Oxford University Press, London.

FICK, R. (1910) : *Handbuch der Anatomie und Mechanik der Gelenke.* Fischer Verlag, Jena.

GRAY, H. (1962) : *Anatomy descriptive and applied.* 33rd ed. Longmans, Green & Co., London.

JOSEPH, J. (1960) : *Man's posture, E.M.G. studies.* Charles C. Thomas, Springfield, Illinois.

JONSSON, B. and STEEN, B. (1966) : Function of the gracilis muscle. An e.m.g. study. *Acta. Morph. Neerl. Scand.* Vol. VI, no. 4, 325.

MacCONAILL, M.A. (1950) : Rotarory Movements and functional decalage. *Brit. J. Phys. Med.* 13, 50-56.

MORRIS, H. (1953) : *Human Anatomy.* 11th ed. J. Parsons Schaeffer editor. McGraw-Hill Book Comp. Inc., The Blakiston Div., New York.

RALSTON, H.J. (1961) : Uses and limitations of e.m.g. in the quantitative study of skeletal muscle function. *Amer. J. of Orthodonties.* 47, 521.

PHYSIOLOGICAL CONCEPTS OF HUMAN VOLUNTARY ACTIVITY

Richard HERMAN, M.D.

Assistant Professor
Department of Rehabilitation Medicine
Albert Einstein College of Medicine
Bronx, New York 10461

During this meeting, the physiological basis of co-contraction and reciprocal innervation during human voluntary movement was described as a function of well-established segmental reflex patterns, primarily influenced by excitatory and inhibitory feedback from muscle receptors (1). While such reflexive mechanisms may play a prominent role in the control of voluntary and postural activity in such mammals as the cat, it should not be assumed that a similar role exists in higher mammals (e.g., primates, man). In fact, recent research suggests that the sensori-motor cortex can directly provide for complex patterns of skilled motor performance previously attributed to local reflex pathways. For example, in the primate, the sensori-motor cortex is capable of controlling force and/or displacement (2) and presumably can make proper adjustments to alterations in the environment either independently or in conjunction with local reflex activity. These findings are not surprising in the light of anatomical evidence of phylogenetic changes in the central nervous system where connections between central and spinal centers become extremely complex.

There is clinical physiological evidence using electromyographic recordings suggesting that acquisition of skilled performance is dependent upon spatiotemporal integration of sensory information and processing of this information to provide adequate motor discharges to appropriate motor groups. Although many levels of the neuraxis may play a definitive role in the control of motor performance, the cerebral cortex is considered the dominant station for sensori-motor organization while reflex pathways play a subordinate role. (3)

A number of experimental observations support this point of view: 1) *Reaction time* (RT) studies utilizing summation of the EEG, which is time-locked to peripheral stimulation prior to and during discrete voluntary movement, has revealed characteristic potentials recorded from both scalp and cortical electrodes over the central regions of the brain. (4) These poten-

This study was supported by grant #RD-1863-M from the Social and Rehabilitation Services, Department of Health, Education, and Welfare

tials precede the onset of muscle contraction. In RT studies, using visual stimuli, when the cortical potential elicited by both a visual stimulus (VCP), as well as the motor contraction (MCP), is subtracted from the cortical potentials derived from the visual stimulus without the accompanying contraction, a motor cortical action potential can be demonstrated. In this manner, afferent and efferent delays involved in the reaction time investigation can be determined. By comparing the absolute value of the visual evoked response (stimulus to VCP) and the motor cortical potential response (stimulus to MCP), a central delay of 20 to 60 msec is observed. This compares to a figure of approximately 70 msec in the monkey. (5) The afferent delay in sensori-motor reaction depends upon the type of stimulus (i.e., visual, auditory) and the intensity of the simulation. In general, the conduction time decreases when the intensity of the stimulation increases and when somatic stimuli (tactile, angular displacement) are used instead of visual or auditory stimuli. (6) The efferent limb is more consistent in terms of its latency ; for example, the MCP precedes motor contraction (EMG) in the upper extremity by 30 to 40 msecs and the distal muscles of the lower extremity by 60 to 80 msecs. This conduction time suggests that movement is initiated by rapidly conducting path-ways which monosynaptically excite the motoneurons. These experiments do *not* indicate that phasic movement is initiated through the gamma-muscle spindle pathway.

2) Despite this evidence of sensori-motor processing prior to and during the initiation of movement, these techniques do not describe the utilization of sensory information in the control of force, displacement, and velocity, nor do they describe the changing patterns of reflex and central activity during naive and learned tasks.

Recent new developments in control systems and communication provide opportunities for improved understanding of the role of the sensory information in motor performance. For example, the most interesting control systems are those commonly referred to as servomechanisms. The importance of both open and closed loop reflex systems in the performance of a skilled movement has been studied by means of tracking experiments which provide a graphic representation of control of force, position, and velocity. The specific role of the feedback (reflex) loop and the supraspinal influences (e.g., visual) upon the loop can be ascertained from the data of electromyography, applied tension, and angular position.

In the study of visual position feedback tasks, the control of a position of a limb can be observed during sudden increments or decrements of load. (6) During such sudden changes in load, analysis of the electromyogram demonstrates changes in motor unit activity. These changes can be described as a function of open and closed loop activity of the muscle.

When a load applied to a limb is suddenly decreased to a new value, analysis of the EMG indicates that an orderly sequence of temporally related events occur : a) The electromyogram is unchanged despite the alteration in load and position for a short period of time suggesting that changes in the attached mechanical system take place without the operation of feedback circuits (open loop behavior), b) There is an early pause in motor firing rate with a delay consistent with transmission along spinal reflex pathways (closed loop behavior), c) A burst of motor units appear in the antagonist which is most likely a consequence of reaction time to the change in position or load (open loop behavior), d) A burst of new units observed at a time suggesting reaction to a visual stimulus (open loop behavior).

Repetition of a task, utilizing similar decrements in load, produces better correction of limb position ; the size of electrical bursts and therefore mechanical oscillations are modified accordingly. Reduction in errors during repeated trials is due to both adjustment in the local feedback circuits as well as the adjustment in the magnitude of the response to the somatic stimulus (e.g., tactual, visual). During repetition of a task, the silent period in the agonist muscle increases in duration (see b) and the motor bursts in the antagonist muscle (see c) decrease in amplitude and duration. (7) These changes allow for a smoother operation of muscle with minimal mechanical oscillations or errors. These findings clearly demonstrate the importance of both reflexive and cortical control during the acquisition of a skilled movement. The increase in the duration of the silent period during learning is similar to the duration of the silent period when a naive task is performed without vision. This suggests that visual stimuli enhance gain on the muscle spindle, thereby inducing large oscillations or errors. This also indicates that, during the learning process, control of motor performance is obtained through cortical response to tactile and joint receptor information rather than through visual information.

3) Examination of electromyographic activity (in conjunction with cortical potentials) during motor performance suggest that a sequence of physiological events takes place with a sensorimotor control system, these events leading to integrative functioning during acquisition of a skilled task. When performing a new or unlearned task in response to a stimulus, the following events seem to occur : a) there is a planning or facilitation stage where the elctromyographic activity is tonic in nature prior to the actual phasic discharge of the muscle, b) a motoneuron stage (e.g., reaction to the stimulus) with short time delay supports the view that there is monosynaptic activation from the cortico spinal pathways, c) a motor stage with development of tension and/or displacement, d) a sensory feedback stage from the nature and consequence of the motor act (e.g., from cutaneous, muscle joint,

visual and auditory receptors) leading to a short loop (spinal cord) and long loop (sensori-motor cortex) influence on the neuraxis, and finally a maintenance stage primarily controlled by somatosensory input from tactile receptors leading to a conscious sense of effort. Sudden changes in load or displacement during this stage induce postural or stabilizing and volitional adjustments (see 2).

REFERENCES

1. SHERRINGTON, C.S. : *The Integrative Action of the Nervous System.* New Haven : Yale Univ. Press, 1947.
2. EVARTS, E.V. : Relation of Pyramidal Tract Activity to Force Exerted During Voluntary Movement. *J. Neurophysiol.* 31:14-27, 1968.
3. PAILLARD, J. : *The Patterning of Skilled Movements.* In : *The Handbook of Physiology* ed. H.W. Magoun Amer. Physiol. Society 1679-1708.
4. GILDEN, L., VAUGHAN, H.G. Jr., and COSTA, L.D. : Summated Human EEG Potentials with Voluntary Movement. *Electro-enceph. Clin. Neurophysiol.* 20:433-438, 1966.
5. EVARTS, E.V. : Pyramidal Tract Activity Associated with a Conditioned Hand Movement in the Monkey. *J. Neurophysiol.* 29:1011-1027, 1966.
6. HERMAN, R. : *Electromyographic Evidence of Some Control Factors Involved in the Acquisition of Skilled Performance.* (in press)
7. HERMAN, R. : *Alterations in the Silent Period During Acquisition of Skilled Performance.* (in press)

STRIATED MUSCLES ACTIVITY AND BIOMECHANICAL EFFECTS IN MAN SUBMITTED TO LOW FREQUENCY VIBRATIONS

A. BERTHOZ and A. WISNER

Laboratoire de Physiologie du Travail du C.N.R.S. et
Laboratoire de Physiologie du Travail du C.N.A.M.
41 rue Gay-Lussac, Paris 5º

The numerous pathological disorders caused by mechanical vibrations (Fishbein, W.I., Salter, L.C., 1950) have led to the study of the response of muscles to a vibratory stimulation. But the transmission of oscillations through the body masses is closely related to their frequency, and a distinction must be made between relatively high frequency vibrations (above 100 Hz) and low frequency vibrations. De Gail, P., and all. (1966), Hagbarth K.E. & Eklund G. (1966), Rushworth, & Young, (1966), and Mattews, P.B.C. (1957) have recently studied the former, but we are particulary interested in the latter in part because of the resonance effects they bring about.

We have previously (Wisner A., Donnadieu A., Berthoz A., 1965) reviewed the numerous data concerning the mechanical effects of the application to man of low frequency vibratory stimuli. But attempts to correlate the resonance observed and the mechanisms of the response of the muscles as well as its regulation are scare (Dellepiane B., Betti M., Cabella G., 1964). However sinusoïdal stretchings have been applied to animals and have yielded valuable information concerning 1º) the sensitiveness of muscular receptors to the various parameters of stretching (Lippold C.J. and all. 1958, Stuart D. and all. 1965, Jansen J.K.S. & Rack P.M.H. 1966), 2º) the part played by the Golgi tendon organ (Houk J & Henneman E. 1967) and 3º) on the organisation of motricity (Glaser G.H. & Higgings D.C. 1967).

After a summary of the main results found by purely biomechanical technics, we shall present results recently obtained by measuring simultaneously the E.M.G. activity and vibratory movements.

Technique

20 subjects were seated on a rigid seat, their posture was closely controlled (Berthoz A., 1967). They were submitted to vertical sinusoïdal vibrations coming from a vibration table (frequency 1-20 Hz, peak to peak amplitude 2-20 mm) (fig. 1).

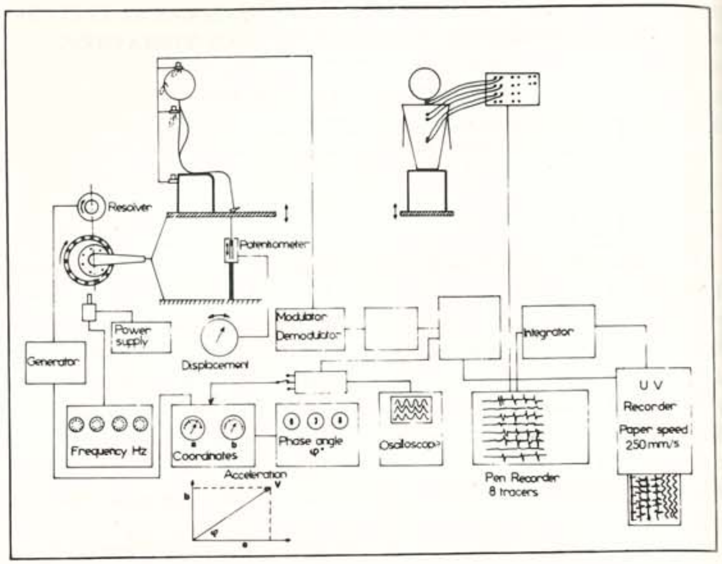


FIG. 1

Sketch of experimental apparatus. A sinusoïdal vibration table gives a mechanical stimulation to a seated subject on whom acceleration transducers, miniaturized neon tube lights, and surface electrodes for the recording of the EMG, are fixed. The mechanical and electrophysiological information are treated and recorded simultaneously.

The EMG activity was recorded by means of surface electrodes placed respectively (1) along the spine at C4, D8 and LI levels, (2) on the trapezius middle fibers, and (3) on the abdominal muscles on a vertical line originating at the iliac crest. The EMG activity has been integrated during several experiments by means of an electronical integrator which measures the area between the EMG tracings and the base line. The amplifiers bandwidth was about 10 to 1000 Hz, the pens had a narrower bandwidth (0-150 Hz).

Mutual inductance accelerometers measuring the vertical and horizontal component of the movements in the sagittal plane, have been, by means of a technique previously described, fixed (a) to the head at the occipital level, and on the top of the skull, (b) at the level of D10, (c) on the sternum and (d) on the vibration table. Miniaturized neon tubes whose glow gave a time basis for the photographs, were put in the neighbourhood of the insertion of the nape muscles and on the head. The photographying of their displacements was synchronized with the recording of the EMG and the acceleration. The transfer function chosen to evaluate the transmission of vibrations through the links of the body was the *transmissibility* (Acceleration ratio). For the study of the response of the muscle and the movements resulting from the vibratory pertubations, the vibration frequency and amplitude were respectively increased.

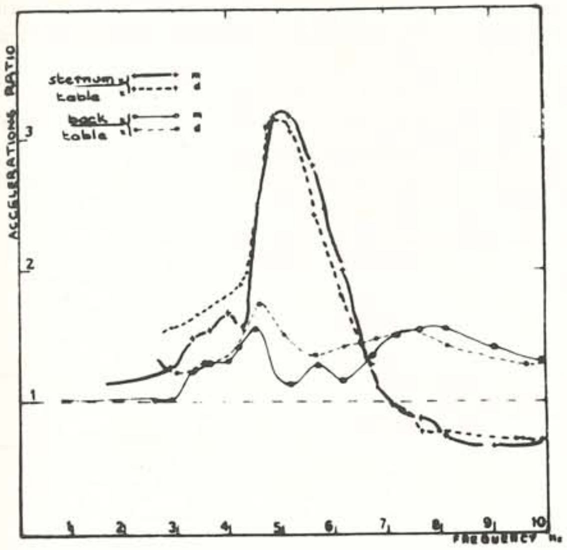


FIG. 2

Transmissibility curves (or acceleration ratio curves) in function of the frequency of the vertical sinusoïdal vibration imposed. Transmissibility between the sternum (thorax) and the seat, the back (C 4) and the seat, going through the scale of frequencies on the way of an increase (m) and a decrease (d). The important resonance of the thorax compared to that of the seat for a frequency of 5 Hz will be noted. Vibration amplitude : 8 mm peak to peak.

Results

1o Resonance phenomena

a) Constant amplitude of vibratory excitation

When the amplitude of the given oscillation is constant and when only the frequency varies, the thorax mass is proppelled by a movement identical to that of the seat, up to 3 Hz, then from 4 to 5 Hz it oscillates vertically with an amplitude that can be 3 or 4 times that of the seat. (fig. 2)

These relative movements of the thorax occur at resonance with a phase angle of approximately 90 in reference to the seat movements. These characteristics relate this phenomenon to a mechanical resonance.

Likewise, the head rotates on the cervical spine at frequency higher than to 3-4 Hz (3) (fig. 3). This rotation is maximal between 5 & 7 Hz, beyond these frequencies, the amplitude of the rotation decrease.

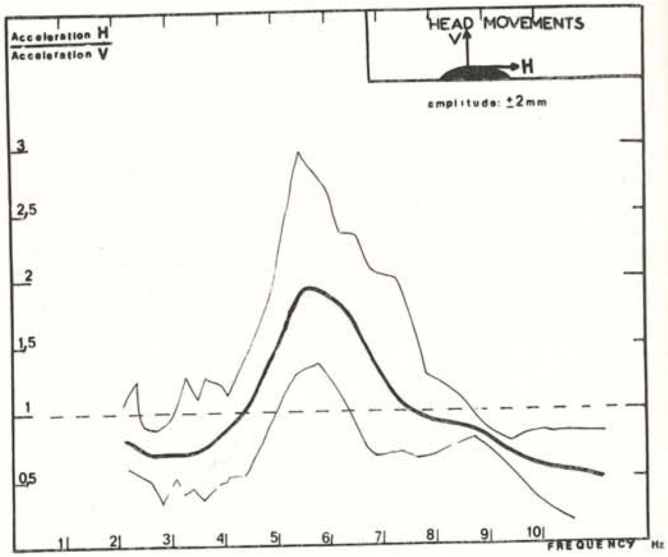


FIG. 3

Variation of the ratio of horizontal acceleration to the vertical acceleration of the top of the head of a seated subject submitted to a vertical sinusoïdal vibration over a frequency range of 0 to 10 Hz. This ratio is an index of the rotation of the head – the oscillating rotation is maximum between 5,5 and 6 Hz. Mean curve and enveloppe curves for 5 male subjects. Amplitude of the table vibration 5 mm peak to peak (± 2mm).

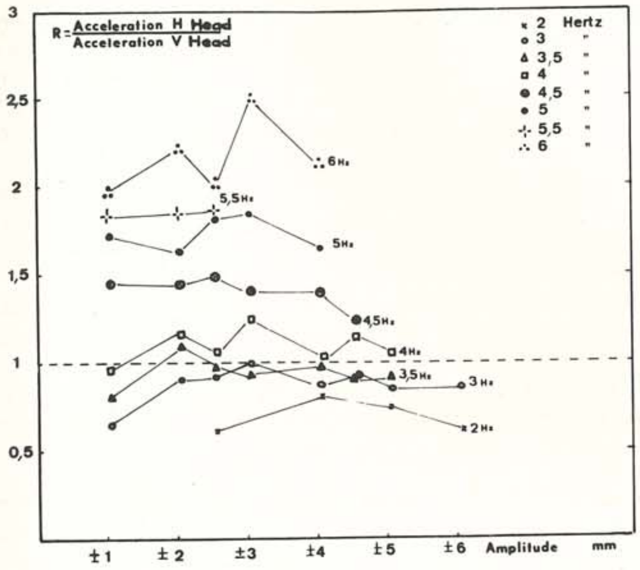


FIG. 4

Variation of the ratio of the horizontal acceleration to the vertical acceleration of the top of the head of a seated subject submitted to a vertical sinusoïdal vibration of frequencies ranging from 1 to 6 Hz, and amplitude from ± 1 mm to ± 6 mm (2 to 12 mm peak to peak). The small effect of the increase of amplitude and the great effect of the increase of frequency will be noted.

b) Vibration of variable amplitude

If the vibration amplitude varies, a relatively small decrease of the resonance frequency is noted when going through the scale of frequencies for each amplitude value. This is typical of a nonlinear system. The relative movements of the body masses are much more affected when the frequency changes than when the vibration amplitude changes (fig. 4).

2º *EMG activity*

1) Due to oscillations, the dorsolombar paravertebral muscles and the nape muscles have a similar rythmical EMG activity (fig. 5) : when the vibration frequency increase from 0,5 to 10 Hz, their EMG activity becomes intermittent at 2-3 Hz. *Bursts of action potentials occur at each cycle of the*

vibration : their duration decreases and amplitude increases with the vibration frequency. Silent periods of variable length (60 msec to 100 msec) take place between the bursts. Also an appreciably linear relationship was noted between the integrated EMG (at D8 level) and the vibration amplitude for a frequency of 4 Hz (fig. 6). For the sitting subject *no activity is recorded* in the *oblique* muscle and vibratory stimulation with a frequency under 4 Hz does not generate any activity. It is from 4 Hz on, and for very small increases in frequency, that this muscle contacts rythmically and intensely. This activity is probably linked to the movements of the thorax mass, which, as we saw, took place between 4 and 5 Hz.

These recordings and the study of the neon tube displacements, clearly show that at the nape level the EMG activity starts ten to thirty milliseconds after the forces of inertia have set the head to rock and therefore the neck muscles to stretch. This is not incompatible with the characteristics of a myotatic response, but it may not be the only response involved. At certain frequencies, separate EMG activities can be distinguished, one following the other during each vibration cycle.

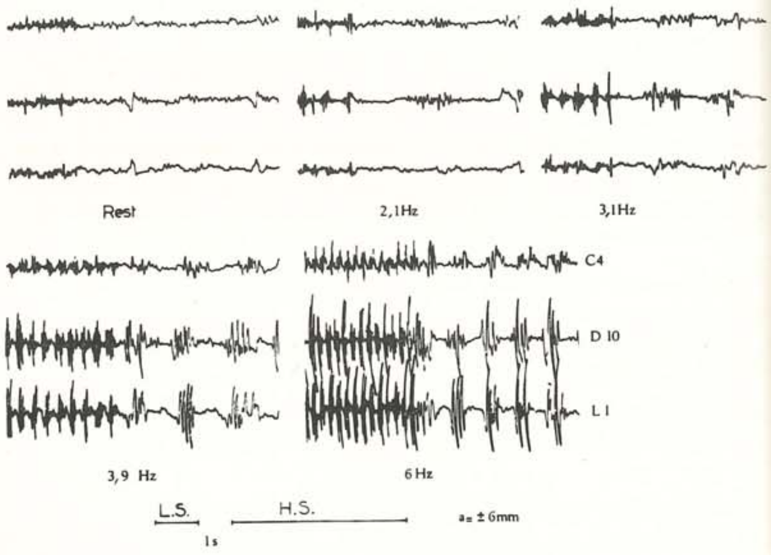


FIG. 5

EMG tracings obtained through recording the paravertebral muscle activity at C 4, D 10 and L 1 levels for a seated subject submitted to vertical sinusoïdal vibrations of frequencies varied from 0 to 6 Hz. The recording was performed at 2 different speeds of paper (L.S. H.S.). Amplitude of the vibration table ± 6 mm (12 mm peak to peak).

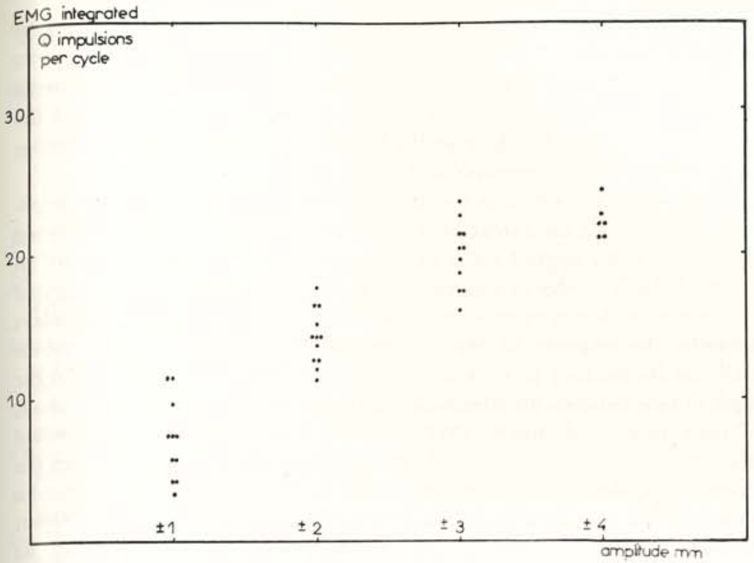


FIG. 6

Integrated EMG activity of the paravertebral muscles recorded at D 10 level. Variations of integrated EMG activity (arbitary units) during each vibration cycle versus amplitude of the imposed vibration : ± 1 mm to ± 4 mm (2 to 8 mm peak to peak)

In any case the electrical silence often seems to occur with the shortening of the nape muscles.

Discussion

The synchronisation of the muscular action potentials observed when the vibration frequency reaches 3-4 Hz, and the occurrence of electrical silence periods are correlated with the mechanical resonances of the body masses. This phenomenon, probably affects all the striated muscles in man when a definite posture has to be maintained. Only a relatively small force compared to the maximal forces that the muscles are able to develop is necessary to cause such tremor in the muscle, with Metral, S. and Scherrer J. we verified this by applying sinusoïdal forces to a subject's upperlimb under close loop control of position.

The particular frequency of resonance which is about 5 Hz requires special attention since it is both the frequency of pathological tremors and the frequency at which are observed the limitations to the execution of certain voluntary tracking movements (Stark et al., 1961)

We saw that the vibration frequency played a greater part than its amplitude to determine the extent of the resonance. Therefore the starting speed of the externally applied force to the muscle can be supposed to have an essential role. In order to explain the resonances observed it can be suggested that when the forces exerted on the muscles happen too rapidly, the delays between the emission of the sensory afferent messages and the motor response are too long to allow a correct compensation of the muscle ; for the lapse of time between the stretching and the maximum reflex tension is about 80 msec. in man (Merton P., 1951 ; Inman U.T. et al., 1952) etc. This would place the rise of tension in the vibratory cycle at the very moment when the externally applied force diminishes (Eldred E. 1967). However, authors who submitted cat muscles to sinusoïdal stretching have observed that the afferent messages tends to be maximal when the speed of stretching is maximal. As the speed of sinusoïdal vibrations is ahead of displacement, this would give a lead of the motor response which (Popele R.L. & Terzuolo C.A. 1968) would compensate for the lag caused by the setting into tension of the muscle. It is however likely that this advance is not sufficient and other factors, among which is the fusimotor regulation (Glaser G.H. & Higgings D.C. 1966), play a still undefined role.

Abstract

Placing accelerometers on various parts of the body can bring into light vibration frequencies at which the relative movements of the body masses are similar to the resonances of suspended mechanical systems. The head, thorax and rachis movements are studied, they reveal the existence of resonances in the 4-6 Hz frequency bandwidth.

A rythmical electromyographic activity, synchronous with the vibration, appear at the same time as resonances, in the postural muscles and in certain abdominal muscles. At every vibration cycle a burst of action potentials occurs, its duration decreases and its amplitude increases when the vibration frequency increases. Silent periods take place between each EMG burst. At higher frequencies, the EMG retains these characteristics whereas the relative movements of the body masses are considerably smaller. The relations between EMG activity or silent periods and the body masses displacement, speed and acceleration are described. Their links with the pathology of vibrations are considered.

REFERENCES

BERTHOZ A. (1967) : Etude Biomécanique du Système homme – siège sur table vibrante. *Travail Humain*, XXX, 3.4, 193-203.

DE GAIL P., LANCE J.W., NEILSON P.D. (1966) : Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *J. Neurol. Neurosurg. Psychiat.*, 29, 1-11.

DELLEPIANE B., BETTI M. and CABELLA G. : Effects des secousses – Observations préliminaires électromyographiques. *Archives des maladies Prof. de Méd. du Travail et de Sécurité Sociale.*, t. 25, n° 12, Décembre 1964, p. 683.

ELDRED E. (1967) : Functional implications of dynamics and static components of the spindle response to stretch. *Amer J. Phys. Med.*, 46, 1, 129-40.

FISHBEIN W.I. and SALTER L.C. (1950) : The relationship between truck and tractor driving and disorders. *Industrial Medecine and surgery*, 19:9-444-445.

HAGBARTH K.E. and EKLUND G. (1966) : Tonic vibration research in spasticity. *Brain Research*, 2, 201-203.

HOUK J. and HENNEMAN E. (1967) : Responses of golgi tendon organs to active contractions of the soleus muscle of the cat. *J. Neurophy. U.S.A.*, 30, 3, 466-81.

LIPPOLD O.C.J., REDFEARN J.W.T. and VUCO J. (1958) : The effect of sinusoïdal stretching upon the activity of stretch receptors in voluntary muscle and their reflex responses. *J. Physiol.*, 144, 373-386.

MERTON P.A. (1951) : The silent period in a muscle of the human hand *J. Physiol.*, 114, 183-198.

MATTHEWS P.B.C. (1967) : The reflex response to muscle vibration in the decerebrate cat. *J. Physiol. G.B.*, 192, 2, 18-19 p.

STUART D., OTT K., ISHIKAWA K., and ELDRED E. (1965) : Muscles receptors response to sinusoïdal stretch *Exp. Neurol.*, 13, 82-95.

STARK L., JIDA M., and WILLIS P.A. (1961) : Dynamic characteristics of the motor coordination system in man. *Biophysical Journal*, 1, 279-300.

WISNER A., DONNADIEU A., and BERTHOZ A. (1965) : Etude biomécanique de l'homme soumis à des vibrations de basse fréquence. *Travail humain*, 1-2, 18-56.

RUSHWORTH R. and YOUNG L. (1966) : An effect of vibration on tonic and phasic reflexes in man *J. Physiol. G.B.*, 185, n° 2, 63-64.

METRAL S., BERTHOZ A. and SCHERRER J. (1968) : Effets de l'application d'une face sinusoidale sur la contraction d'un muscle chez l'homme. A paraître dans la *Revue de Neurologie.*

TERZUOLO C.A. and POPELE R.E. (1968) : Myotatic Reflexe : Its input-output Relation *Science*, 159, 743-745.

GLASER G.H. and HIGGINGS D.C. (1967) : Motor stability, stretch response and the cerebellum. in : *Granit – Muscular afferent and motor control.* 1rst Nobel Symp. Almquist, Stockholm, 121-137.

INMAN V.T., RALSTON H.J. and SAUNDERS J.B., FEINSTEIN C.M. and WRIGHT B. (1952) : Relation of human electromyogram to muscular tension *EEG Clin. Neurophysiol.*, 4, 187-194.

JANSEN J.K.S. and RACK P.M.H. (1965) : The reflex response to sinusoïdal stretching of soleus in the decerebrate cat. *J. Physiol.*, 133, 15-36.

From the Department of Anatomy, Karolinska Institutet,
Stockholm, Sweden.

CO-CONTRACTION AND RECIPROCAL ACTIVATION OF THE EXTENSOR AND FLEXOR MUSCLES DURING MOVEMENTS AT THE ANKLE AND KNEE JOINTS

S. CARLSÖÖ and G.H. SCHWIELER

Since the electromyographical technique first began to be used in studying the function of muscles, it has been realised that a muscle's active period does not always occur simultaneously with the movement that the muscle is mechanically equipped to perform. Wachholder demonstrated as early as in 1928 "that in alternating flexion and extension of the elbow action potentials in the extensor muscles are noted during the last phase of the flexor movements and continue until the middle of the extensor phase". The occurrence of what is known as co-contraction, i.e. a simultaneous activation of the muscles acting antagonistically on a joint, has also been demonstrated by several workers (Levine and Kabat 1952, and others). No clear picture of where and when a co-contraction occurs emerges from the investigations so far reported. Even more diffuse is the discussion about the purpose of co-contraction. This is probably due partly to a misunderstanding of Sherrington's concept of "reciprocal innervation". Many have believed that it exists a contradiction between "reciprocal innervation" and co-contraction. We shall return to this misunderstanding below.

When the hamstrings are active simultaneously with the vastus muscles, for instance in a knee extension performed in the standing position with the feet fixed on the ground, this is one form of co-contraction. But such a form of co-contraction is in agreement with the mechanical capabilities of the hamstrings, namely to function as knee joint extensors in a "closed" muscular chain (Carlsöö and Molbech 1966). It is not, however, this form of co-contraction on which opinions differ, but the occurrence of activity in muscles that operate antagonistically to the movement being performed and the muscles which achieve it. The controversial views at present prevailing as to this form of co-contraction have been reported, for instance, by Hubbard in "Science and Medicine of Exercise and Sports" (1960) and Basmajian in "Muscle Alive" (1967). As a contribution to the discussion about the phenomenon of co-contraction, we wish to report here the results of certain electromyographical studies of the interplay between the knee extensors and flexors and the ankle extensors and flexors in various forms of voluntary movements, and in some muscular reflexes.

The questions which this study was primarily concerned to answer are as follows :

1) Does co-contraction occur in isolated voluntary flexions and extensions at the ankle and knee joints ?
2) If such a co-contraction occurs, at which stage of the movement is it to be found ?
3) Is the co-contraction influenced by the speed of the movement, or by any external resistance to the movement ?
4) Does co-contraction occur in ordinary habitual movements, e.g. in walking ?
5) Does co-contraction occur in muscular reflexes ewoked by a reflex hammar ?

Methods and material

Investigations were performed on students and members of the staff of the Anatomical Department. Wire, needle and surface electrodes were used. Recordings were made on a Honeywell Viscicorder 1508, to which the action potentials were transferred either telemetrically, as in the walking experiments, or by cable, as in investigations of reflexes and isolated individual movements. The range of the movements were recorded by an electrogoniometer. In the investigation of the muscular activity during walking, forceplates were used for recording the stance and swing phases (Carlsöö 1967).

Studies of voluntary movement were performed with subjects in the following positions (Fig. 1) :

1) In the sitting position, with the lower leg freely hanging. In this position both isolated and repetitive voluntary extensions and flexions were performed.
   Movements were performed both with and without an outer load. As load was used a Darcus dynamometer or weights of 2 to 5 kp.
2) In the standing position on one leg, with support for the arms, and the other leg hanging free. In this position, flexions and extensions were performed in the same way as in the sitting position. But no movements against an external load were performed.

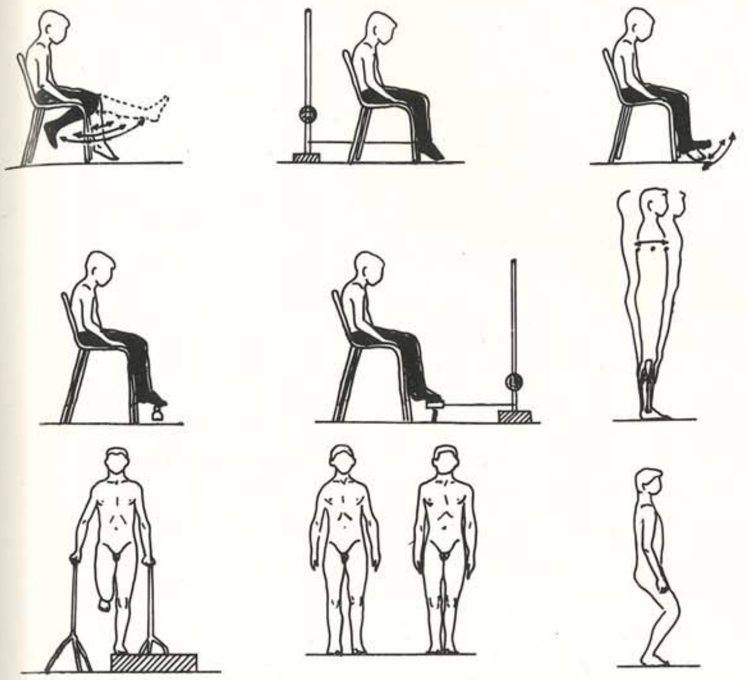


FIG. 1

3) In a symetrical standing rest position. In this position, a foreward – and – backward swaying of the body around the ankle joint was performed. Starting from the symetrical rest position, squatting and "attention" positions were also assumed.

In addition to the above, muscular activity was recorded during habitual walking on different floors and at different speeds.

Finally, muscular activity was investigated in a series of muscular reflexes elicited by taps with a reflex hammar against the tendons. The ankle jerk was tested with the subjects kneeling on a chair. With the other reflexes, subjects sat on a bench with their legs hanging free. The tap with the reflex hammar against the tendons was recorded electronically on the Honeywell Viscicorder (Fig. 2).

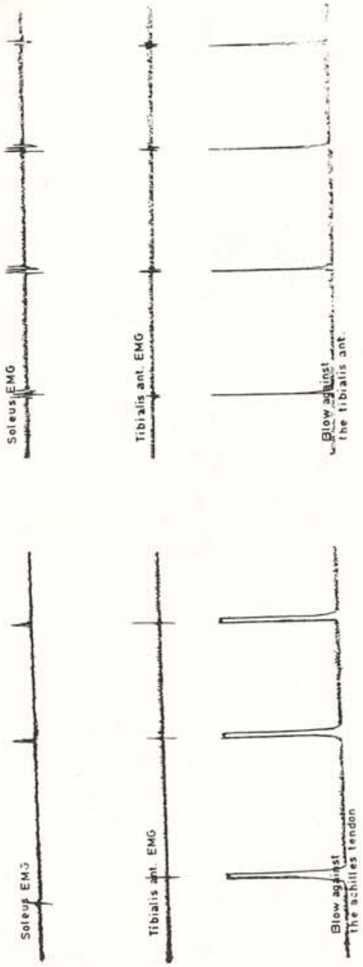

Soleus EMG
Tibialis ant. EMG
Blow against the achilles tendon
1sec.
Soleus EMG
Tibialis ant. EMG
Blow against the tibialis ant.

FIG. 2

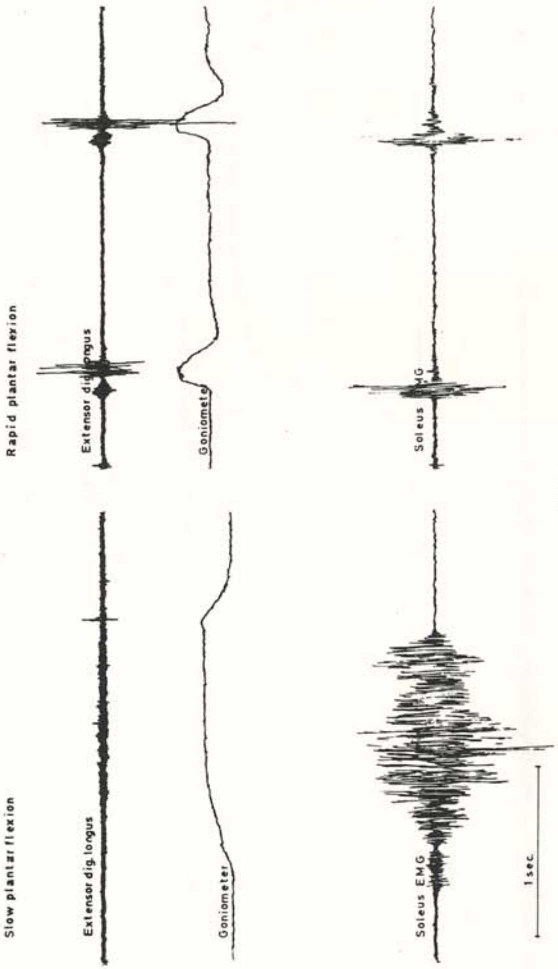

Slow plantar flexion
Extensor dig. longus
Goniometer
Soleus EMG
1sec.
Rapid plantar flexion
Extensor dig. longus
Goniometer
Soleus EMG

FIG. 3

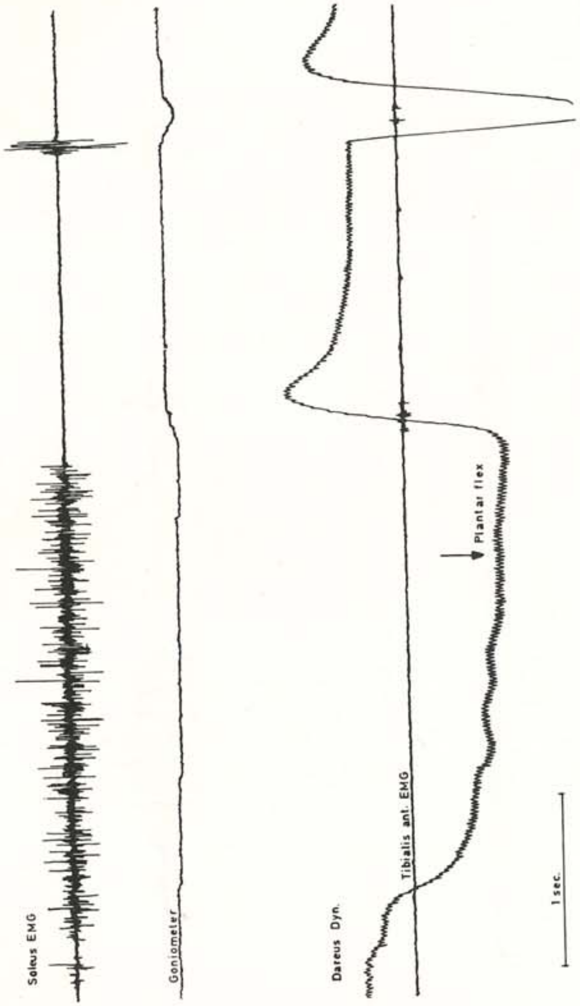


FIG. 4

Results

Ankle joint

Voluntary movements

When isolated voluntary extensions or flexions at the ankle joint are performed with the leg freely hanging, there is usually a co-contraction, Fig. 3. Only in very slow movements is the antagonist activity lacking. In repetitive flexions and extensions, periods of co-contraction occur during both dorsal and plantar flexion ; the higher the frequency of movement, the stronger the activity in both the agonists and the antagonists.

When the movements are performed against an outer load the activity in the antagonist muscles decreases as the load increases and if the load is so big that a movement in fact cannot be performed, i.e. the agonist is working almost isometrically, then no co-contraction occurs, Fig. 4.

Standing and walking

In the standing position and in foreward – and – backward swaying, there is no co-contraction. In walking, there regularly occurs a brief period of "co-contraction" when the heel strikes the ground, but the activity in the pretibial muscles ceases when the fore-foot has made contact with the ground. Gastrocnemius ans soleus which are activated immediately before the heel strikes the ground, continue as a rule to be active during almost the entire stance phase, and reach their peak of activity at the push-off. A co-contraction can also occur towards the end of the stance phase just before the foot leaves the ground. During the swing phase, on the otherhand, there is no co-contraction. The periods of co-contraction become longer in walking on an uneven or unstable substrate, e.g. when walking on tottering shoes or on an unstable surface such as an thick foam mat.

Reflexes

With taps on the Achilles tendon or on the tendons of the pretibial muscles, activity is elicited in both the stimulated muscle and in the antagonists, Fig. 2.

Knee joint

Voluntary movements

With voluntary flexions at the knee joint, only the hamstrings are active as a rule – regardless of wheter the movement is performed against an outer load or not. If, however, the movement is performed so rapidly that the whole movement takes a time of about a quarter of a second and the greatest possible part of the knee joint's range of movement is utilized, then an activity of the vastus muscles occurs in the final stage of the flexion. With extension in the knee joint, on the other hand, co-contraction occurs as a rule – the maximum activity of agonists and antagonists coinciding – and is invariably found if the extension is performed against an external load, Fig. 5.

The faster the extension is performed, the stronger the activity in both the vastus and hamstring muscles. With repetitive flexions and extensions at the knee joint, no entirely uniform pattern of activity was found with the different experiments and subjects. Unless movements are performed extremely slowly, the vastus muscles are activated already during the latter part of the flexion and the hamstring muscles during the latter part of the extension. In such cases there is then a clearly reciprocal activity situation, but equally often the activity in the antagonist muscles remains when agonists are activated and a shorter or longer period of co-contraction occurs. This co-contraction can sometimes occur only at the transision between flexion and extension, but it usually occurs also at the transition between extension and flexion. If the amplitude of movement is exploited to any considerable extent, co-contraction occurs at both "turning points".

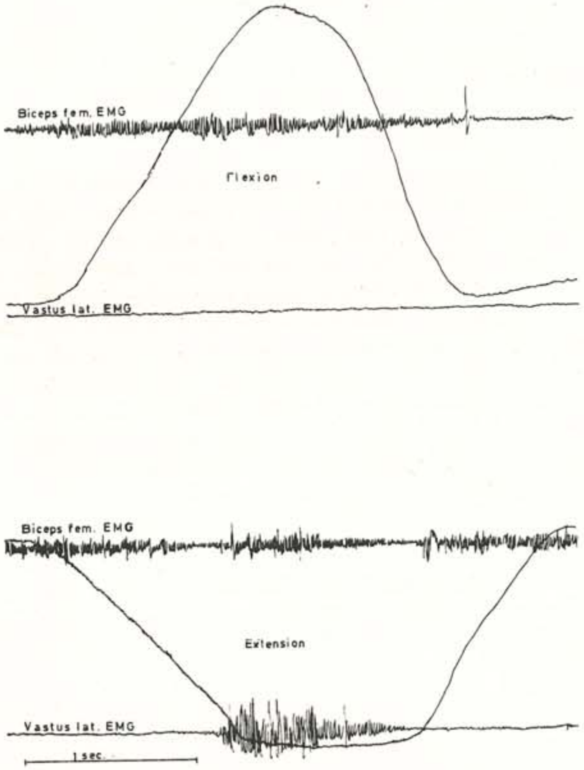


FIG. 5

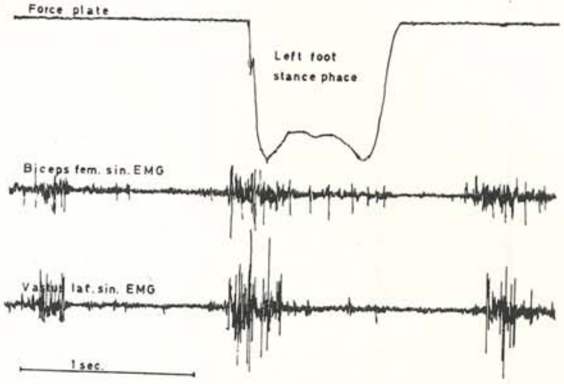


FIG. 6

Standing and walking

In standing at ease, there is no activity in the muscles investigated. In the "at-attention" position, both the vastus and hamstring muscles are activated. In a knee flexion to the squatting position only the vastus muscles are active, but in the return to standing at ease, i.e. in the knee extension, there is always a co-contraction.

In ordinary walking, the hamstrings are activated during the latter part of the swing phase and remain more or less active for the greater part of the stance phase. There activity is strongest when the heel strikes the ground and at the push off. The vastus muscles also become active simultaneously with the hamstrings, Fig. 6).

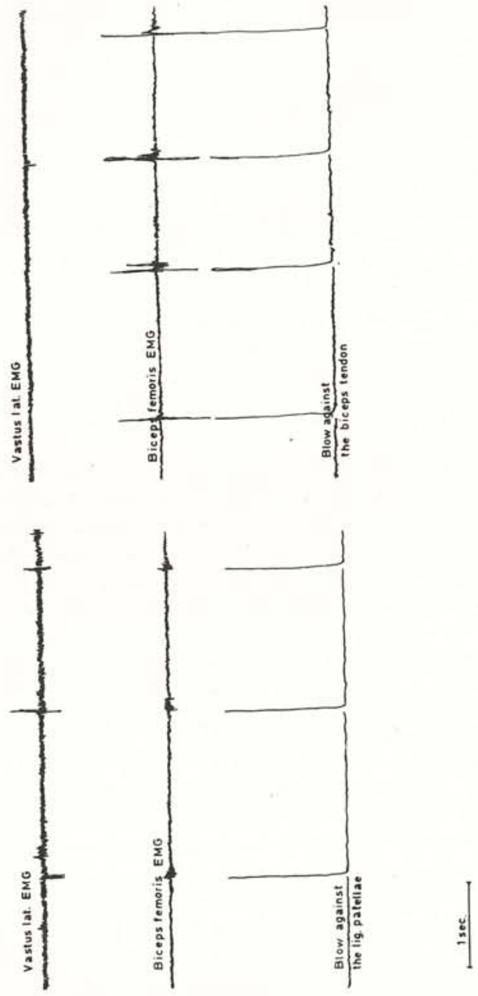


FIG. 7

Reflexes

With taps against the ligamentum patellae, both the quadriceps and the hamstrings respond by activity ; with taps, however, against one of the tendons of the hamstrings only the stimulated muscle was activated and the quadriceps remained in all cases passive, Fig. 7.

Discussion

The results of this study show that co-contraction occurs in movements at both the ankle and knee joints, This co-contraction is particularly marked in rapid movements. In certain respects, however, the two joints differ ; co-contraction occurs, for instance, at the knee joint only as a rule in extension, but at the ankle joint both in flexion and extension. Also, no reduction of antagonist activity is noted with increased resistance to extension at the knee joint, as is the case with plantar and dorsal flexion at the ankle joint.

To establish that the activity recorded from the antagonist muscles did not stem from the agonists, experiments were made with both surface and wire electrodes. Results were the same regardless what type of electrodes was used.

The majority of habitual movements in the knee joint occur within the part of this joint's range of movement that lies close to its maximal extent, and in the part where only simple ginglymus movements occur. A maximally or almost maximally extended knee joint is therefore a common phenomenom. It is probable that continuously repeated extensions toward a joint's utmost limit, achieved as in the knee joint by the powerful quadriceps together with the momentum of the lower leg, can lead to traumatization of the joint. An activation of the antagonist muscles, i.e. the hamstrings, would therefore seem functionally purposeful. The more powerfully and rapidly the extension is performed, the more powerfully the hamstrings should then be engaged, as shown also by the present investigations.

The situation with knee flexions is different. The hamstrings cannot as a rule achieve a maximal knee flexion owing to active insufficiency. There is thus no need for the movement to be braked with the help of active antagonist muscles. Is is true that activity has been recorded in the vastus muscles when extreme knee flexions were performed very rapidly. This activity in the vastus muscles, however, is of very short duration and occurs at the same time as the flexion ceases, i.e. when lig. patellae is almost maximally extended. It seems probable that we are dealing here with a stretch reflex in the vastus muscles.

The co-contraction that occur in an extension at the knee joint with the leg freely hanging can consequently be regarded as a protective mechanism.

That it is a reflex activity in the hamstrings and a part of the normal innervation pattern of the knee movements is argued by the active muscular response regularly obtained in the knee jerk reflex not only from the quadriceps but at the same time also from the hamstrings. That the vastus and the hamstring muscles should be simultaneously active in extension of the knee when the foot is fixed on the ground, as in the return from a squatting to an upright position or in the "at-attention" position, is in full agreement, as already suggested, with the mechanical properties of the muscles. That the same pattern of activity did not occur in all subjects with repetitive extensions and flexions in the knee joint seems ascribable to the fact that we were dealing with unusual and artificial movements. It proved to be very difficult, for instance, and in some cases impossible, to avoid accompanying movements of the hip joint in the standing position, a circumstance that naturally makes it more difficult to interpret the results, since both quadriceps and the hamstrings act on the hip joint. Knee joint movements in the sitting position were easier to perform. In this position, however, the range of movement is displaced towards the flexion side, since the joint is in the initial position flexed at 90°. More pronounced extension are therefore required for the lower leg to reach the horizontal position and the knee joint to become maximally extended. On the other hand, extreme flexions can be performed more easily. The greater the lower legs amplitude of movement, the more marked, too, is the co-contraction in the extension movement. With a sufficiently high frequency of movement, co-contraction occurs also around the transition between flexion and extension.

It may seem contradictory that co-contraction should not occur in the ankle joint musculature in foreward – and – backward swaying but in isolated dorsal and plantar flexions with the legs freely hanging. Such a swaying, however, can only be performed slowly with the weight of the body resting the whole time on the soles of the feet. Owing to the short radius of curvature of the superior surface of the body of the talus, the movements in question are very small. The amplitude of movement of the centre of gravity of the body in a ventro-dorsal direction projected against the ground must not exceed a length of 15-18 cm, i.e. the distance between the front part of the heel and the heads of the matatarsal bones, otherwise the body will loose its balance. This means that only a small part of the ankle joint's range of movement can be utilized : 10-12° out of a total range of about 60°. With isolated plantar and dorsal flexions, however, the joint's range of movement is utilized much more, as is the case also when these movements are performed repetitively with the leg freely hanging or in habitual walking. Also, movements in the joint then occur more rapidly and there is no stabilization of the movement with the help of the body's weight. In these movements, co-contraction occurs both during plantar and dorsal flexion. In walking, the co-contraction is particularly pronounced when walking on tottering shoes or no unstable ground. It is quite evident that co-contraction has here a stabilizing function on the joint. That this co-contraction is a reflex and a normal phenomenom in the innervation pattern of the ankle muscles is indicated by the active responses obtained simultaneously from both plantar and dorsal flexors in taps against either of these muscles with a reflex hammar. We cannot in this respect share the view of certain workers (Basmajian 1967, and others) that this form of co-contraction is due to an unnatural tension in the subject, and would vanish with training. The effect of increased resistance to movement can be taken to have the same effect on the joint as a co-contraction in the antagonist musculature, i.e. it has a stabilizing and steering function.

How do the above mentioned types of co-contraction arise, how are they controlled, and how can they be explained against the background of Sherrington's concept of "reciprocal innervation" ? The most common argument in the literature against the occurrence of a pure co-contraction is that it would be contradictory to the principle of Sherrington's "reciprocal innervation". (See for instance Basmajian 1967 and Björck 1955). It has been pointed out, however, by Sherrington himself (Creed et al. 1932) and by Granit (1955) that the principle of reciprocity relates only to each receptor individually. The final effect on muscular activity depends on the double reciprocal innervation, which means that both excitatory and inhibitory afferents act on the motor neuron. From receptors in muscles, tendons, joint capsules and ligaments come impulses, a number of which facilitate the motor neuron in question while other inhibit it. It therefore seems selfevident that in a contraction of the agonist the effect on an antagonist need not be the same in all movements of the body, since different receptors must bu activated differently according to the amplitude of the movement, its speed, load etc. Also, the relation between receptors with excitatory and inhibitory effects can be asymmetrical (cf. Granit 1955). This can be one of the explanations why "co-contraction" occurs in extension but not in flexion at the knee joint. It is remarkable that the situation with this joint should be the same in man as in the cat, and that is should be the same with voluntarily and reflectorily elicited activity. This argus that co-contraction is controlled via spinal reflexes even in voluntary movements. The origin of co-contraction of the type occurring at the transition from flexion to extension and vice versa could be explained in a similar manner. It is known that the strongest flow of impulses from the knee joint nerves occurs in cat at maximal flexion and extension (Skoglund 1956), and that there are also receptors which fire only in these extreme positions. It seems extremely probable that the situation is the same in man, and that the firing of these receptors activates the antagonists at the turning points of the movement, i.e. at maximal flexion and extension. The occurrence of reflectorily elicited co-contraction has been previously observed by Rao (1965).

Summing up, we can thus say that co-contraction of different types occur normally with movement at a joint, and can be explained against the background of results obtained in animal experiments. We assume that its function is to stabilize, steer and protect the joint, and that it occurs as a reflex.

REFERENCES

BASMAJIAN, J.V. : *Muscles Alive. Their functions revealed by electromyography.* Williams and Wilkins Company, Baltimore, 1967.

BJÖRK, Å. : The electromyogram of the extraocular muscles in opticokinetic nystagmus and in reading. *Acta ophthalmologica,* 1955.

CARLSÖÖ, S. : The initiation of walking. *Acta anat.* 65:1-9, 1966.

CARLSÖÖ, S. and MOLBECH : The functions of certain two-joint muscles in a closed muscular chain. *Acta morph. Neerl.-Scand.* Volume VI, No 4, 1966.

CREED, R.S. et al. : *Reflex activity of the spinal cord.* The Claredon Press, Oxford, 1932.

GRANIT, R. : *Receptors and sensory perception.* Yale University Press, New Haven, 1955.

HUBBARD, A.W. : *Homokinetics : Muscular function in human movement. Science and Medicine of Exercise and Sports.* Edited by Warren R. Johnson, Harper and Row, New York, 1960.

LEVINE, M.G. and KABAT H. : Cocontraction and Reciprocal Innervation in Voluntary Movement in Man. *Science* Vol. 116, 1952.

RAO, V.R. : Reciprocal Inhibition : Inapplicability to tendon jerks. *J. Postgrad. Medic.* 1965:11.

SKOGLUND, S. : Anatomical and Physiological studies of knee joint innervation in the cat. *Acta Physiolog. Scand.* Vol. 36, Suppl. 124, 1956.

WACHHOLDER, K. : Willkürliche Haltung und Bewegung. *Erg. d. Physiol.* 26, 1928.

CRYPTO-TETANY ELECTROMYOGRAPHY AS A DIAGNOSTIC TOOL

Israel MUSS, M.D.

Chief, Physical Medicine & Rehabilitation Service
Veterans Administration Hospital
Louisville, Kentucky

This is sometimes referred to as latent tetany, a clinical entity, characterized by vague subjective complaints. These are sub-sternal tightness, frequently labeled as angina ; lump in the throat ; difficulty in swallowing ; paresthesias or pins-and-needles sensation in the hands and feet and about the mouth. Women are more commonly affected with this syndrome, and are labeled neurotics more often. Mood swings, frequently fearful in nature, bring the patient to the doctor. Deep sighing as well as hyperventilation claims the foreground of the visit.

The Problem

Because these subjective sensations are frequently unsupported by objective findings, these unfortunate people are labeled hysterics, and perhaps, make up a sizeable quota of the general practitioner's busy daily log. These patients are subjected to myriads of medical and laboratory investigations, and are often finally counseled to "learn to live with it as a method of coping with your problem". This is understandable, in that these patients with their bizarre complaints, when finally diagnosed as having latent tetany, remain not only a problem to the clinician but to the laboratory investigator as well. The intrinsic basic problem remains, as it were, within the internal milieu or the patient's own body as a laboratory enigma.

This study was started over five years ago as a part of a summer medical student program on electromyography. The patients were drawn from all services in the hospital. Using a check list of clinical symptoms prepared by Rosselle, (1) patients were chosen at random and frequently interlarded with normal student volunteers.

A case report is presented of a patient seen initially five years ago and followed every six months to study the persistence of the symptom complex. A 45-year old married female, was seen in the Diagnostic Clinic of the Rehabilitation Center in Louisville, Kentucky.

Chief complaint was, "I can't do the least bit of housework without sheer exhaustion. I used to love working with roses but now I am too fatigued to try even that". Patient is employed in the Greyhound Bus Terminal as information clerk. This requires paying attention to thousands of aimless questions daily.

When questioned, we were struck by her breathlessness, followed by deep sighing. When we commented on that, she stated, "I can't seem to come to the end of my breath. I nearly smother to death. After I digest my meal, that feeling wears off. I also notice a tight, choking sensation in my throat whenever I am upset. If I walk any distance, I become extremely fatigued and short-winded, and always have the feeling I have a lump beneath my breast like I'm smothering. I also have a peculiar sensation in my finger tips and toes. I feel jittery and my hands tremble". All of these constitute prodromata of latent tetany (res ipse locquitur).

The patient has been on tranquillizers (Valium & Meprobamate) for over a year. Prior to the EMG, it was advised that she discontinue all drugs, including thyroid, for one week. The following week, the test for crypto-tetany was run.

Technique

Patient was permitted to lie supine for 20 minutes and the blood pressure was determined at 120 mm Hg. Prior to this, the purpose of the entire procedure was fully explained. A monopolar Teflon-coated needle, 2 cm. long, was inserted in the first dorsal interosseus muscle. Reference electrode was a short, bared needle, inserted in the hypothenar eminence. The ground electrode was placed in the dorsum of the forearm.

The verification of the muscle locus was determined by having the patient abduct the index finger and perform a pinch. Calibration was set at 200 mv/cm, with a 20 ms/cm sweep. (We wish to note that, perhaps, our time base was too rapid) (1). In our future studies we plan to use 4-10 milliseconds per centimeter sweep. The blood pressure cuff was rapidly inflated to approximately 160 mm Hg. In about 15 seconds, we noted bizarre potentials of low frequency, steady beat-doublets and multiplets. These fired from the same site. Both the EMG findings and the time phase monitoring were recorded on a 2-channel, high-fidelity electromagnetic tape. Associated with these bizarre potentials was the adducted position of the thumb, ending in definite carpal-pedal spasm. The toes were drawn into flexion and the arch elevated.

Immediately after the blood pressure was released, bizarre potentials of high frequency appeared and continued for 15 seconds. All the muscles

showed irritability, as well as peri-oral tremor. Each time the test was repeated, the iterative EMG pattern returned.

The patient described the sensation in the ischemic extremity "My thumb feels like it is being pulled down inside my hand. I have no power over it. It feels asleep". The patient was able to extend the thumb with extreme effort.

When the test was repeated, multiplets, 400-500 mv in amplitude, were seen, about 10 clusters per second. This time, after compression was released, patient was asked to hyperventilate deeply for 90 seconds. She complained of being dizzy, light-headed and we noted the scope was covered with bizarre high-frequency potentials.

Upon the release of the blood pressure cuff, there occurred about 15-20 seconds of continuous high frequency potentials, associated with the accoucheur hand. At the conclusion, the patient complained of thightness and fatigue in all her muscles, and this caracterized her original somatic complaints.

On the basis that her fatigue was based on a lowered metabolic disorder, her family physician originally placed her on up to eight (gr. 8) grains of whole thyroid daily. This, she felt, stimulated her but did not prevent her breathing disorder. She was also given Prostigmin by another doctor for her myasthenic-like complaints. She stopped this medication because of gastrointestinal cramping.

Since it was felt that this patient could trigger off tetany with manifest ease, it was felt that the electrolytes in her blood must surely show a disorder. However, studies of electrolytes for Na, K, Ca and Mag, as well as her blood CO^2 tension, before and after ventilating, showed no abnormalitites. This blood was venous, and perhaps, should have been arterial.

The normal adult range of serum magnesium (2) is usually quoted as 1.42-2.5 (average 2.0). To other investigators, the normal range is narrower from 1.5 to 1.8. About 70-85 per cent of the serum magnesium is in a diffusable state. Little is known regarding the factors influencing the regulation of the magnesium content in the blood, although it is felt there is a reciprocal relationship between magnesium and calcium. The role of bound tissue magnesium is still unknown.

There is evidence indicating that magnesium deficiencies may be responsible for the production of rather distinct clinical syndromes, characterized by hyper-irritability of the neuro-muscular system ; cardiovascular abnormalities ; and tremors, twitching and hyperactive states. Although true tetany does not usually occur in the absence of hypocalcemia, a positive Chvostek sign may still occur (3). The effects of hyperventilation on tetany-prone patients are quite different in normal controls. The explanation is seen in the lowered threshold of Nerve VII in hemifacial spasm (4). Thomas found that, in general (5), these were young women who displayed various manifestations of underlying anxiety and developed tetany after brief ventilation. After 15-30 seconds, they become unaware of their surroundings and continue to breathe deeply without urging. We too, found that these susceptible patients developed a treadmill-downhill syndrome, and in spite of the tetany, could not stop hyperventilating (6). Physical examination requirements for astronauts exclude tetany-prone candidates. High altitudes and O^2 deprivation induces tetany.

A case study report of a 48-year old male who had clinical tetany (7) revealed the investigators Feildman and Granger were able to correlate the elctromyographic, arterial blood, and blood-gas studies with hyperventilation. The pH increased from 7.44 to 7.63. The CO^2 tension comparably fell from 41 mm Hg to 21.5 mm Hg. It can thus be seen that the ischemia is an arterial deprivation and not venous stasis.

Role of Epinephrine & Catecholamines

The role of Epinephrine in clinical tetany has been studied fully (8). It was found that this agent has induced tetany in hyperventilating children, and aggravated hypocalcemic tetany. The role of sympathetic reacting following injection of Epinephrine is well documented. Forced deep exhalation causes excessive loss of CO^2 from the pulmonary alveolae and produces a state of relative respiratory alkalosis and elevated pH.

O'Donovan (9) states that cases of latent tetany, using hypo-calcemia as an index, revealed that the established tests were unreliable. Using the Trousseau arterial compression test, results were found negative in 45 % of 89 observations. There is a close correlation of the three cardial signs : Chvostek facial irritability, Trousseau arterial compression, and tetany. Hyperventilation triggers off the train.

O'Donovan (ibid) was of the opinion that hyperventilation should be started within 15 seconds after releasing the tourniquet, and only needed 75 seconds of maximum hyperventilation to induce carpal spasm. He was of the opinion that in cases of latent tetany, the extremity treated with a tourniquet should show spasm before 75 seconds had elapsed. When this was done, he was assured of 95 % positive results. Prolonged washing out of CO^2 will certainly induce tetany.

Calciferrol (Vitamin D^2) or activated Ergosterol, (50,000 to 150,000 U,) were said to render the test for latent tetany negative, even though the serum calcium remained subnormal. Apparently, it is the ionizable calcium fraction which causes latent tetany.

Ionized calcium in neuromuscular excitability has been investigated thoroughly (10 & 11). Modest diminution in the level of ionized portion may increase the irritability of nervous and muscle tissue in a striking fashion, leading to tetanic seizures and positive Chvostek and Trousseau signs. (12) Calcium regulates the permeability of the cell membrane to sodium and potassium, and excess appears to diminish and a decrease augments the permeability.

Calcium is also responsible for the coupling excitation-muscle contraction. In the presence of ATP and magnesium, actomyosin is relaxed, whereas in the presence of calcium, the actomyosin contracts. Since tetany id definitely related to neuro-muscular excitability, it is best correlated electrically to the index of accommodation (13). Kugelberg proved that the nerve membrane adapts to slowly rising exponential currents. In presence to low CA++ a shift in pH to the alkaline side, accommodation deteriorates to zero, and the nerve to discharge iteratively and spontaneously.

Writers's Cramp

In the past few years, we have studied this bizarre syndrome, an occupational hazard in auditors, bookkeepers, and perhaps of counterfeitors. These patients exhibit extensive and inappropriate muscle fasciculations, simulating the hand of tetany. Amyotrophic lateral sclerosis is often the fearful tentative diagnosis. Thumb becomes rigid, adducts, extends at the MP joint. The index finger and long finger, which normally form a three-point chuck with the index finger to hold the pen, instead, go to into lumbricale position with loss of control.

A comparison of writing before and after the onset of the syndrome, as well as a potential loss in earning power, cannot be ignored. EMG studies show a tetany-like muscle spasm. These patients are tense, and quite natu rally, and upset. They also hyperventilate. We propose to study them in depth. Whether this is a natural occupational disease or not is of importance from a compensation standpoint.

Conclusion

We have presented the current thinking in latent crypto-tetany a study which has spanned five years introduced "writers' cramp" as a clinical subgroup.

BIBLIOGRAPHY

1. ROSELLE, N. and coll. *Atlas of Electromyography,* Louvain, 1960.
2. CANTEROW & TRUMPER : *Clinical Biochemistry*. W.B. Sanders Company, Philadelphia, 6th edition, 1962, p. 48.
3. FLINT, E.B. : Magnesium Deficiency Syndrome in Man. *J.A.M.A.* 160 (16) : 1407-1409, 1956.
4. WATERBURY, Rober , : *Hemifacial Spasm : A Clinical and Pathophysiological Study,* Oxford University, 1952, p. 86.
5. THOMAS, W.C., SCHWALBE, F.C., GREEN, J.R., LEWIS, A.M., and BIRD, E.O. : *Transactions of the Americal Clinical and Climatological Association.* 76 : 26-39, 1964.
6. FELDMAN, R.G., and GRANGER, C.V. : Electromyography in Latent Tetany. *New England Journal of Medicine,* Vol. 269: 1064-1067, 1963.
7. SIMONS, Dr. David, Houston VA Hospital, Director of PM&R Research, Personal communication.
8. O'DONOVAN (quotation) Stewart, PURVIS., and DROUGHT, Worster : *Diagnosis of Nervous Diseases.* Edward Arnold Company, London, 10th edition p. 186, 1952.
9. (ibid)
10. GOODMAN & GILLMAN, *The Pharmacological Basis of Therapeutics.* MacMillan, New York, 3rd edition, 1965.
11. (ibid)
12. TROUSSEAU, A. : *Lectures on Clinical Medicine.* Delivered at Hotel Dieu, Paris, Vol. I, edited by P.V. Brazier, p. 712.
13. KUGELBERG, E. : Accomodation in Human Nerves and Its Significance for the Symptoms in Circulatory Disturbances and Tetany. *Acta Physiol. Scandinav.,* Suppl. 8.24, 1944.

CREDITS : MARSHALL SACK, M.D. was the Medical Student and co-worker in 1963.

AN ELECTROMYOGRAPHIC STUDY OF SOME HIP AND THIGH MUSCLES IN MAN [1]

John E. PAULY and Lawrence E. SCHEVING

Departments of Anatomy, University of Arkansas Medical Center, Little Rock,
Arkansas and Louisiana State University Medical Center,
New Orleans, Louisiana, U.S.A.

Introduction

One hundred years ago Duchenne stimulated the muscles of the human body by the application of faradic current and studied the movements produced by their contractions. In addition, he noted the disabilities that resulted when these same muscles were paralyzed. The knowledge of what a muscle can do by itself when artificially and individually stimulated or the disability that results when it is unable to contract may not tell everything about its role in normal motion, because most movements are produced by the stimultaneous contraction of several muscles.

Multiple channel electromyography can tell which muscles participate in a motion ; but it can tell only if a muscle is contracting, not whether it is functioning as a prime mover, antagonist, fixator or synergist. The final answer to a muscle's role can be resolved only by the correct interpretation of the electromyogram, based upon the experience and skill of the investigator.

Although many studies have been done on the muscles that cross the hip, one only has to examine the literature to see that there is no unanimity of opinions as to their exact roles. An even greater disparity may be found in the textbook descriptions where there is a tendency to perpetuate erroneous notions of muscle function. In an attempt to resolve some of the controversies, an electromyographic study was made of several of these muscles.

Materials and Methods

Because both superficial and deep muscles were to be studied, it was decided to implant thin electrode wires rather than to use surface techniques. The electrodes were prepared by removing the Formvar insulation from one end of a length of number 38 gauge copper electronics wire, trimming the

---

[1] This investigation was supported by Public Health Service grant AM 08310-03 from the National Institute of Arthritis and Metabolic Diseases.

uninsulated portion until only about one millimeter of the bare wire was exposed an then bending it back with a forceps to form a small hook. The opposite end was threaded through the sharp end of a 22 gauge disposable hypodermic needle until the hook of the wire engaged at the tip. About five millimeters of insulation were removed from the other end of the wire, and the electrode wires and the needles were sterilized.

Pairs of electrodes were inserted to the proper depth into the iliopsoas, just medial to the sartorius and inferior to the inguinal ligament ; into the tensor fasciae latae, about two centimeters posterior-inferior to the anterior superior iliac spine ; through the gluteus medius into the gluteus minimus, about two-thirds of the way along a line between the posterior superior iliac spine and the anterior superior iliac spine ; into the gluteus medius, just inferior to the highest point along the crest of the ilium, posterior to the tensor fasciae latae and superior to the gluteus maximus ; into the gluteus maximus through the midpoint of the buttock ; and into the three hamstring muscles, one-half way between the gluteal fold and the popliteal fossa. The long head of the biceps femoris was entered one centimeter lateral to the midline of the thigh, the semitendinosus one centimeter medial to the midline of the thigh and the semimembranosus just medial to the palpable belly of the semitendinosus.

Each pair of electrodes was connected to an E.M.G. integrator coupler in an 8-channel recorder. Differential signals within a selected bandpass of 5-10 kilocycles per second were linearly amplified, rectified and filtered in the integrating circuits and further amplified to operate the coils of the writing units. The gains were set so that each 200 μ V of potential produced a one millimeter pen excursion. The integrated electromyograms were proportional to the frequency and amplitude of the action potentials and correlated well with the force generated by the muscles.

Twenty-three young men and women were studied. Many movements and exercises were evaluated in order to appraise the role of the muscles in flexion, extension, hyperextension, abduction, adduction, medial rotation and lateral rotation of the thigh.

Results

Flexion of the Thigh and Resistance to Extension – Four movements were employed : (1) flexion of the thigh from the supine position, (2) flexion at the hips by elevation of the head and trunk from the supine to the sitting position (situp), (3) standing on one extremity and flexing the contralateral

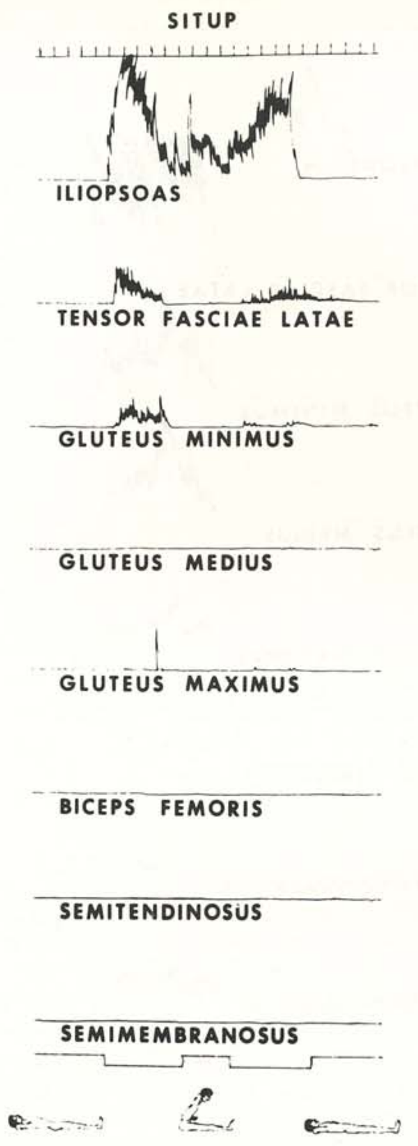


FIG. 1

Situp or flexion of the hips by elevation of the head and trunk from the supine to the sitting position. Iliopsoas most active followed by tensor fasciae latae and gluteus minimus.

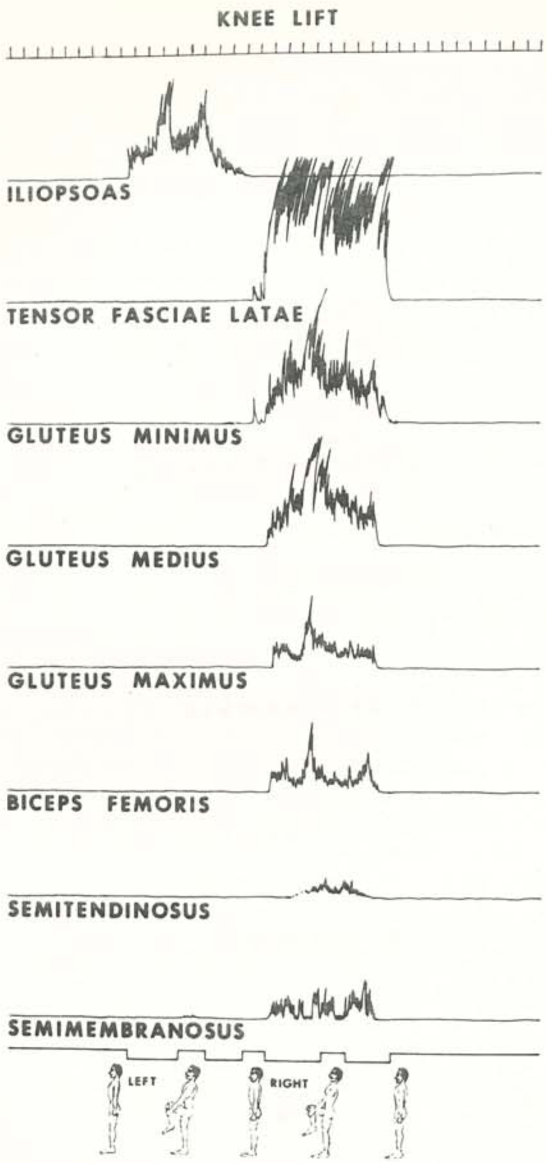


FIG. 2

Knee lift or standing on one extremity while flexing the contralateral thigh. Tensor fasciae latae, gluteus minimus and gluteus medius transfix pelvis ; gluteus maximus and hamstrings prevent flexion at hip. Note activity greater in biceps femoris and semimembranosus than in semitendinosus. Iliopsoas acts alone to produce flexion.

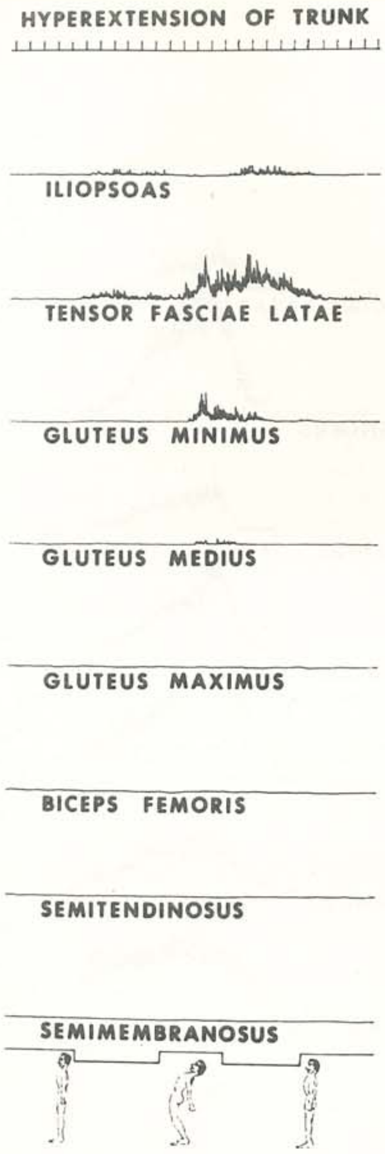


FIG. 3

Hyperextension of trunk from orthograde.
Activity greater in tensor fasciae latae than in iliopsoas.

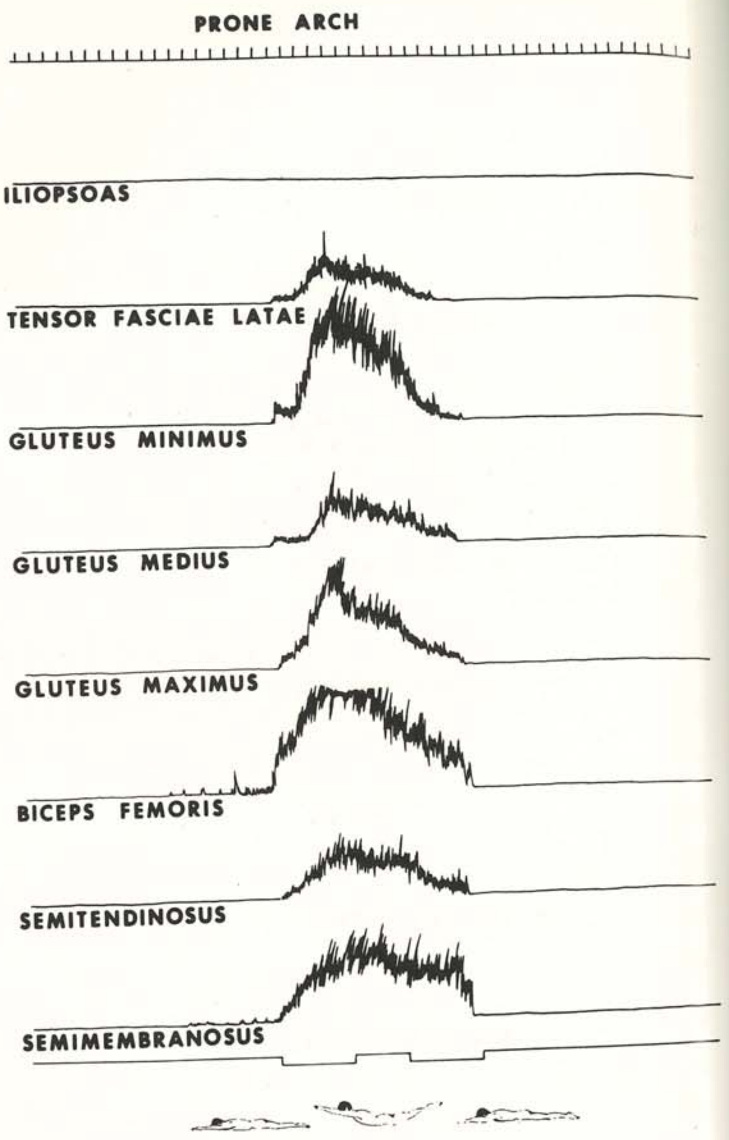


FIG. 4

Prone arch or hyperextension of back from prone position. Hamstrings, gluteus maximus and possibly gluteus medius extend thigh. Tensor fasciae latae counteracts lateral rotation by biceps femoris.

thigh while permitting the leg to hang freely at the knee (knee lift), and (4) hyperextension of the back from the orthograde position.

The ilipsoas usually was the only one of the muscles studied that contracted when the thigh was flexed from the supine position and during the knee lift from the orthograde (Fig. 2). In the situp (Fig. 1) the tensor fasciae latae and the gluteus minimus also were active. When the back was hyperextended from the orthograde position (Fig. 3), the tensor fasciae latae was the most active muscle followed by the gluteus minimus and the ilipsoas. In a few cases the iliopsoas did not resist the motion at all.

Extension of the Thigh and Resistance to Flexion – Four movements were employed : (1) the prone arch or hyperextension of the back from the prone position, (2) the barbell curl or elevation of heavy weights held in front of the body so that it was necessary for the standing subject to resist the forward shift in the center of gravity, (3) the standing toe touch or flexion of the thighs at the hip and touching the floor both with and without flexion of the knees, and (4) the half-knee bend or crouching from the orthograde to the squatting position.

The hamstrings contracted powerfully in the prone arch (Fig. 4). The semimenbranosus and biceps femoris showed activity before the semitendinosus and contracted more powerfully. The gluteus medius usually was active before the minimus, and the maximus was the last to participate ; however, the gluteus maximus produced the highest potentials if the movement was forced. The tensor fasciae latae was active from the beginning of the movement.

When a barbell loaded with weights was held in front of the body with the elbows fully extended and then elevated until they were flexed 90°, the center of gravity was shifted forward ; and it was necessary for the subjects to resist flexion at the hip in order to prevent themselves from falling forward. This resistance was accomplished by the isometric contraction of the hamstring muscles. If the weights were increased, the gluteus minimus, maximus and finally the medius were recruited. As in the previous exercise the semitendinosus showed less activity than the biceps femoris or the semimenbranosus. The tensor fasciae latae was not involved.

When the subjects bent forward to touch the floor from the orthograde position (Fig. 5), strong potentials were recorded from the biceps femoris and semimenbranosus. The gluteus minimus and medius were active throughout the movement, but the maximus showed strong potentials only after a considerable degree of flexion at the hips had taken place. The gluteus maximus was more active when the knees were permitted to flex slightly, and

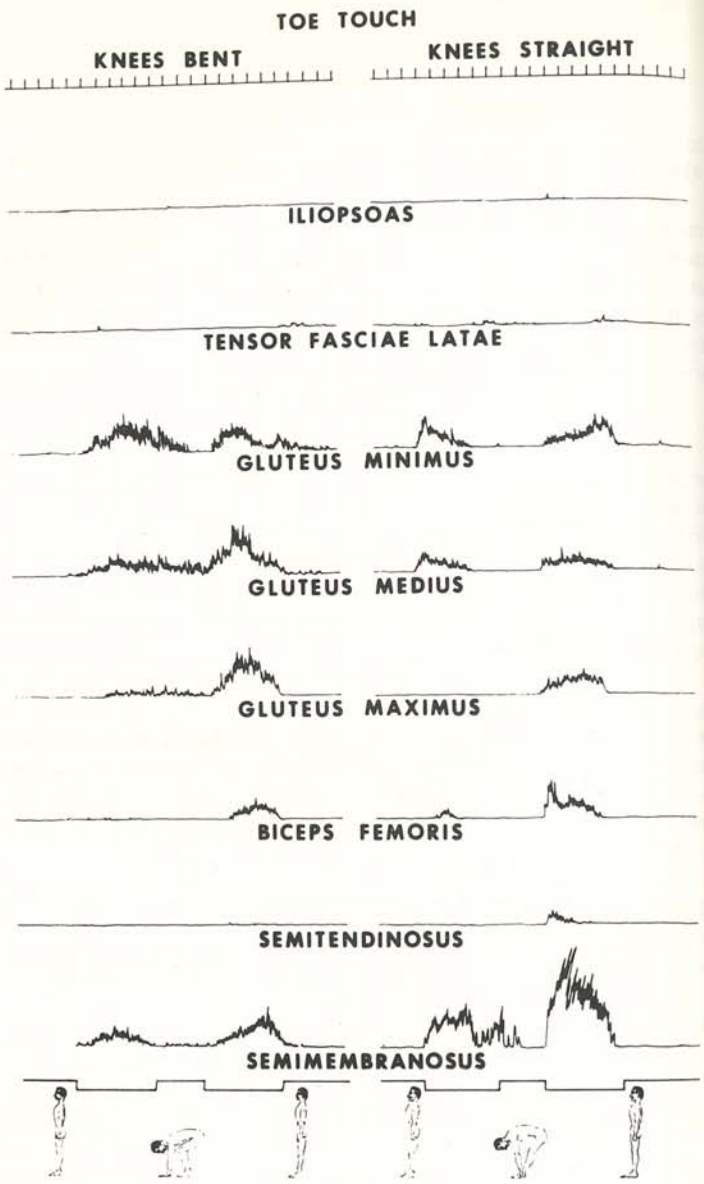


FIG. 5

Toe touch or flexion of trunk from orthograde. Gluteus minimus and medius extend flexed thigh. Hamstrings more active when knees remain extended. Increased contractions in gluteus maximus compensate for reduced activity in hamstrings when knees are flexed.

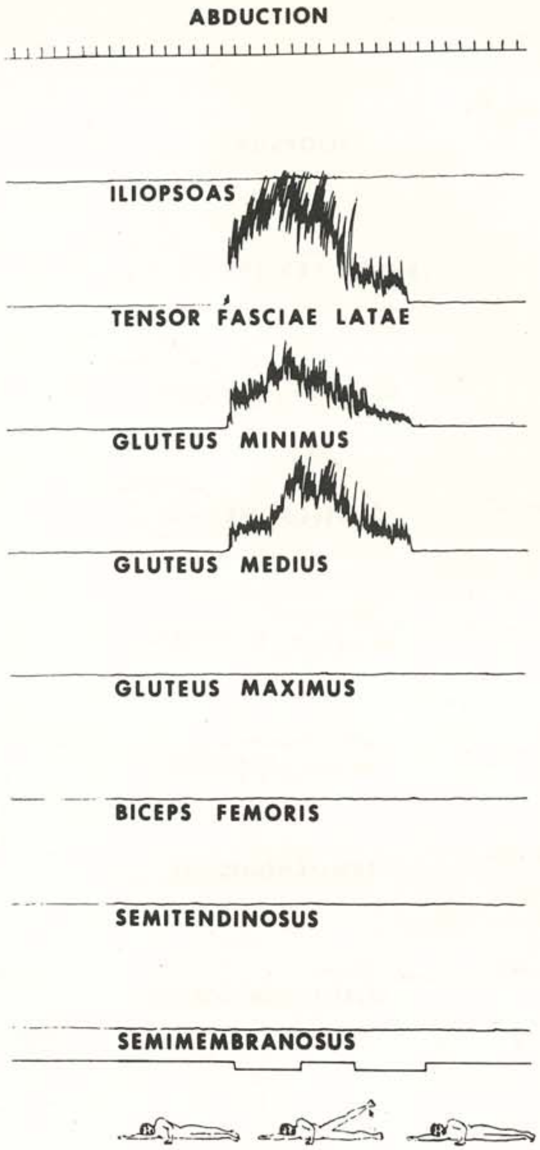


FIG. 6

Abduction of thigh while lying on side accomplished by tensor fasciae latae, gluteus minimus and gluteus medius.

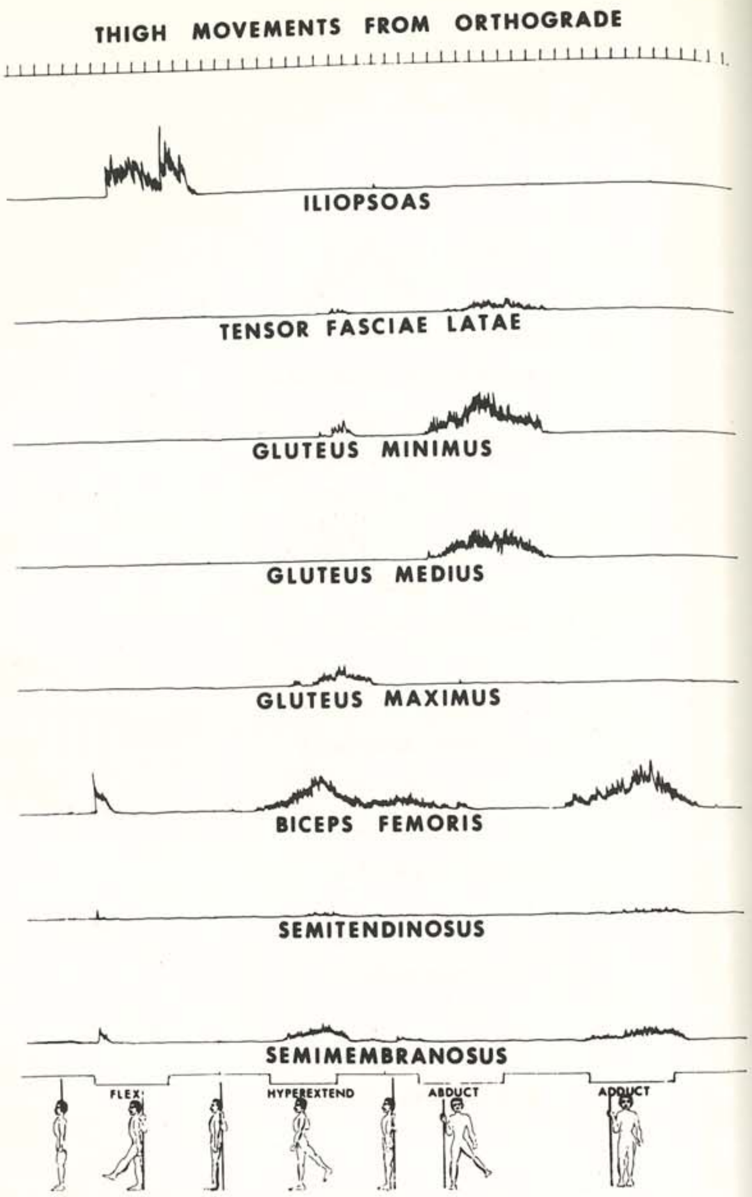


FIG. 7

Thigh movements from orthograde. Flexion produced by iliopsoas ; extension by gravity ; hyperextension by hamstrings and gluteus maximus (activity delayed) ; and abduction by tensor fasciae latae, gluteus minimus and gluteus medius.

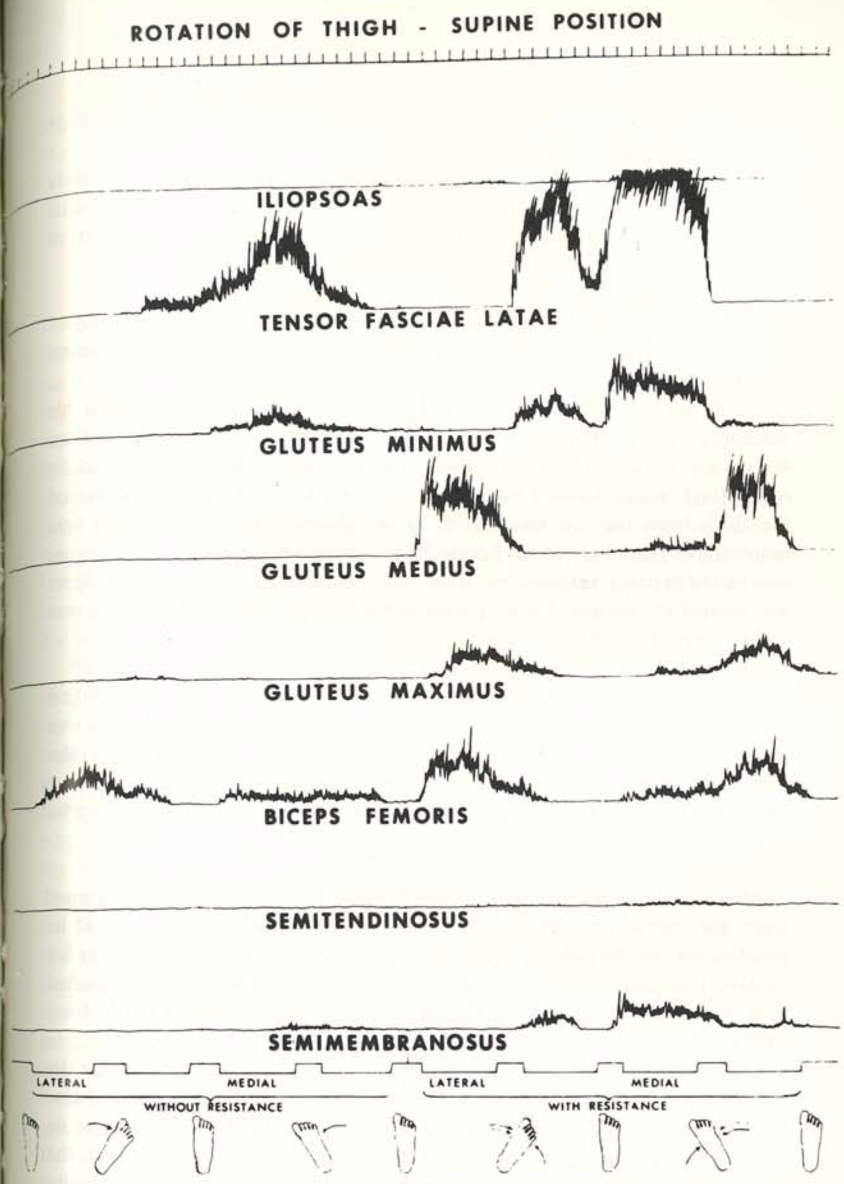


FIG. 8

Rotation of thigh from supine position. Lateral rotation produced by biceps femoris and gluteus medius. Gluteus maximus is recruited for forced movement. Medial rotation by tensor fasciae latae and gluteus minimus. Iliopsoas not active in rotation.

the semitendinosus contracted more powerfully when the knees were kept fully extended throughout the motion.

Very little activity was recorded from the hamstrings when the subjects crouched down in the half-knee bend. The gluteus minimus and medius contracted almost immediately. The strongest potentials were recorded from the gluteus maximus, although the initiation of activity was delayed.

Abduction of the Thigh – Three positions were employed : (1) the subject lying prone, (2) lying on the side and elevating (abducting) the contralateral extremity and (3) abduction of the thigh from the orthograde.

When the subject was lying on his side and elevating (abducting) his extremity (Fig. 6), the tensor fasciae latae exhibited greater potentials than the gluteus medius. This same pattern of activity was evident when abduction of the thigh was performed from the prone position. As the subjects abducted the thigh from the orthograde (Fig. 7), the gluteus minimus frequently was more active than the tensor fasciae latae and gluteus medius. The iliopsoas contracted in many subjects, but its activity could be eliminated if the subject was careful to maintain the extremity in the coronal plane or if the thigh was slightly hyperextended as it was abducted.

Adduction of the Thigh – Adduction was done from the supine and orthograde positions (Fig. 7). No activity was noted unless the motion was carried out against resistance ; then potentials were recorded from the hamstrings, particularly the biceps femoris and semimembranosus. In one case some activity was noted in the gluteus medius. The main adductor muscles were not considered in this study.

Medial and Lateral Rotation of the Thigh – The motions were performed from the supine position both with and without resistance (Fig. 8), while standing on one leg holding a pole for support and permitting the rotating leg to hang free, and from the orthograde while the subject held a barbell loaded with weights in front of himself at waist height and rotated his trunk from right to left.

Medial Rotation : The tensor fasciae latae was most active followed by the gluteus minimus. When the motion was forced, potentials were recorded also from the gluteus medius. When the trunk was rotated to the left while holding the loaded barbell at waist level (medial rotation of left thigh), the same three muscles contracted. In addition, potentials were recorded usually from the hamstrings.

Lateral Rotation : All three gluteal muscles contracted to some degree. The gluteus medius usually initiated the activity and was much stronger than

the minimus. After some delay, the gluteus maximus was recruited ; and in forced movements, it showed the highest potentials. Once again, potentials were recorded frequently from the hamstrings.

Discussion

Duchenne (1867) stated that the muscles designed to flex the thigh are the iliacus, the psoas and the tensor fasciae latae. He said that whereas the ilipsoas flexed the thigh and slightly rotated it laterally, the tensor fasciae latae flexed and rotated it slightly medially ; and the lateral rotation produced by the iliopsoas was cancelled out by the medial rotation produced by the tensor fasciae latae. All of the standard textbooks of anatomy describe the iliopsoas as a flexor of the thigh, and most of them indicate that the tensor fasciae latae also flexes the hip to some degree. Some authors, however, still claim that the ilipsoas is a medial rotator (Lockhart, '64) ; whereas others say it is a lateral rotator, particularly when the thigh is in a flexed position (Woodburne, '61). The literature on this subject has been reviewed thoroughly by Basmajian ('67).

When the thigh is in a flexed position, some lateral rotation may be produced by the iliopsoas, but recent electromyographic studies by Basmajian and Greenlaw ('68) as well as by the present investigators support the contention that the iliopsoas is neither a medical or lateral rotator of the extended thigh. Activity usually is not seen in the iliopsoas during flexion of the trunk from the orthograde, but we consistently recorded action potentials when subjects hyperextended the trunk from this position. In the latter case the iliopsoas acted as a flexor to counteract the backward force of gravity. The iliopsoas is more active than the tensor fasciae latae, in regular flexion of the thigh or when extension of the partially flexed thigh is resisted ; however, the tensor fasciae latae appears to play a greater role in resisting hyperextension of the trunk from the orthograde. The probable explanation for this is that the iliopsoas yields or relinquishes its role to a muscle with a greater mechanical advantage. The tensor fasciae latae enjoys such an advantage because of its more anterior origin from the ilium. The iliopsoas tends to lose any mechanical advantage it may have as hyperextension progresses, because the movement causes the tendon of insertion to bend over the joint capsule at even a more obtuse angle. Hyperextension of the back also is resisted by the rectus abdominis, and the pelvis in turn is stabilized against the pull of the rectus abdominis by the rectus femoris ; the latter, as a two joint muscle, simultaneously resists further extension of the thigh at the hip and flexion of the leg at the knee.

Some authors (La Ban, Raptou and Johnson, '65) contend that the iliopsoas exhibits little or no activity during the first 30 to 45° of flexion in the situp. Although strong potentials were recorded from the early stages of the exercise in a few cases. Again the probable explanation is that muscles enjoying the greatest mechanical advantage act first and exert greater force ; then other muscles participate as the effort becomes greater or the angle of pull becomes more advantageous (Pauly, '66).

Close ('64) reported activity in the iliopsoas during extreme abduction. Although our initial results agreed with this, it was noted later that the muscle was electrically silent when care was taken to abduct the extremity in the frontal plane. It appears that the iliopsoas has nothing to do with abduction per se but is associated only with the flexion that usually occurs during extreme abduction. No effort was made to consider any effect this muscle may have on the lumbar vertebrae in the present study.

Wheatley and Jahnke ('51) said that the tensor fasciae latae was active in flexion, medial rotation and abduction of the hip. Duchenne (1867) was unable to produce abduction by electromuscular stimulation of the muscle and concluded that it was a flexor and weak medial rotator of the thigh. This muscle always was active during abduction in our studies, and it was the most active of all the muscles in medial rotation. At the same time it assists the iliopsoas in flexing the thigh during the situp, the tensor fasciae latae probably counteracts the tendency for the iliopsoas to laterally rotate the flexed thigh. As previously mentioned, the tensor fasciae latae contracts powerfully when the trunk is hyperextended from the standing position. It also is very active when the back is hyperextended from the prone position. Could the muscle be acting as a flexor of the hip at one time and as an extensor another ? Probably not, for although it acts simultaneously as a flexor of the thigh and extensor of the leg during hyperextension of the trunk from the standing position, its only role in the prone arch undoubtedly is to help maintain extension at the knee by its pull on the iliotibial tract. Such is necessary, because the hamstrings have a tendency to produce flexion at the knee at the same time they hyperextend the hip joint.

The gluteus minimus is described as an abductor and medial rotator of the thigh, and most textbook authors admit that its anterior fibers can produce a certain amount of flexion (Lockhart, '64 ; Goss, '66). It particularly was active during abduction and medial rotation of the thigh or when the pelvis was transfixed on the thigh during walking or standing on one extremity while the contralateral one was lifted from the floor. Also, considerable activity was recorded during the prone arch, hyperextension of the back from the orthograde, the situp and the toe touch. The gluteus minimus probably acts as a medial rotator to counteract the lateral rotation produced by the long head of the biceps femoris as the latter extends the thigh in the prone arch. Almost certainly the gluteus minimus is resisting further flexion in the toe touch ; its role in extension of the flexed thigh has been known since the time of Duchenne. In hyperextension of the trunk from the orthograde, the gluteus minimus may act as a medial rotator to counteract any tendency for the iliofemoral ligament to produce lateral rotation ; or it may assist the tensor fasciae latae as a flexor against gravity.

The gluteus medius works with the minimus as an abductor and as an extensor of the flexed thigh. During the prone arch it probably acts as an extensor of the thigh. It contracts only when lateral rotation is forced and is not involved in medial rotation. So, contrary to the opinions of some authors, the gluteus minimus and medius are not simply separated portions of the same muscle. Although both are active in abduction and in extension of the flexed thigh, only the minimus is active in forced lateral rotation and hyperextension against resistance.

The gluteus maximus is a powerful extensor of the thigh and participates in forced lateral rotation. Extension or resistance to flexion at the hip usually is initiated by the hamstrings, and the gluteus maximus acts synergistically when a greater force or effort is required (Pauly, '66). Duchenne noted that this muscle was not necessary for walking on a flat surface but was recruited when walking up an incline or getting up from a sitting position. Joseph and Williams ('57) showed that the gluteus maximus and the hamstrings were electrically silent in relaxed standing ; but when the arms were raised to 90° in front of the body, the hamstrings showed activity. Forward sway at the ankle joints recruited the same muscles. They confirmed the findings of Wheatley and Jahnke ('51) that the gluteus maximus did not participate unless the subject flexed his trunk to a considerable degree or when extra effort was required. The present studies correlate well with these and other findings that show increased activity in the hamstrings, soleus, gastrocnemius, peroneus, flexor hallucis longus and deep muscles of the back when the center of gravity shifts forward (Portnoy and Morin, '56 ; Carlsöö, '61 ; Pauly, '66). When the trunk was flexed from the orthograde to touch the toes, the gluteus maximus payed out to effect a smooth rather than a falling motion ; but it always was more active as the subject extended back to the upright position. Such findings confirm earlier works by (Allan, '48 ; Joseph and Williams, '57 ; Karlsson and Jonsson, '65 ; Paul, '66 and others).

The hamstrings are powerful extensors of the thigh and pelvis. The biceps femoris and semimenbranosus are more active in extension than the semitendinosus. All three are two joint muscles which simultaneously act on the hip and knee. The semitendinosus particularly is important in flexion at the knee. During the toe touch with the knees extended, all three hamstrings contracted ; when the knees were partially flexed, there was less activity from the hamstrings, but this was compensated by more from the gluteus maximus. Almost no action potentials were recorded from the semitendinosus. In this case it appears that the gluteus maximus assumes a greater share of the burden so that undesired flexion at the knee will not be aided by the hamstrings. Saio ('66) reported strong contractions in the gluteal muscles and hamstrings in the half rising posture, but he stated that the greatest activity was recorded from the quadriceps femoris. Obviously the latter group maintains the proper degree of extension at the knee.

Muscles not involved as prime movers or synergists may contract for purposes of stabilizing a joint during a maximum effort (Pauly, Rushing and Scheving, '67). All of the muscles considered in the present study cross the hip joint and probably contribute to its stability. Much of the variation seen from one subject to the next may be attributed to the efforts of the body to stabilize the joint in the presence of the many forces acting upon it. Other occasional bursts of action potentials may be the result of muscles contracting unnecessarily (Joseph, '63). Only when a muscle contracts with a degree of consistency in a movement should it be said to be a participant. In order to get a more accurate appraisal of gross body movements, we masked the minor postural, stabilizing or random bursts that otherwise would have been encountered by employing lower gains on our amplifiers.

Summary

Thin wire electrodes were implanted in some muscles of the hip and thigh in 23 young men and women. Pairs of electrodes were connected to separate integrator couplers in an 8-channel, pen writing recorder. The subjects performed a variety of movements and exercises, and the following results were obtained :

The iliopsoas flexes the hip. It resists extension of the thigh more than hyperextension. The muscle is not an abductor, adductor or medial rotator, but it will laterally rotate the partially flexed thigh.

The tensor fasciae latae acts in abduction and medial rotation. It resists hyperextension of the thigh from the orthograde position and participates in forced flexion.

The gluteus minimus medially rotates the femur and resists the tendency for lateral rotation that is produced by other muscles acting on the joint. Along with the gluteus medius it abducts the thigh. These two gluteal muscles also will extend the partially flexed thigh. The gluteus medius is active in forced lateral rotation and hyperextension of the thigh from the prone position.

Extension of the thigh usually is initiated by the hamstrings, but the gluteus maximus shows activity when extra effort or power is required.

The biceps femoris and semimembranosus are powerful extensors of the hip and act to a lesser extent as flexors of the knee joint ; however, the semitendinosus is equally important as an extensor of the hip and flexor of the leg. The hamstrings are less active in crouching motions where they would cause additional flexion at the knee. Increased activity from the gluteus maximus partially compensates for this loss.

BIBLIOGRAPHY

1. ALLEN, C.E.L. 1948 : Muscle action potentials used in the study of dynamic anatomy. *Brit. J. Phys. Med.*, 11 : 66.
2. BASMAJIAN, J.V. 1967 : *Muscles Alive. Their Functions Revealed by Electromyography,* Ed. 2. Williams & Wilkins Co., Baltimore.
3. BASMAJIAN, J.V. and GREENLAW, R.K. 1968 : Electromyography of iliacus and psoas with inserted fine-wire electrodes. *Anat. Rec., 160* : 310.
4. CARLSÖÖ, S. 1961 : The static muscle load in different work positions : An electromyographic study.*Ergonomics, 4* : 193.
5. CLOSE, J.R. 1964 : *Motor Function in the Lower Extremity : Analysis by Electronic Instrumentation.* Charles Thomas, Springfield, I11.
6. DUCHENNE, G.B.A. 1867 : *Physiologie des Mouvements,* transl. by E.B. Kaplan (1959). W.B. Saunders Co., Philadelphia and London.
7. GOSS, C.M. 1966 (editor) : *Gray's Anatomy of the Human Body,* Ed. 28. Lee & Febiger, Philadelphia.
8. JOSEPH, J. and WILLIAMS, P.L. 1957 : Electromyography of certain hip muscles. *J. Anat., 91* : 286.
9. JOSEPH, J. 1963 : *Posture and electromyography. The Scientific Basis of Medicine.* Annual Reviews, 158.
10. KARLSSON, E. and JONSSON, B. 1965 : Function of the gluteus maximus muscle : An electromyographic study. *Acta morph. neer.-sandinav., 6* : 161.
11. LA BAN, M.M., RAPTOU, A.D. and JOHNSON, E.W. 1965 : Electromyographic study of iliopsoas muscle. *Arch. Phys. Med., 46 :* 676.
12. LOCKHART, R.D. 1964 : In : *Cunningham's Textbook of Anatomy,* Ed. 10. G.J. Romanes (editor), Oxford University Press, London.
13. PAULY, J.E. 1966 : An electromyographic analysis of certain movements and exercises. I. Some deep muscles of the back. *Anat. Rec., 155 :* 223.
14. PAULY, J.E., RUSHING, J.L. and SCHEVING, L.E. 1967 : An electromyographic study of some muscles crossing the elbow joint. *Anat. Rec., 159 :* 47.
15. PORTNOY, H. and MORIN, F. 1956 : Electromyographic study of postural muscles in various positions and movements. *Am. J. Physiol., 186 :* 122.
16. SAIO, M. 1966 : Muscle fatigue in the half rising posture. *Zinruigaku Zass : J. Anthropol. Soc. Nippon., 74 :* 195.
17. WHEATLEY. M.D. and JAHNKE, W.D. 1951 : Electromyographic study of the superficial thigh and hip muscles in normal individuals. *Arch. Phys. Med., 32 :* 508.
18. WOODBURNE, R.T. 1961 : *Essentials of Human Anatomy,* Ed. 2. Oxford University Press, New York.

AN ELECTROMYOGRAPHIC STUDY ILLUSTRATING MUSCULAR COMPENSATION FOR SENSORY FEED-BACK DEFICITE IN REGAINING POSTURAL STABILITY AFTER DISMOUNTING FROM AN UNKNOWN HEIGHT

A Pilot Study

Alice L. O'CONNELL

Boston University, Sargent College
Boston, Massachusetts U.S.A.

The original intent of this study was to explore the contributions of various forms of sensory feedback to some postural reflexes ; in particular, the subject's reflex control of joints of the lower extremity upon landing from a downward jump of (to him) an unknown height.

Electromyograms synchronized with cinematographic records of four subjects were studied under conditions of increased sensory deprivation by : (1) eliminating visual feedback by blindfolding the subject, and (2) in addition to the blindfold, feedback from proprioceptors in the intrinsic muscles and in the soles of the feet was decreased by immersing the feet in ice water for twenty-five minutes.

Changes in the time course of contractile electrical activity (BMG) occuring in the Vasti lateralis and medialis upon landing from the downward jump under test versus control conditions was studied.

The films and electromyographic records of the four subjects showed the following factors in common :

1. As seen in the films, the legs were always swung forward (knees extended) and the feet plantar flexed in preparation for the jump. This is also indicated in the EMGs by the appearance of a burst of early activity in the two vasti and the gastrocnemius muscles.
2. This burst of activity in these muscles either decreased or stopped until contact point. (Point at which the toes and balls of the feet made full contact with the floor.)
3. In all cases activity increased immediately at contact point in the control jumps, after a slight delay in test jump B and followed by a further delay after test jump C.
4. Each subject checked her knee flexion at approximately the same angle (within 2°) after each *test* jump, (both B and C0, and held this angle for a brief interval.

5. The ,Hold' angles for the test jumps are in all cases within 10° of the angle of the control jump. One control Hold was at the same angle as those of the test jumps, that of another subject was only 4° larger than the test jumps.

These limited data seem to indicate that increasing sensory deprivation is concomitant with increasing delay in the onset of muscular activity in the extensors on landing from the downward jump. When there is no sensory deprivation (control jumps) muscular activity appears instantly on foot contact with the floor. This implies a ,readiness' of the body to receive and ,catch' its own weight and thus to absorb the shock of landing. Such readiness is undoubtedly a result of voluntary setting of spindle bias by cortical signals to gamma efferents. The appropriate lower motor neurons of the muscles involved are facilitated, ready to respond at contact. That this ,setting of the spindle' is a result of visual feedback seems indicated by the slight delay in muscle activation that occurs when the subject makes a jump blindfolded. Without visual stimuli to trigger the response, the postural recovery mechanisms must depend for excitation upon feedback arising as a result foot contact causing: (1) skin strech, (2) pressure on deep receptors, and (3) stretch of muscle spindles in the intrinsic muscles of the feet. When these responses are reduced by chilling the feet as in the third procedure, the time to muscular activity is further increased from approximately 240-250 to 650 or more milliseconds.

BIBLIOGRAPHY

1. BUCHWALD, Jennifer S. : Proprioceptive Reflexes and Posture. *Am. J. Phys. Med. 46* : 104-113, Feb. 1967.
2. BUCHWALD, Jennifer S. : Exteroceptive Reflexes and Movement. *Amer. J. Phys. Med. 46* : 121-188, Feb. 1967.
3. ELDRED, Earl : Posture and Locomotion, in *The Handbook of Physiology,* Section I. *Neurophysiology,* Volume II, edited by J. Field. Baltimore, The Williams and Wilkins Co., Baltimore, 1960, pp. 1067-1088.
4. ELDRED, Earl : The Dual Sensory Role of Muscle Spindles, in *The Child With Central Nervous System Deficit,* U.S. Depart. of Health, Education & Welfare, Welfare Administration Childrens Bureau, 1965, pp. 50-62.
5. ELDRED, Earl : Peripheral Receptors : Their Excitation and Relation to Reflex Patterns. *Amer. J. Phys. Med. 46* : 69-87, Feb. 1967.
6. ELDRED, Earl : Functional Implications of Dynamic and Static Components of Spindle Response to Stretch. *Amer. J. Phys. Med. 46* : 129-140, Feb. 1967.
7. RUCH, Theodore C. et al. : *Neurophysiology.* W.B.Saunders Co., Philadelphia, 1961, pp. 206-219.

INTERDEPENDENCE OF RELATIONS BETWEEN INTEGRATED EMG AND DIVERSE BIOMECHANICAL QUANTITIES IN NORMAL VOLUNTARY MOVEMENTS

S. BOUISSET and F. GOUBEL

Laboratoire de Physiologie Générale,
Faculté des Sciences, Lille, France

The existence of relations between the integrated electromyographic activity and each of several biomechanical quantities, which can characterize a *movement,* has been demonstrated by several authors. For example, linear relations have been established between the integrated EMG and (a) the tension developped during a contraction at constant velocity or the velocity of shortening at constant tension (Bigland and Lippold, 1954), (b) the external mechanical work (Scherrer et al., 1957 ; Bergström, 1959), and (c) the tangential acceleration (Bouisset et al., 1963 ; Bouisset and Denimal, 1964).

It seemed desirable to reconsider these different relations during the course of the same experiment in order to examine their interdependencies, and to determine the *pertinent* physiological relation(s). This article considers the case of small amplitude unidirectional movements of flexion and extension of the elbow about the resting position, performed against light inertias. Under these conditions the muscular tension and the velocity during the course of a movement are not necessarily constant. Two types of voluntary movements are considered. These experimental conditions allow one to evaluate the significance of these considered relations with respect to the classical studies on muscular contraction, particulary those of Hill (1938). This article also develops certain initial studies by Bouisset and Goubel (1967), Goubel (1967), and Goubel and Bouisset (1967).

Methods

Small amplitude unidirectional flexions or extensions of the right forearm are performed in a horizontal plane. The hand is maintained in a position of semipronation, and the wrist is immobilized. The two types of movements are only distinguished by the way in which a particular motion is stopped, that is, with or without a barrier. In the first type, a given movement is interrupted abruptly when the arm comes in contact with a barrier. In the second type, the movement is stopped without a barrier. The point at which it is stopped is determined visually, and indicated by photoelectric cells. In both situations the amplitude of the movement is the same, and is limited to ± 20° (± 0.349 radians) about the resting position of the elbow.

The experimental system is similar to that used in previous studies. The forearm is fixed in a splint. The latter forms part of a mechanical system which rotates about a vertical axis. The movable mechanical system is equipped with tangential and radial accelerometers, and a goniometer. The angular velocity is obtained by continuous differentiation of the signal from the goniometer. The axis of rotation of the elbow, determined by anatomical criteria, coincides approximately with that of the mechanical system. A back support is used to insure the stability of the shoulder. In order to change the inertia of the mechanical system, weights could be added at a point 26 cm from the axis of rotation approximately at the level of the styloid.

The EMG of the biceps brachii and the triceps was detected by means of surface electrodes. The EMG from the biceps was recorded at the motor point, whereas, the electrical activity of the triceps was recorded in a median position from the long head of this muscle. The impedance of the electrodes was small (2-10 KΩ) with respect to the input impedance (I MΩ) of the first stage of amplification. An integrator was used which permited one to obtain the integrated electrical activity of the biceps (Q_B) and of the Triceps (Q_T) in the form of pips. The number of pips was proportional to the total area under the electromyogram curve. The integrator was essentially a capacitor which charges linearily and discharges automatically at a predetermined level of charge (FEUER, 1967). The EMG, the integrated EMG, and the different biomechanical variables are simultaneously recorded by a nine channel ACB recorder on photosensitive paper which may be developped by ordinary daylight (see fig. 1).

Each of four subjects were examined twice. Each examination consisted of both types of movements previously described. Each series of movements was performed without any weight added to the mechanical system, and with the addition of light weights (I kg, 2 kg and 3 kg). For each experimental situation, that is, for each inertia, the subject first performed the movements at some selfdetermined velocity, then, according to the instructions of the experimenter the movements were performed at slower and at more rapid velocities. A series of five movements were carried out for each inertia. Each subject was instructed on the necessity of relaxing the biceps and triceps before the test, and to perform a continuous movement with respect to the amplitude of the movement. In the case where the movements were interrupted by a barrier, the subjects were asked to continously increase their effort, as much as possible, up to the point of impact. It is easy to learn the

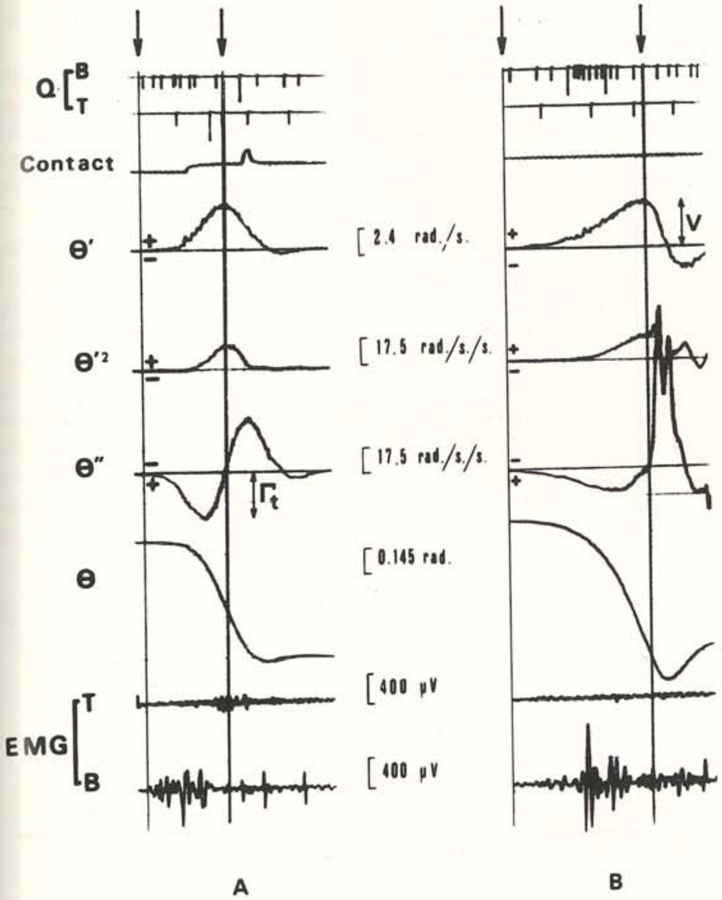


FIG. 1

Experimental curves for a flexion movement

from top to bottom :
Q_B and Q_T; integrated EMG of the biceps brachii and the triceps, respectively.
Contact corresponding to the passage of the finger under the mark constituted by the photo-electric cells (case of a movement stopped by a visual control)
θ', θ'^2, θ'', θ correspond sucessively to the angular velocity, the radial acceleration, the tangential acceleration, the angular displacement of the movement.
EMG-T and EMG-B are the electromyograms of the triceps and biceps, respectively.
A movement stopped by a visual control is shown on the left (A), and a movement stopped by a barrier on the right (B). Both types of movements are only unidirectional.

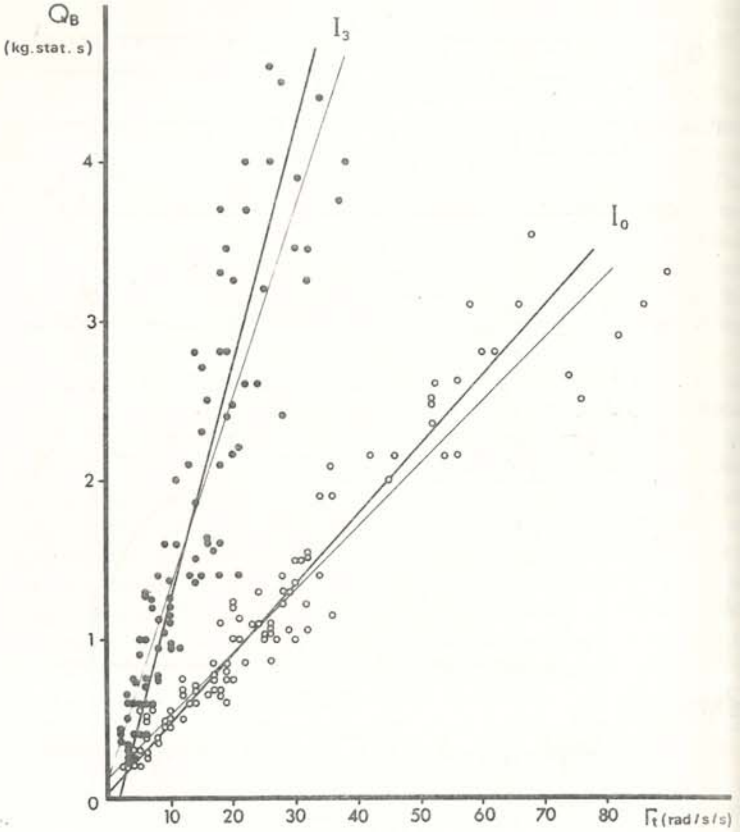


FIG. 2

Relation between the integrated EMG and the acceleration

The graph presents the results of flexion movements stopped by a barrier, and performed under two conditions of inertia. The results obtained from all subjects, each one examined twice, have been grouped together.
Q_B : integrated EMG (in kg. static-second)
B_t ; maximum value of the acceleration (in rad/s/s)
I^0 and I^3 correspond to the two conditions of inertia defined by no addition of external weight (0 kg) and the addition of 3 kg.
The correlation coefficients for Q_B as a function of B_t are .96 and .89. The regression lines are indicated.

movement, and all of the subjects had had previous practice.

In order to avoid fatigue the subjects were allowed to rest between each series of movements, as well as between changes in weight within each type of movement. A test of static work was routinely performed at the beginning and at the end of each series. Weights of 0.5, 1 and 2 kg were used for the static test. This test served as a control to indicate the absence of fatigue of the biceps or the triceps.

In addition, the test of static work permits one to express the number of pips counted during the course of a movement into a unit valid from one experimental condition to another. There is a *correspondance* between a given weight and the number of pips per second. The integrated electrical activity (in pips/sec) is a linear function of the maintained weight. Therefore, one can express a given quantity of integrated electrical activity in *kg static-second.* Since the relation between the integrated electrical activity and the weight depends on the position of the forearm, all the static tests were carried out with the forearm placed perpendicular to the upper arm. The usage of this relation is questionable, since during the course of a movement, the tension varies with the length of the muscle. However, since the amplitude of the movement during a test situation is limited, the advantages which result

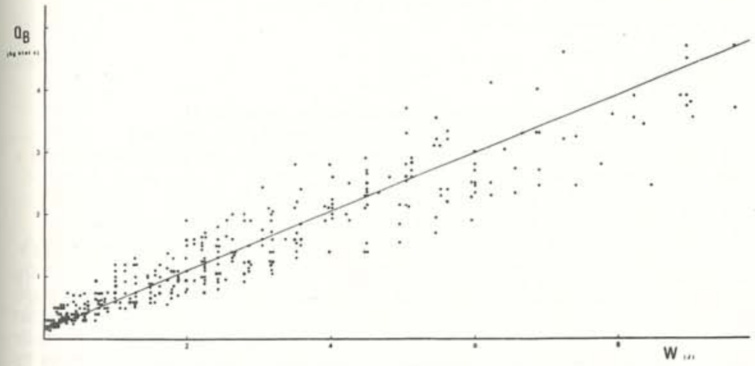


FIG. 3

Relation between the integrated EMG and the mechanical work

This graph presents the results of flexion movements stopped by a barrier, and carried out under four conditions of inertia. All the results for each subject examined twice have been grouped together.
Q_B : integrated EMG of the biceps brachii (in kg static-second)
W : mechanical work (in joules)
The regression line for $Q = f(W)$ is shown ($r = .95$).

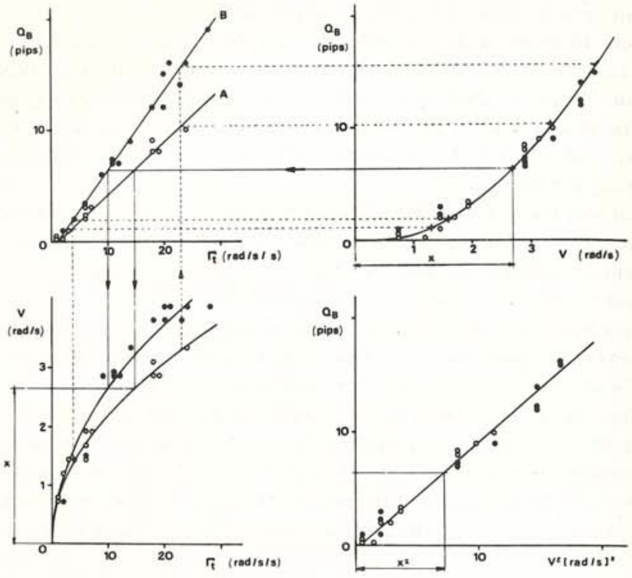


FIG. 4

Effect of the type of movement on the relations
between the integrated EMG and the biomechanical quantities

This figure demonstrates that the different relations studied are not dependent for a given inertia. As follows :

$Q = f(V)$ implies $Q = f(\Gamma_t)$ if one takes into consideration $V = f(\Gamma_t)$: a given value of V on the graph $Q = f(V)$ corresponds to an unique value of Q_B, and this value of Q_B corresponds to two values dependent on the type of movement of Γ_t on the graph $Q = f(\Gamma_t)$. If one projects these two values into the graph $V = f(\Gamma_t)$, then it is seen that they correspond to an unique value of V, and this value is equal to that originally selected on the graph $Q = f(V)$. Conversely, if one wants to trace the graph point by point, given $V = f(\Gamma_t)$, one obtains the values indicated by crosses. The graph thus obtained within the limits of construction errors, corresponds to the experimental graph.
$Q = f(V)$ implies $Q = f(V^2)$ by construction.
Q_B : integrated EMG of biceps (in pips)
Γ_t and V : maximal values of the tangential acceleration (in rad/s/s) and the velocity (in rad/s).
These graphs are constructed from the individual values obtained during the course of an experiment relative to flexions executed against a given inertia corresponding to an added weight of 2 kg. The two types of movements were considered simultaneously : (A) movement stopped by a visual control, and (B) movement stopped by a barrier.

from the transformation of the integrated EMG in pips into units of kg. Static second are not invalidated by an increase in the dispersion of the results.

Results

The following results are applicable to the agonistic activity of the biceps or triceps during the phase of acceleration which corresponds to the time required to reach the maximal angular velocity. This time interval is indicated

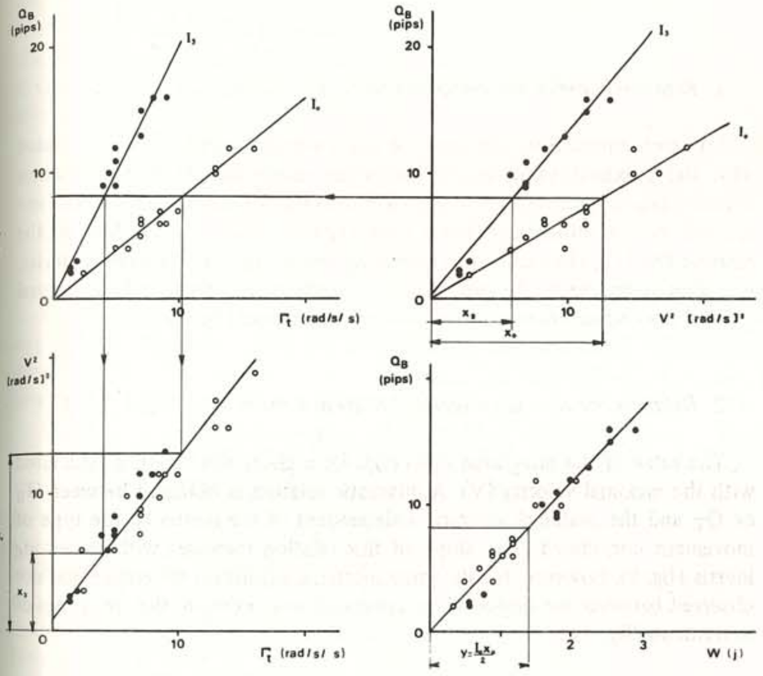


FIG. 5

Effect of inertia on the relations between the integrated EMG
and the biomechanical quantities

This figure shows that the different relations studied or not independent for a given type of movement. The explanation given in fig. 4 can be repeated.
There are two values of V^2 corresponding to a given value of Q in $Q = f(V^2)$, and these two values are successively equal to the values found on the graph $V^2 = f(\Gamma_t)$, passing by the intermediary relation $Q = f(\Gamma_t)$. [Also, note that the relation $Q = f(V^2)$, $V^2 = f(\Gamma_t)$, and $Q = f(\Gamma_t)$ are linear, with correlation coefficients from .93 to .98]
The meaning of the symbols is the same as in figure 2 and figure 4.

between the arrows on fig. 1. The number of pips is determined for this period and, therefore, provides a measure of the total quantity of electricity produced by the muscle during the movement ; in same cases this number is, if it is necessary, subsequently converted into units of kg static-second.

Since the results of this experiment do not depend on whether a particular movement was a flexion or an extension, the two situations are not considered separatly in this paper, with the exception of one case.

The results are illustrated in figs. 2-5.

1. *Relation between the integrated EMG and acceleration* $Q = f(\Gamma_t)$

For each movement, the value of the integrated EMG (Q) is associated with the maximal value of the tangential acceleration (Γ_t). The relation between Q_B or Q_T and Γ_t is linear over the range of inertias considered, and for each type of movement. For a given type of movement the slope of the relation $Q= f(\Gamma_t)$ increases with increasing inertia (fig. 2). For a given inertia, the slope is smaller in the case where a movement is interrupted by a visual control than when a movement is stopped by a barrier (fig. 4).

2. *Relation between the integrated EMG and the velocity :* $Q = f(V)$

The value of the integrated EMG (Q), for a given movement, is associated with the maximal velocity (V). A quadratic relation is obtained between Q_B or Q_T and the maximal velocity, independent of the inertia or the type of movement considered. The slope of this relation increases with increasing inertia (fig. 5), however, for the same inertia, a significant difference was not observed between the slopes of the curves corresponding to the two types of movements (fig. 4).

3. *Relation between the integrated EMG and the kinetic energy or the work :* $Q = f(W)$

From the quadratic curves obtained in part 2, it is possible to construct a linear relation between the integrated EMG and the square of the velocity (V^2). As above, the slope of this curve depends on the inertia (fig. 5). Given the moment of inertia of the mechanical system – determined for each weight, as well as that of the forearm – estimated on the average to be 0.059 kg.m^2, it is possible to calculate the kinetic energy $W = IV^2/2$. Therefore, one can represent on the same graph the relation between the integrated EMG and the kinetic energy corresponding to the four different inertias. This relation is linear, and the slope is not affected by the inertia (fig. 3). In the case of flexions, a given value of inertia does not change the slope. For extensions, this phenomenon is less clear, because of a slightly larger dispersion of the data. Furthermore, since the variation of kinetic energy from the beginning to the end of a movement is equal to the algebric sum of the work effected by the applied forces against the mechanical system during the movement, these results indicate the existence of a linear relation between the integrated EMG and the total mechanical work supplied by the entire system of forces put into play during the corresponding phase of a movement, that is, from the beginning of the movement where the velocity is zero to the moment where the velocity is maximal.

Discussion

The discussion is limited to the following two points : (a) the interdependence of the relations considered in the results section, and (b) the physiological significance of the results. The second point will be treated only briefly since it will form the substance of another publication.

1. The different relations considered between the integrated EMG and the several biomechanical quantities characterizing a movement are *not mutually independent* (figs. 4-5). This is evident in the case of $Q = f(V)$ and $Q = f(W)$: since the kinetic energy equals a constant coefficient times the square of the velocity, therefore, if one relation if given the other is determined. Also the existence of the relation $V^2 = K\Gamma_t$ determines the dependence between the integrated EMG and the velocity, and the integrated EMG and the acceleration.

The relation $V^2 = k\Gamma_t$ which appears to be independent of inertia, is a consequence of the way in which the muscular force is exerted at each instant of a movement. This is confirmed by the fact that the constant k changes according to the type of movement. That is, k is a function of the organization of the movement (fig. 4). Therefore, the relation $V^2 = k\Gamma_t$ appears to be a purely *biomechanical property*, where the coefficient depends on the type of movement. Thus, for a given velocity, the maximal value of acceleration is smaller for a movement stopped by a barrier, and this value is reached at a larger amplitude of movement, than in the case where the motion is not stopped by a barrier.

Since the different relations considered above are dependent, one must determine which is the *pertinent* relation from a physiological point of view. That relation which does not appear to be effected by a modification of the conditions of the movement will necessarily be the pertinent relation. Since $Q = f(W)$ is independent of the inertia and is also insensitive to the type of movement, it can be considered as the pertinent relation.

2. The results presented above appear to be quite general. That is, the linear relation between the integrated EMG and the total mechanical work, described above for the case of the biceps and triceps working against light inertias, has also been emphasized for the case of the contraction of the triceps working against heavy weights (Scherrer et al., 1957), the abductor of the index (Bergström, 1959), and the respiratory muscles during the course of a normal inspiration (Delhez et al., 1965 ; Viljanen, 1967). An interpretation of this linear relation on the basis of the existence of passive and active muscular forces has been proposed by Goubel and Bouisset (1967). Since an equivalence between the integrated EMG and the work, and the integrated EMG and the velocity has been established, it is sufficient to discuss the generality of the former in terms of the latter. The muscular properties which are reflected by the latter relation have been discussed by Bigland and Lippold (1954). These authors consider $Q = f(V)$ to be a consequence of Hill's equation (1938), which would therefore imply that Hill's equation is valid for the case of submaximal contractions. If it is incontestable that the relations between the integrated EMG and the different biomechanical quantities reflect the mechanical properties of the muscle, then the interpretation of Bigland and Lippold does not appear to hold as a general rule without supplementary verifications. For example, it must be verified for the case of movements of diverse amplitudes about different initial positions, as suggested by the findings of Inman et al. (1952).

It has been emphasized that the relation between the integrated EMG and the square of the maximum velocity did not differe in slope according to the two types of movements, whatever the value of inertia. Therefore, in order to reach a maximal velocity, the same amount of electrical energy is expended in each type of movement.

For the two types of movements considered, and within the limits of our experiments, there exists the same regulation previously indicated by Bergström (1962), which leads to a strict proportionality between the integrated EMG, – i.e., the expression of the electrical energy exhibited by the muscle – and the variation of kinetic energy of the system during the phase of the movement considered. If one admits the well known hypothesis according to which a muscle augments its tension by increasing the numer of active units and the frequency of their discharge then this relation implies a proportionality between both these factors, i.e. the motor activity and the mechanical work effected. It would be interesting to see whether the relation between the integrated EMG and the kinetic energy would be linear for values of kinetic energy greater than those considered in this study.

Summary

1. During the course of the same experiment, the relations between the integrated EMG and several bio-mechanical quantities characterizing a movement were studied simultaneously.

2. The case of unidirectional flexions or extensions of limited amplitude $\pm 20^\circ$ about the resting position of the joint – against light inertias was considered. A given movement was stopped in one of two ways : (a) by the impact of the forearm against a barrier, (b) by replacing this situation by one in which the movement is stopped at a particular point, under visual control.

3. It was shown that : (a) a linear relation exists between the integrated EMG and the acceleration, (b) a quadratic relation exists between the integrated EMG and the velocity, and (c) a linear relation exists between the integrated EMG and the external mechanical work or the variation of the kinetic energy. The coefficient of relation (a) depends on the inertia and the type of movement, whereas the coefficient of relation (b) depends only on the inertia, and that of relation (c) depends neither on the inertia nor the type of movement.

4. It was established that these different relations, taking consideration the existence of a purely biomechanical quadratic relation between velocity and acceleration, are mutually dependent. The relation between the integrated EMG and the mechanical work is the pertinent relation from a physiological point of view. The generality of this relation is emphasized and its physiological significance is briefly considered on the basis of the fundamental properties of muscle, and the type of motor command.

The authors would like to express their appreciation to Dr Jay ROSENBERG for the translation of the manuscript, and to G. DUTRIEUX and Miss M.A. LAMBLIN for their technical assistance.

REFERENCES

BERGSTRÖM, R.M. (1959) : The mechanical work produced by voluntarily controled muscle action and the frequency of the motor discharge. *Acta Physiol. Scand.*, *47*, 191-198.

BERGSTRÖM, R.M. (1962) : The relation between the integrated kinetic energy and the number of action potentials in the electromyogram during voluntary muscle contraction. *Ann. Acad. Sci. Fenn. Ser. A. V. Medica, 93,* 1-24.

BIGLAND, B. and LIPPOLD, O.C.J. (1954) : The relation between force, velocity and integrated electrical activity in human muscles. *J. Physiol.*, London, **123**, 214-224.

BOUISSET, S. et DENIMAL, J. (1964) : Etude de la relation entre l'activité électromyographique intégrée et l'accélération d'un mouvement de percussion. *Rev. Neurol.*, Paris **110**, 347-349.

BOUISSET, S. DENIMAL, J. et SOULA, C. (1963) : Relation entre l'accélération d'un raccourcissement musculaire et l'activité électromyographique intégrée. *J. Physiol.*, Paris, **55**, 203.

BOUISSET, S. et GOUBEL, F. (1967) : Activité électromyographique intégrée et vitesse d'exécution d'un mouvement monoarticulaire simple. *J. Physiol.*, Paris, **59**, 359.

DELHEZ, L., PETIT, J.M. et BOTTIN, R. (1965) : Activité électrique intégrée du diaphragme, fonction du travail inspiratoire. *J. Physiol.*, Paris, **57**, 598-599.

FEUER, D. (1967) : Intégrateur convertisseur (analogique-numérique). Application à l'évaluation de l'activité électrique cellulaire. *J. Physiol.*, Paris, **59**, 319-321.

GOUBEL, F. (1967) : *Etude quantitative de l'activité musculaire au cours de mouvements monoarticulaires. Effets de l'inertie et de la finalité du mouvement.* Diplôme d'Etudes Supérieures, Lille, I vol., 61 p. ronéot.

GOUBEL, F. et BOUISSET, S. (1967) : Relation entre l'activité électromyographique intégrée et le travail mécanique effectué au cours d'un mouvement monoarticulaire simple. *J. Physiol.*, Paris. **59**, 241.

HILL, A.V. (1938) : The heat of shortening and the dynamic constants of muscle. *Proc. Roy. Soc. B., 126,* 136-195.

INMAN, V.T., RALSTON, H.J., SAUNDERS, J.B. de C.M., FEINSTEIN, B. and WRIGHT, E.W. (1952) : Relation of human electromyogram to muscular tension. *EEG Clin. Neurophysiol., 4,* 187-194.

SCHERRER, J., BOURGUIGNON, A. et MARTY, R. (1957) : Evaluation électromyographique du travail statique. *J. Physiol.*, Paris, 49, 376-378.

VILJANEN, A.A. (1967) : The relation between the electrical and mechanical activity of human intercostal muscles during voluntary inspiration. *Acta Physiol. Scand., 71, I,* Suppl. 296, 61 p.

AN ELECTROMYOGRAPHIC STUDY OF THE TEMPORALIS AND MASSETER MUSCLES OF MONOZYGOTIC TWINS*

Norman L. BIGGS, Horace E. POOL and Patricia L. BLANTONN

Department of Gross Anatomy, Baylor University
College of Dentristry, 800 Hall St., Dallas, Texas

Introduction

Since the original electromyographic study of the temporomandibular muscle contraction patterns (Moyers, 1949), much work has been done concerning functions of muscles of mastication during various movements of the mandible (Pruzansky, 1952 ; Perry and Harris, 1954 ; Jarabak, 1954 ; Perry, 1955 ; Pruzansky, 1958 ; Artz, 1964 ; Moller, 1966 ; Ahlgren, 1966). Dahlberg (1964) made a very thorough statistical study of the factors controlling the number of chews during mastication. A review of the literature fails to reveal any previous electromyographic study made with monozygotic (identical) twins. Also very little work has been done on the relative sequential contraction pattern between the masseter and temporalis muscles. Because of these observations, it was decided that an electromyographic study of monozygotic twins comparing the relative sequential contraction pattern between the masseter and temporalis muscles would be of value.

Materials and Methods

The sample used in this study consisted of 14 sets of monozygotic twins, 8 male and 6 female, 9 - 14 years old. Zygosity was determined according to comparative blood studies, fingerprints, photographs and a thorough history of each individual. The electromyographic recording instrument used was a Hewlett Packard (Sanborn) four channel, thermal paper recorder equipped with a four beam oscilloscope and utilizing high gain preamplifiers. The gain was set so that 100 μV potential from a muscle produced a one centimeter excursion of the recording stylus and a simultaneous one centimeter vertical deflection of the beams on the oscilloscope. Identical gain settings were used on all four channels, making it possible to quantitatively compare the activity of one muscle with the other. The frequency range accepted throughout the course of this study was 15-1500 Hz (cycles per second), although the paper

(*) Credits : 1) Medical Research Foundation of Texas; 2) DE21 Training Grant; 3) General Research Grant FR 5343.

recordings were limited to 125 Hz which is the maximum frequency response of the galvanometers in the thermal recorder. All recordings were made with a paper speed of 25 mm/sec.

The electrodes used in this study were Beckman biopotential surface electrodes. This type of electrode was chosen since the objective was to pick up the mass of muscle activity rather than the finite activity obtained with needle electrodes. Another consideration in choosing surface electrodes was the resistance of the parents and subjects to the suggestion of needle electrodes.

In preparing the subject for an electromyographic survey of his masseter and temporalis muscles, the subject was given a brief explanation of equipment and procedure and reassured that there would be no discomfort. This was done to help prevent any apprehension which might be manifest in the recordings due to added muscle tension caused by fear.

The position for the electrodes was chosen by palpation of the temporalis and masseter as the subject tightly clinched his teeth. After selection of the location for the electrodes, the area was abraded with Sanborn Redux abrasive electrode paste to reduce surface resistance. To further reduce surface resistance the cornified layer of the skin was scratched lightly with a hypodermic needle. Beckman disposable adhesive disks were used to secure the electrodes which were placed on the masseter muscles. The electrodes used on the temporalis muscles were secured by a one inch wide ajustable elastic band places around the circumference of the head, using just enough pressure to insure stability of the electrodes during mastication. Sanborn Redux electrode paste was applied to the electrodes to insure contact with the skin.

A stainless steel wrist plate secured by an elastic band was used for the ground with the skin under the wrist plate being prepared in the same manner as it was for electrode placement.

To assure against the possibility of the twins competing with each other, they were separated after the initial introduction to the equipment and not allowed to watch each others performance. All recordings were made with the subjects seated in a grounded copper screen enclosure to insure the prevention of extraneous electrical interference.

All recordings were made with the subject masticating and swallowing a vanilla wafer as one bolus.

Ten complete masticatory strokes from the middle twothirds of each recording of a complete mastication of the wafer were selected for evaluation. A masticatory stroke was considered as originating with the initial recorded electrical activity of the muscle and extending through contraction to relaxation and cessation of electrical activity back to the original base line of

Table 1

Average duration of contraction of masseter and temporalis and number of chewing strokes to deglutition

Twin Set	Duration of Contraction		Chewing Strokes to Deglutition
No.	Masseter	Temporalis	No.
1A	.292	.420	32
B	.252	.572	36
2A	.184	.220	36
B	.244	.268	34
3A	.360	.344	28
B	.404	.512	27
4A	.588	.648	70
B	.856	.596	51
5A	.214	.392	30
B	.316	.368	30
6A	.468	.420	34
B	.368	.288	37
7A	.352	.296	40
B	.468	.516	37
8A	.516	.564	50
B	.492	.356	41
9A	.308	360	33
B	.280	.408	51
10A	.488	.376	60
B	.600	.496	63
11A	.456	.360	47
B	.504	.424	39
12A	.416	.380	53
B	.316	.260	50
13A	.244	.256	37
B	.600	.472	58
14A	.472	.456	47
B	.408	.400	40

the graph. From the ten masticatory strokes selected from the electromyograms, the following observations and/or calculations were made. Arithmetic averages were established in seconds where applicable.

1. Duration of contraction of masseter and temporalis muscles.
2. Number of masticatory strokes to deglutition for each subject.
3. Relationship of masseter and temporalis activity.
   a. Do both masseter muscles contract synchronously?
   b. Do both temporalis muscles contract synchronously?
   c. Do the masseter and temporalis muscles contract synchronously?
      1) If the masseter and temporalis muscles do not contract synchronously, wich muscle contracts initially and which muscle reaches maximum activity (peaks)first?

Comparisons were made of data obtained from the twins of a set, as well as among sets.

Results

The following data was obtained from observations made on the twins of a set and individually.

1. The masseter and temporalis muscles showed little uniformity in the duration of contractions during mastication among the 28 individuals, however some uniformity in duration was observed between members of a set (Table 1).
2. Comparing each twin with his twin, the number of masticatory strokes required to deglutition was very close in 8 sets of the twins, with the range being somewhat wider in the other 6 sets (Table 1). Comparing the sets of twins, there was a wide range of difference in the number of masticatory strokes (27-70) required to deglutition. The average number of masticatory strokes in the wafer chewing test was 43 strokes.
3. Bilaterally the masseter muscles of each subject exhibited initial contraction, maximum contraction and relaxation simultaneously, as did the temporalis muscles, but the masseter and temporalis muscles did not exhibit initial contraction, maximum contraction or relaxation synchronously (Figs. 1, 2).

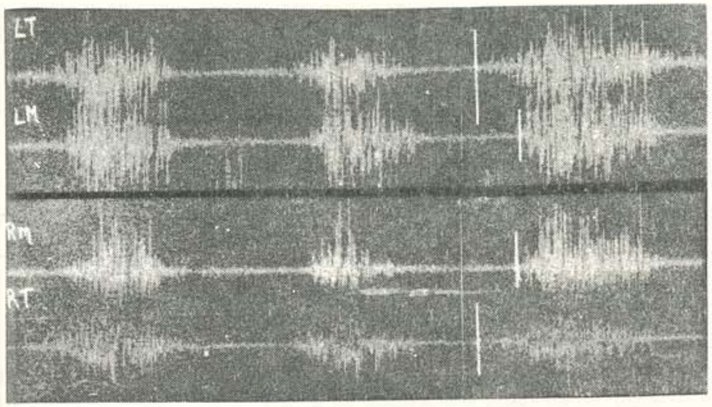


FIG. 1

Electromyogram of the activity of the right and left temporalis muscles (RT, LT) and the right and left masseter muscles (RM, LM) illustrating the chewing pattern of a monozygotic twin. Note that the firing of the temporalis muscles is relatively synchronous, as is that of the masseter muscles. In this instance, the temporalis muscles initiate contraction before the masseter muscles.

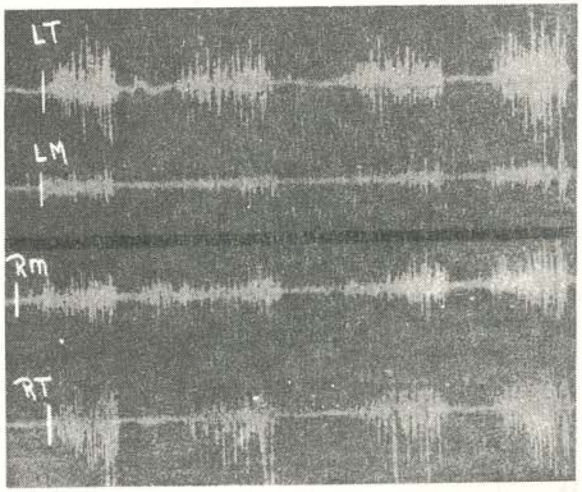


FIG. 2

Electromyogram of the activity of the right and left temporalis muscles (RT, LT) and the right and left masseter muscles (RM, LM) illustrating the chewing pattern of a monozygotic twin. This twin illustrates initial firing of the masseter muscles before the temporalis muscles.

Table 2

Sequential Relationship of Masseter (M) and Temporalis (T) activity

Twin Set No.	M Initiated Contraction Before T No.	M Peaked First No.
1A	2	3
B	8	5
2A	5	9
B	9	9
3A	2	10
B	5	9
4A	10	5
B	8	10
5A	2	4
B	1	1
6A	4	2
B	7	0
7A	8	8
B	6	3
8A	7	8
B	8	0
9A	2	2
B	2	2
10A	8	3
B	8	6
11A	7	5
B	5	6
12A	3	4
B	8	0
13A	3	7
B	2	10
14A	4	2
B	8	6
	11	

4. There was a lack of uniformity in the relative contraction sequence of the masseter and temporalis muscles of all subjects, i.e., the masseter may contract first on one masticatory stroke and the temporalis might contract first on the next masticatory stroke.
5. In this sample of 28 children, the masseter muscle showed electrical activity before the temporalis 54 % of the time (Table 2).
6. The temporalis peaked first 50 % of the time and the masseter peaked first 50 % of the time (Table 2). There was no correlation between which muscle showed electrical activity first and which muscle reached maximum contraction first during natural chewing.

Differences in the muscle function patterns were found to exist between members of the individual monozygotic twin sets. There were variations in the time interval between maximum contraction peaks of the masseter and temporalis muscles, in the time interval between initiation of contraction of these muscles, and in the duration of contractions (Table 1, 2). However, the overall patterns of activity obtained from the individuals in a set of monozygotic twins were relatively similar when compared to the muscle function patterns among the different sets of twins. Several twin sets showed only slight differences in the number of masticatory strokes necessary to masticate a standardized bite (Table 1).

Discussion

Previous electromyographic investigations of the masseter and temporalis muscles have resulted in a myriad of various findings. In 1954, Jarabak stated that the masseter and temporalis muscles, ipsilaterally and contralaterally, contracted synchronously in a subject with excellent Angle Class I occlusion. In cases with wide interocclusial space, such as a cleft palate case, Jarabek stated that the temporalis muscles contract simultaneously and the masseter muscles contract simultaneously, but the masseter and temporalis muscles do not initiate contraction synchronously. Subjects of the present study were declared by an orthodontist as persons having normal occlusion, yet the electromyographic results obtained from these subjects do not support Jarabak's findings. The present investigators found the masseter muscles to function relatively synchronously bilaterally ; the temporalis muscles also were found to function synchronously bilaterally, but the masseter and temporalis muscles did not appear to exhibit simultaneous initiation or cessation of contraction. The findings of this study partially support the data reported by Perry and Harris in 1954. They found in ten patients with cephalometrically and anatomically normal occlusion the temporalis muscles and masseter muscles on both sides were synchronized and that the temporalis muscles always displayed electrical activity before the masseter muscles went into action. Perry and Harris observed in Class II Division I malocclusions that the masseter muscles frequently were the first to manifest electrical activity. In the present study, among 28 subjects with normal occlusion, the masseter was found to show initial contraction before the temporalis 54 % of the time, however, there was a lack of uniformity in the relative contraction sequence of the masseter and temporalis muscles of all subjects. In recent studies (Perry, 1955 ; Ahlgren, 1966) the temporalis muscle of the functional or „working" side was reported to manifest action potentials before the ipsilateral masseter muscle or the contralateral temporalis and masseter muscles, the latter three contracting synchronously 0.05 sec. later. The subjects of Ahlgren's study who showed such results were chewing gum. Ahlgren reported the appearance and disappearance of the activity of the masseter and temporalis muscles to occur simultaneously 50 % of the time in peanut chewing. Eight percent of Ahlgren's subjects gave results similar to the results obtained in this study, i.e., synchronous firing of the masseter muscles, synchronous firing of the temporalis muscles, but asynchronous firing between the masseter and temporalis muscles.

The question quite naturally occurs, „Why all the varying results? " Surface or hook electrodes (no needle or indwelling wire electrodes) were used in all of the previously mentioned investigation and electrode placement was quite similar in each case. Possible differences in ages of the subjects cannot be held accountable. Ahlgren's subjects ranged from 9-14 years of age as did the subjects of the present study. Ahlgren ascribed the difference in muscular patterns among his subjects to be due partially to the substance chewed (peanuts and chewing gum). The subjects of the present study were chewing a wafer, a substance of consistancy quite different from either peanuts or chewing gum. The results of the present study, based on the use of a quite different test material, might therefore be expected to vary from previously reported results. Without further study, the present investigators will nog attempt to establish reasons for the differences in results reported among investigators, but merely wish to recognize the need for further substantiative studies.

The outstanding consideration of this study was the comparison of electromyographic activity between twins of a monozygotic set and among the sets. Quite definite similarities were observed in the duration of contraction of the masseter and temporalis muscles between twins of a set in twelve of the fourteen sets (Table 1). Eight of the fourteen sets of twins showed striking similarities in the number of chewing strokes required to deglutition in view of the range of chewing strokes (27-70) evidenced among the sets. Twins of nine sets showed initial contraction of the masseter to occur before initial contraction of the temporalis. The statistical significance of occurence of similarities was not determined in this study. However, the overall patterns of activity obtained from the members of a set of monozygotic twins were relatively similar when compared to the muscle function patterns among the different sets of twins. More extensive investigation of muscle patterns among monozygotic twins is forthcoming.

BIBLIOGRAPHY

1. AHLGREN, J. 1966 : Mechanism of mastication. A quantitative cinematographic and electromyographic study of masticatory movements in children, with special reference to occlusion of the teeth. *Acta Odont. Scand. 24* suppl. 44.
2. ARTZ, E.E. 1964 : *An electromyographic investigation of the temporal peri-oral and suprahyoid musculature of noncleft and repaired cleft lip and palate individuals.* Master's Thesis, Northwestern University, Dental School, Chicago, Illinois.
3. DAHLBERG, B. 1964 : The masticatory habits. *J. Dent. Res. 25* : 67-72.
4. JARABAK, J.R. 1954 : The adaptability of the temporal and masseter muscles ; an electromyographical study. *Angle Ortho. 24* : 193-213.
5. MOLLER, E. 1966 : The chewing apparatus. *Acta Physiologica Scandinavica. 69* :280.
6. MOYERS, R.E. 1949 : Tempo-mandibular muscle contraction patterns in Angle Class II, Div. I malocclusions,: An electromyographic analysis. *Am. J. Prosthodont. 35 :* 837-857.
7. PERRY, H.T. and HARRIS, S.C. 1954. Role of the neuromuscular system in functional activity of the mandible. *J. Am. Dent. Assoc. 48 :* 665-673.
8. PERRY, H.T. 1955 : Functional electromyography of temporal and masseter muscles in Class II, Div. I malocclusion and excellent occlusion. *Angle Ortho. 25 :* 49-58.
9. PRUZANSKY, S. 1952 : Application of electromyography to dental research. *J. Am. Dent. Assoc. 44 :*49-68.
10. PRUZANSKY, S. 1958 : Quantitative electromyographic analysis of mastication. *Am. J. Orthodont. 44 :* 307. Abstract.

AN ELECTROMYOGRAPHIC STUDY OF COMPLEX LEARNING

H. W. LADD
Department of Psychology, Loyola of Montreal, Montreal, Canada

A. A. SMITH
Department of Psychology, University of Windsor, Windsor, Canada

Studies of the electrophysiological activity in skeletal muscles of individual humans while performing various psychological tasks have been reported in the literature since the late 1930's. It has been found, in general, that the activity increases monotonically during the task, and then decreases rapidly with task completion. Malmo (1965) and Thompson, Lindsley and Eason (1967) have presented excellent reviews of the studies in this area of electrophysiological research. Basmajian (1965) has presented a review concerned with the underlying anatomical considerations of the electrophysiological activity in the skeletal muscles. Hodgkin (1964) has presented a definite explanation of the bio-chemical and the bio-physical mechanisms underlying the electro-physiological activity. Sidowski (1967) has presented a detailed report on the current status of instrumentation and methodology in this area.

In the present research three different experimental tasks were designed to study the relationship of the electrophysiological activity of the forearm extensor muscles and of muscles closely associated with speech (*depressor labii inferioris, geneoglossus, platysma* and the *diagasteric* muscles) during individual complex learning. Experimental task one was operationally defined as a *motor* learning task ; task two was defined as a *stimulus-reponse* learning task ; and task three was defined as a concept learning task. The electrophysiological activity was studied by the surface electromyographic technique.

Subjects : The subjects were nine male undergraduate students between 19 and 21 years of age. The subjects were randomly assigned to the three different experimental learning tasks. Three subjects each were assigned to the three tasks.

Learning Apparatus : The general Learning Apparatus (GLA) of the department of Psychology, University of Windsor, was used. The apparatus consisted of six isolated individual subject panels and a programming console and, has been fully described elsewhere (Cervin, Smith and Kabisch, 1966). Of the six panels A through F, panel B was used. A diagrammatic represen-

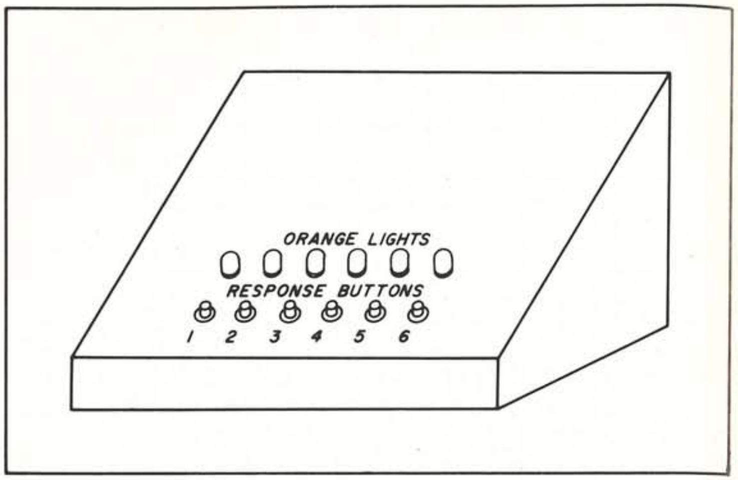


FIG.1

Panel B as it appeared to each subject in the Motor Learning task.

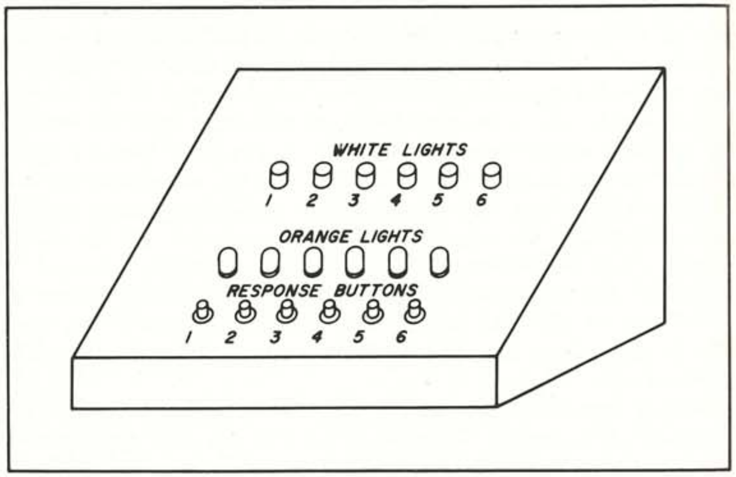


FIG. 2

Panel B as it appeared to each subject in both the Stimulus-Response and the Concept Learning tasks.

tation of panel B as it appeared to each subject in the motor learning task is presented in Figure 1 and, as it appeared to each subject in both the stimulus-reponse and in the concept learning tasks in Figure 2.

The panel was situated at a distance from the programming console of the GLA, in a small sound-treated room adjacent to the electrophysiological recording apparatus.

Electrophysiological Apparatus: A standard Offner eight-channel, ink recording TYPE R DYNOGRAPH was used to measure, amplify and record the electrophysiological activity in the form of electromyograms (EMGs). One channel each was used to record the direct EMGs of the left forearm extensor muscle, the right forearm extensor muscle, and the speech muscles. One channel each was used to record the integrated EMGs of the three direct EMGs. The integrated EMGs were proportional to the average number, amplitude and duration of the impulses of the direct EMGs. The integrated EMGs, summing the positive and negative changes without reference to sign, were recorded in one direction from a predetermined base and were used for analysis. The direct recordings were used to monitor the integrator channels, and thus avoid the spurious scoring of artifacts due to lead movement or other events not directly related to muscle tension. For each area of measurement, left and right forearm extensor muscles and speech muscles, two electrodes were used (Offner type 350069 surface electrodes). The two electrodes were spaced two inches apart, centre to centre. This electrode placement procedure has been described as a bipolar lead, or, recording from two points, both of which are active (Davis, J.C., 1959). In addition, one ground electrode was attached to the inside surface of the left forearm of the subject.

Procedure (Electrophysiological): The specific positions for the two electrodes over the left forearm extensor muscle and for the two electrodes over the right forearm extensor muscle were determined in the following manner. A point, on a straight line, one-third of the distance from the lateral humeral epicondyle (elbow) to the styloid process of the ulna (wrist) was determined. The first electrode was centered over this point. A second point was determined two inches in the distal direction from the first point. The second electrode was centered over this point. The specific positions for the two electrodes over the speech muscles were then determined as follows. On the midline of the chin a point three-quarters of an inch above the point of the chin was determined. The first electrode was centered over this point. On the midline of the chin a point three-quarters of an inch below the point of the chin was determined. The second electrode was centered over this point. These electrode positions have been shown to be the optimal anatomical positions to measure the electrophysiological activity, in the form of surface EMGs. The detailed anatomical considerations accounting for the determination of the electrode positions have been reported by J.C. Davis (1959).

After the seven electrodes were positioned the subject was seated comfortably in an arm chair in front of the subject panel. The subject was instructed to sit quietly and relax while the experimenter adjusted the recording apparatus. The skin resistance for each pair of electrodes was then measured. If the resistance for each of the three pairs of electrodes was less than ten kilo-ohms the subject was used. The subject was replaced if the skin resistance for any one pair of electrodes was in excess of ten kilo-ohms. Following determination of the skin resistance the subject rested for approximately ten minutes during which the dynograph was adjusted to measure and record the direct and integrated EMGs. After this adjustment period a two minute recording was made of the six channels while the subject remained in the resting position. The recording was made, as were all recordings, at ten milimeters per second. The purpose of this pre-experimental recording was to determine base levels for comparison with those obtained while the subject performed the experimental task. On completion of the pre-experimental recording the subject was instructed in the experimental task procedure. This procedure varied for the three different experimental tasks as follows.

Procedure (Experimental Tasks) : Motor Learning Task : The subject was instructed to depress and release the response button directly below each orange light as it came on. This procedure consisted of 72 orange light presentations ; i.e., each of the six orange lights was presented in random order 12 times. The duration time for the orange light and inter-trial interval was 4.00 seconds each. The physiological responses were recorded continuously throughout the experimental task.

Stimulus - Reponse Learning Task : The subject was instructed to learn six randomized connections between the six white lights and the six response buttons ; e.g., white light 6 to response button 2. This procedure consisted of 144 trials as follows. For any one trial the white light came on for eight seconds. During seconds five through eight of this eight second period the appropriate orange light came on. The orange light signalled the correct response button that the subject would have to depress for a correct response. The inter-trial interval, time between white light presentations, was 4.00 seconds. This white and onrange light presentation procedure was

operationally defined as a delayed procedure. Each of the six white lights was randomly presented 24 times in the 144 trials and was followed always by the appropriate orange light. This delayed procedure was used to allow the subject to respond before the orange light came on. Thus, the empirical criterion of 100 per cent learning, 12 consecutive correct responses before the orange light, where each white light had appeared twice, was established. It has been shown by Ladd (1965) that subjects respond consistently before the orange light in this 4.00 second delayed procedure. In addition, Ladd found that subjects learned to criterion within 72 trials on the average. The physiological responses were recorded continuously throughout the experimental task.

Concept Learning Task : The subject was instructed to find out and learn the connection between 12 white light pairs and the six response buttons ; e.g., white light pair 6, and 1 to response button number 5. The concept was numeric, that is the larger minus the smaller. This procedure consisted of 144 trials as follows. For any one trail the white light pair came on for eight seconds. During seconds five through eight of this eight second period the appropriate orange light came on. This white light pair and orange light presentation was operationally defined, again, as a delayed procedure. The orange light signalled the correct response button the subject would have to depress for a correct response. The inter-trial interval, time between white light pair presentations, was 4.00 seconds. Each of the 13 white light pairs was randomly presented 12 times in the 144 trials and was followed always by the appropriate orange light. The delayed procedure was used, again, to allow the subject to respond before the orange light came on. Thus the empirical criterion of 100 percent learning, 12 correct consecutive responses before the orange light, where each white light pair had appeared once was established. It had been determined previously by Schiech (1965) that subjects learned to this criterion in the problem-solving task within 72 trials on the average. For each subject in each of the three learning tasks the physiological responses and the appropriate empirical task events (white light onset, offset and/or orange light onset, offset, the response and the inter-trial interval) were ink-recorded simultaneously on the same chart paper. This, in turn, has allowed for a precise and critical evaluation, for each subject, of the relationship between the physiological responses and the experimental task.

Results : The three physiological responses, active arm (the arm used to depress and release the response button), passive arm and speech, were, in each case, the mean microvolt variations from zero for blocks of six trials. There were 12 such measurements for each of the three physiological responses for each of the three subjects in the motor learning task. There were 24 such measurements for each of the three physiological responses for each of the three subjects in both the stimulus-response learning and the concept-learning tasks. The physiological responses were determined from the integrated recordings for each of the nine subjects. The individual physiological response of the passive arm and of speech was determined by measuring the average height of pen deflection from the base-line, in millimeters, for each complete trial. That is, from the onset of one orange light to the onset of the next orange light for each of the three subjects in the motor learning task ; and, from the onset of one white light to the onset of the next white light for each of the three subjects in both the stimulus-response and concept learning tasks. The physiological response of the active arm was determined by measuring the average height of pen deflection, in millimeters, from the base-line during the inter-trial interval. That is, from the off-set of one orange light to the onset of the next orange light in the motor learning task ; and, from the off-set of the white light (s) to the onset of the next white light (s) in the other two learning tasks. It was felt that by measuring the physiological response of the active arm during the inter-trial interval only, the effect of physical work (depressing and releasing the response button) on the physiological response would be minimized.

The measurement, average height of pen deflection from the base in millimeters, for each trial and for each of the three physiological measures was a straight line-of-best-fit parallel to the base. The distance between the base and line-of-best-fit was then measured in millimeters. This same procedure was used to determine the pre-experimental base-levels for each of the three physiological responses and for each of the nine subjects. These measurements were determined in the last 12 seconds of the two-minute pre-experimental recording. The subjects were not engaged in the experimental task during the pre-experimental recording. These data, in millimeters, were then converted to microvolts of pen deflection for each trial, for each of the three physiological measures, and for all the subjects. This was done by multiplying the millimeters of pen deflection by micro-volts per millimeter. The micro-volts per millimeter of deflection were determined individually for each of the three physiological responses of all subjects in terms of the sensitivity settings of the equipment required to obtain adequate recordings. The appropriate pre-experimental base-level in microvolts was then subtracted from each physiological response for each trial, for all subjects. This procedure reduced the three physiological responses to the same zero point of microvolts relative to the three experimental tasks. Thus, the microvolt variation in the physiological response during the experimental tasks could be attributed only to the subjects' participation in the task.

The individual physiological responses in microvolts for each trial, for each physiological response and for each subject were then summed and averaged for each block of six trials. This average is now referred to as the *mean* physiological response for each of the three physiological measures ; i.e., active arm, passive arm and speech. The total mean physiological response of each of the three electrophysiological measures for each of the three subjects in the motor learning task was then determined. This was accomplished by summing the 72 physiological responses for each electrophysiological measure and then taking the mean. These three means are referred to as the *net* physiological responses. The net physiological responses were then determined by the same procedure for each electrophysiological measure for each of the three subjects in both the stimulus-response learning and the concept learning tasks. These results are presented in Table 1.

Table 1

Net Physiological Responses in Microvolts

Subject	Active Arm	Passive Arm	Speech
Motor learning No. 1	1.59	–5.00	4.19
Motor learning No. 2	6.07	0.00	–0.57
Motor learning No. 3	11.47	16.66	12.89
Stimulus-Response Learning No. 1	67.24	7.05	20.08
Stimulus-Response Learning No. 2	41.81	7.55	9.21
Stimulus-Response Learning No. 3	3.36	–2.02	24.03
Concept Learning No. 1	43.48	65.45	33.05
Concept Learning No. 2	106.90	90.57	17.26
Concept Learning No. 3	12.50	9.03	23.19

An analysis of variance was done on the data in Table 1 to determine if the difference among the net physiological responses over the three experimental procedures were significant. The results of the analysis of variance indicate that the difference in the net physiological responses over the three experimental tasks were significant at the 0.05 level. This result indicates a significant increase in the net physiological responses from the motor learning task, to the concept learning task. These results are clearly demonstrated by comparing the same physiological response for the same trial, for one subject in each of the three tasks. A comparison of the integrated speech response for one subject from each task during trial number 48 is presented in Figure 3. The defection in each case is from the base level.

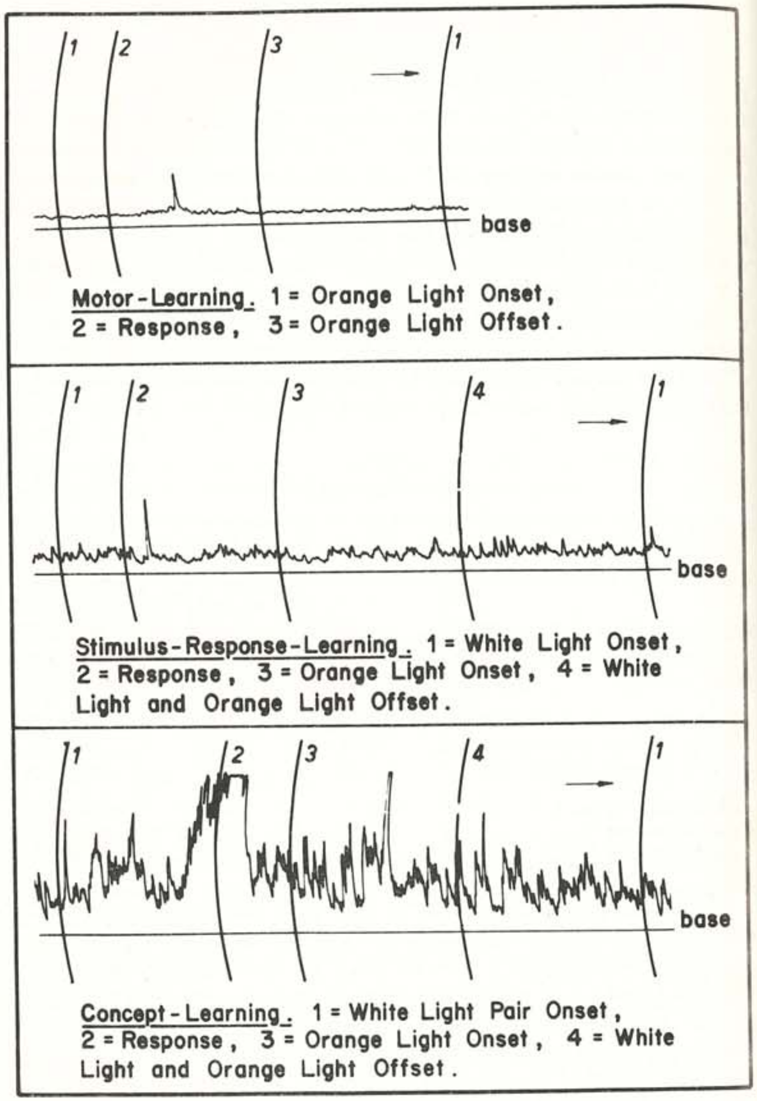


FIG. 3

A comparison of the integrated EMGs from the speech muscles during trial number 48 for one subject in each of the three experimental tasks. The trace is from the same mechanical base in each case

Table 2

Analysis of Variance of the Net Physiological Responses

Source of Variation	df	Ms	F Ratio
Between subjects	8		
A (Experimental Tasks)	2	3,563.59	3.58*
Subjects Within Groups	6	994.56	
Within Subjects	18		
B (Physiological Responses)	2	662.46	
AB	4	542.16	
B × Subjects Within Groups	12	409.80	

* $F_{.95}(6,2) = 3.46$

The lack of significance of the main effect between the three physiological responses is accounted for by the close similarity of the three physiological responses for each subject in the motor learning task ; by the close similarity of at least two of the physiological responses for each subject in the stimulus-response task ; and by the fact that at least two of the physiological responses for each subject in the concept learning task show a close similarity, (see Table 1). The results of the analysis of variance are presented in Table 2.

A Newman-Keuls analysis was performed on the difference between the physiological responses for the three experimental tasks, main effect A. These results indicate that differences in the net physiological responses between each of the three experimental tasks were significant. That is, the net physiological responses in the motor learning task were significantly less at the 0.05 level than in both the stimulus-response learning and concept learning tasks. The net physiological responses in the stimulus-response learning task were significantly less at the 0.05 level than for the concept-learning task. These results are presented in Table 3.

The results of the Newman-Keuls test on the net physiological responses are very meaningful when it is considered that the three net physiological responses for each subject, when combined, yield a relative percentage indication of the total electrophysiological activity in the skeletal musculature during task performance. Thus, participation in the motor learning task required significantly less electrophysiological activity than did participa-

Table 3

Tests of Means of the Net Physiological Responses Using Newman-Keuls Procedure

Tasks	Motor Learning a_1	Stimulus-Response Learning a_2	Concept Learning a_3
Ordered Means	15.77 a_1	59.29 a_2	133.81 a_3
a_1	Differences Between Means	43.52	118.04
a_2			74.52
	$S_{\bar{A}}$ = 10.47	r = 2	r = 3
	$q_{.95}(r,6)$ =	3.46	4.34
	$S_{\bar{A}}q_{.95}(r,6)^{*}$ =	36.23	45.44
	$q_{.99}(r,6)$ =	5.24	6.33
	$S_{\bar{A}}q_{.99}(r,6)^{**}$ =	54.86	66.27

	a_1	a_2	a_3
a_1		*	**
a_2			**

tion in either the stimulus-response learning or the concept-learning tasks. Further, participation in the stimulus-response task required significantly less electrophysiological activity than did participation in the concept learning task. These differences in the net physiological responses are presented graphically in Figure 4.

Discussion : It is important, first, to restate that the magnitude of each of the three net physiological responses for each of the nine subjects was determined from the same relative zero point. This was accomplished by subtracting the appropriate pre-experimental base-level from the net physiological responses. Therefore, the differences between the net physiological

---

1 WINER, B.J. *Statistical Principles in Experimental Design.*

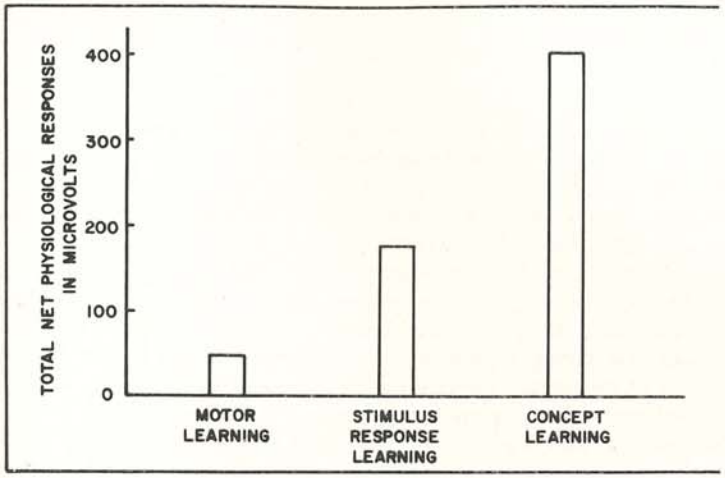


FIG. 4

A comparison of the total net physiological responses in microvolts (sum of active arm, passive arm and speech net responses) of all three subjects for each experimental task.

responses in the three experimental tasks can be discussed in terms of the demands and complexity of the tasks. The discussion of the results is prefaced, further, by the writers' theoretical position on the meaning of the physiological responses in relationship to performance. The physiological responses as measured and quantified in this research are, at least, a relative percentage indication of the *total central physiological activity* required of the subjects to successfully perform the different experimental tasks. This theoretical position is set out in the assumptions listed below.

1) Task performance is controlled by the development of a specific and organized central process.
2) This central process not only controls the immediate stage of performance, but also „anticipates" later stages.
3) The particular level (magnitude) of central organization depends not only on the duration of previous activity, but also on the complexity of the task.
4) The central process has properties very similar to those postulated by Hebb (1955) for the „cell assembly" and phase sequence. In particular it

a) usually has a specific motor facilitation, and b) when well organized it will tend to diminish in, or cease activity altogether.

Through analysis of variance the increase in the magnitude of the physiological response between the motor learning task and the stimulus-response learning task was shown to be significant at the 0.05 level. This significant increase in magnitude is interpreted as meaning that performance of a complex learning task of a stimulus-response nature requires greater output in, and organization of the central processes than does performance of a motor learning task. That performance is controlled by the *development* of a specific and organized central process was shown by the continuous increase in magnitude of the physiological responses during acquisition. This would indicate that during acquisition both the level of central activity and the number of mechanisms involved was an increasing function. Then, with the establishment of asymptotic performance the response showed a rapid decrease and then levelled out. This rapid decrease and levelling out is attributed to the assumption that learning was complete or organized and the level of central activity and/or the number of mechanisms required to maintain learning diminishes. The assumption that performance is controlled and anticipated centrally is supported by the immediate and sharp decrease seen in the responses prior to continued asymptotic performance. This prior decrease is, further, a clear indication that learning centrally precedes the overt or performance activity, and *is relatively independent of sensory stimulation.* This idea was first postulated by Smith (1953).

It was demonstrated in the concept learning task that the three physiological responses for each subject showed a relationship to performance. The relationships were : 1) a substantial increase in the magnitude of the responses during acquisition ; 2) a general decrease in the magnitude of the responses following acquisition of the concept ; 3) a relatively high and random activity in the responses after the initial decrease. Analysis of variance showed that the increase in magnitude of the physiological responses between the motor learning task and the concept-learning task was significant at the 0.01 level. The increase between the stimulus-response learning task and the concept-learning task was significant, as well, at the 0.01 level. These significant increases in magnitude are interpreted as indicating that the performance of a complex learning task of a cognitive nature requires greater output in, and organization of, the central processes than does the performance of either a stimulus-response learning task or a motor learning task. In terms of the assumptions listed previously, the significant differences give empirical support to the assumption that : the particular level (magnitude) of central organization depends not only on the duration of previous activity, but also on the complexity of the task. The increases in the physiological responses during acquisition are interpreted as signifying the development of a specific and organized central process necessary to comprehend and successfully perform the concept learning task. That is, during acquisition both the level of central activity and number of mechanisms involved is an increasing function. The decreases in the magnitude of the responses with the acquisition of the concept are interpreted as meaning that once learning has been achieved the level of activity and/or number of mechanisms of the organized central process necessary to maintain learning is greatly reduced. The assumption that performance is controlled and anticipated centrally is supported, again, by the decreases in the responses prior to continued asymptotic performance. The relatively high and consistent random activity of the physiological responses following acquisition is attributed to the nature of the task. That is, the subject must continuously mediate, use the concept to perform successfully in the problem-solving task. This results in an increased level or central activity during over-learning when compared to the responses in the stimulus-response learning task during over-learning. This activity during over-learning clearly differentiates the concept-learning task from the stimulus-response task.

The lack of any significant differences between the three physiological responses (active arm, passive arm, and speech) within subjects is interpreted as supporting the theory that the physiological responses are a relative percentage indication of the total central physiological activity required to perform the experimental tasks. If this were not so one might expect to get significant differences between the physiological responses, at least between the responses of the active arm and the other responses.

In relation to previous research the present results of the stimulus-response and concept learning tasks are, for the most part, markedly different. The majority of previous research has shown that the physiological responses (physiological gradients) have been relatively smooth, monotonically increasing responses during acquisition (Malmo, 1965). In contrast, the present research shows that the physiological responses are generally highly variable during acquisition. This difference is attributed to the difference between the current and previous experimental tasks ; i.e., complex learning tasks versus perceptual-motor tasks. In general it was felt that the present study supports the theory that the electrophysiological activity in the skeletal muscles during performance of complex learning tasks is a relative indication of the total central activity required to successfully perform the tasks. This relative activity in the muscles is probably accounted for, in part, by the sensitive gamma efferent system or, muscle-spindle feed back circuits, and would presumably be mediated between the higher cortical areas and periphery by the ascending reticular activating system and the descending reticular facilitatory system (Magoun, 1964).

REFERENCES

BASMAJIAN, J.V. : Normal electromyography. Reprinted from *Muscle*, Proceedings of the symposium held at University of Alberta, June, 1964 : Pergamon, 1965.

CERVIN, V. B., SMITH, A. A., & KABISCH, C. H. : Multiple S-R apparatus for individual and social learning. *Psychol. Reports,* 1965, 17, 499-510.

DAVIS, J. F. : *Manual of Surface Electromyography.* WADC Technical Report 59-184, Aerospce Medical Laboratory, Wright-Patterson Air Force Base : Ohio, 1959.

HODGKIN, A. L. : *The Conduction of the Nervous Impulse.* Liverpool, Liverpool University Press, 1964.

LADD, H. W. : *Individual learning as a function of the interstimulus interval in a delayed classical procedure.* Unpublished M. A. thesis, University of Windsor, 1965.

MAGOUN, H. W. : *The Waking Brain* (2nd ed.). Springfield : Charles C. Thomas, 1964.

MALMO, R. B. : Physiological gradients and behavior. *Psychol. Bull., 1965,* 64, 225-234.

SCHEICH, S. M. : *A study of rule and rote learning under classical and operant arrangements.* Unpublished M. A. thesis, University of Windsor, 1965.

SIDOWSKI, J. B. (ed.) : *Experimental Methods and Instrumentation in Psychology.* New York : McGraw-Hill, 1966.

SMITH, A. A. : An electromyographic study of tension in interrupted and completed tasks. *J. exp. Pschol.,* 1953, **46,** 32-36.

THOMPSON, R., LINDSLEY, D., & EASON, R. Physiological Psychology. In : *Experimental Methods and Instrumentation in Psychology.* J. Sidowski (ed.) New York : McGraw-Hill, 1966.

WINER, B.J. : *Statistical Principes in Experimental Design.* New York : McGraw-Hill, 1962.

From the Medical Clinic of the University of Bonn
(Director : Prof. Dr. A. Heymer)

ELECTROMYOGRAPHIC STUDIES ON THE EXCITABILITY OF MOTONEURONS UNDER THE EFFECT OF PSYCHIC AND PHARMACOLOGICAL INFLUENCES

H. JÖRGENS and R. HORMANN

Since the early investigations of Sherrington and Paul Hoffmann and those of Lloyd in the early 1940s on the mechanism of reflexes, the electrically induced reflex or H-reflex has been the subject of numerous publications. In particular, we should like to call attention to the monograph of Paillard (1955) which was followed by many studies on special problems of the H-reflex. Also there should be mentioned the investigations on alterations of the H-reflex in spastic patients (Angel & Hofmann 1963, Zschocke & Brune 1965, Birkmayer et al. 1967). The aim of these studies was to find out or to test drugs which will diminish the spasticity and ameliorate limb motility. Our own investigations may provide a contribution to further research and therapy in spastic conditions, and it seems appropriate, therefore, to present the results of our studies on motoneuron excitability at this „Meeting of Electromyographic Kinesiology". Our experimental findings should give some answer to the questions

a) wich are the variations of the H-reflex in normal persons,

b) whether and to what degree the H-reflex or the motoneuron excitability resp. may be influenced by neurotropic drugs, and

c) whether the usual method of testing will provide sufficiently reliable and comparable data.

For stimulation we used the Multistim of DISA, Copenhagen, and - as different electrode - a silver disk which we fixed upon the skin in the popliteal fossa at that site of the popliteal nerve where we achieved the maximal reflex by stimulating with rectangular currents of 1 msec duration. The reflex action potentials were led off by means of superficial electrodes from the soleus-gastrocnemius-group, and were amplified by an electromyograph (Elektrophysik, Bad Godesberg) and registered by means of a Mingograf (Elema-Schönander, Stockholm). The subjects were placed prone on a padded couch in a position as comfortable as possible ; the legs were fastened to a support. For stimulation we chose that intensity which produced a reflex amplitude of approx. 60 % of the maximal amplitude and stimulated with a constant frequency of 0.1/sec, in order to avoid interferences which might - during the interval between two stimulations - come into play by way of polysynaptic tracts.

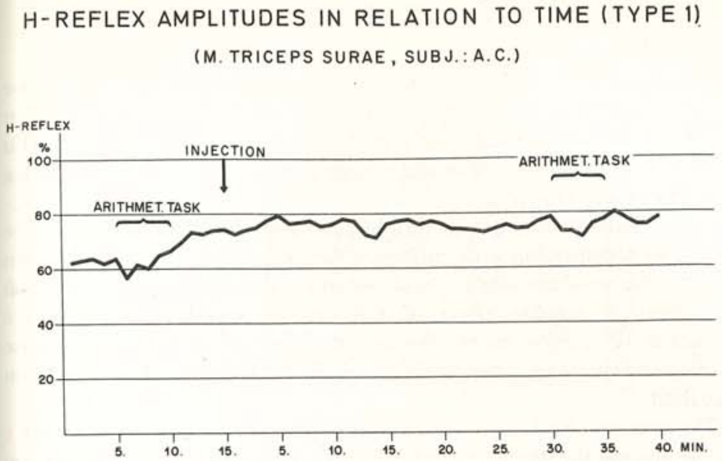
The first slide demonstrates the result of such an investigation of our first test series. Each point of this curve represents the mean value of the 6 reflex amplitudes per minute. The time is plotted on the abscissa ; a 5-minute period of rest was followed by 5 minutes in which the volunteers had to add, as quickly as possible, some simple figures, which were projected against a wall ; after another period of 5 minutes of rest, a test drug was injected intramuscularly, and then we observed the development of the H-reflex during the following 30 minutes with the subject at rest ; a period with arithmetical tasks and 5 minutes under resting conditions concluded the test.

You will see from the example that there is a definite increase of about 10 % in the amplitude of the reflex during the first 10-12 minutes. After the injection, no significant further increase is observed ; apart from slight oscillations in both directions, in three sites you see a more marked decrease of the amplitude, two of these coinciding with the phase of the arithmetical task or with the beginning of this calculation phase resp..

Slide No 2 shows another example with similar alterations, but with oscillations of much greater amplitude, with a more striking reduction of the amplitudes at the start of the arithmetic task. Besides that there is a distinct trend to higher amplitudes after these periods, the amplitudes after the injection reaching nearly four times those observed in the first 10 minutes.

For further analysis we compared the reflex reaction of a group of 6 volunteers who received 15 mg of „Pervitin" – a stimulant drug of the ephedrine-benzedrine group – with another series of 6 subjects who received placebo ; there were no significant differences. This is shown by slide No 3 in which the mean values of the amplitudes of the various periods are plotted side by side. Differences between the single periods, however, are significant (pH 0.01 by the FRIEDMAN-test) ; at the beginning of or during the periods with mental activity, we find the lowest amplitudes and subsequently the higher ones.

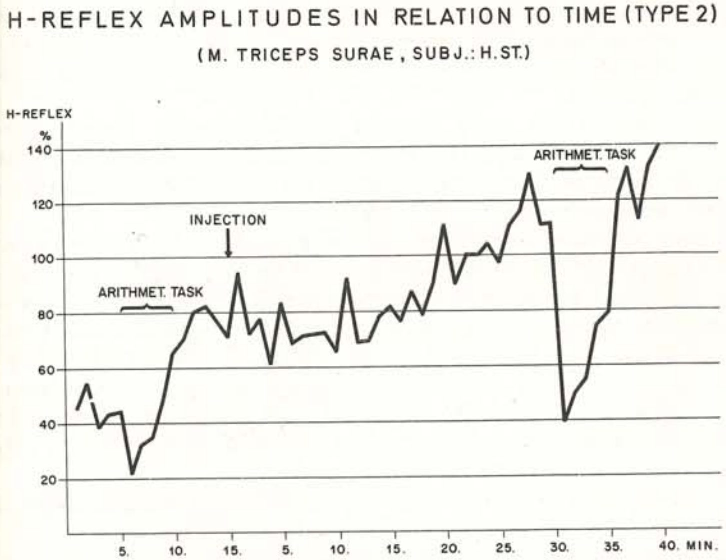
If one observes the original amplitudes of the H-reflex during the arithmetic periods and not the mean values per minute, it becomes obvious, that the sudden decrease at the beginning of the calculations is followed by a gradual increase of the reflex amplitudes reaching or even exceeding the


H-REFLEX AMPLITUDES IN RELATION TO TIME (TYPE 1)

(M. TRICEPS SURAE, SUBJ.: A.C.)

FIG. 1

Mean values of H-reflex amplitudes (6 amplitudes each minute) in the volunteer A.C.– During the "arithmetic task" the subject had to add some simple figures as quickly as possible. "Injection" = at the arrow a test drug was injected.


H-REFLEX AMPLITUDES IN RELATION TO TIME (TYPE 2)

(M. TRICEPS SURAE, SUBJ.: H.ST.)

FIG. 2

Diagram like fig. 1 ; volunteer H.St.

initial values. For statistical validation of this "arithmetic effect" we compared the amplitudes of the last minute of rest with those of the first minute of the arithmetical task, both before and after the injection. This confirmed that the effect of mental activity consists in a diminution of reflex excitability (slide No 4).

In this slide the two groups with placębo and with "Pervitin" resp. were considered together, since no difference between the two groups had been detected. We were not able to decide whether "Pervitin" has no effect at all or whether a possible effect of this drug is superimposed upon the "spontaneous" trand of the H-reflex amplitude to increase with time. Because of this observation we chose another method of determining the motoneuron excitability.

The next slid (No 5) shows a stimulus-response-curve, as it is well known : On the abscissa the stimulation intensities are plotted in relative units, and on the ordinate the H-reflex amplitudes. The curve on the left represents the development of the H-reflex which, after reaching a maximum, is becoming smaller and smaller and finally disappears as the motor reaction increases obtaining its maximum with maximal and supramaximal stimuli on the right.

The observation of the first test series that the H-reflex amplitude gradually increases with constant stimulus intensity indicates that a reaction of a specified degree is achieved by a stimulus of progressively less intensity. The curves here demonstrated would thus shift to the left during the course of the experiment.

Moreover, it was to be expected that unforeseeable changes at the periphery – such as displacement of the electrodes – would affect the reflex and the motor reactions in quite a similar way so that the ratio between the maxima of the two curves would not be altered essentially.

Slide No 6 demonstrates the reflex activity of a subject during about 50 minutes. One discerns the displacement of the curves to the left as well as the increase of the maxima – especially in curve B as compared to curve A –, that is an augmentation of the reflex amplitude as well as of the motor reaction. The ratios RR_{max}/MR_{max} have, in this case, changed only slightly ; in other cases, however, one has to expect greater variations, as you will see in the following table (slide No 7). Subject No 9 is a female volunteer who showed marked psychic tension at the beginning of the test and only gradually came to a resting condition.

The fact, that there may be some change of the ratios during the course of the investigation led us to take into account the influence of the factor 'time' by an analysis of variance in a following series.

On 8 persons (neurologically healthy female students) we performed 6 investigations, with intervals· of at least 8 days, on each subject. Each

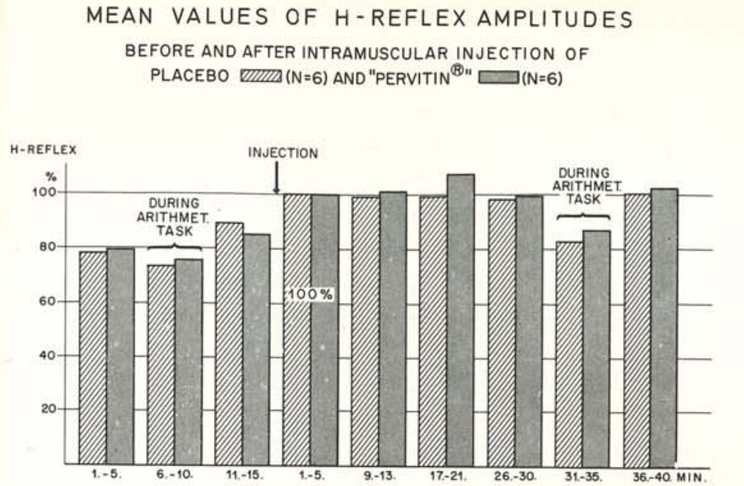


FIG. 3

Mean values of H-reflex amplitudes in a group of 6 subjects who received placebo and in another group of 6 equally healthy persons who received Pervitin (an ephedrine-benzedrine derivative). The whole time of investigation has been divided into 5 minute periods. In all the volunteers the mean amplitude of the first 5 minute period after the injection of the drug or the placebo has been taken as 100 %.

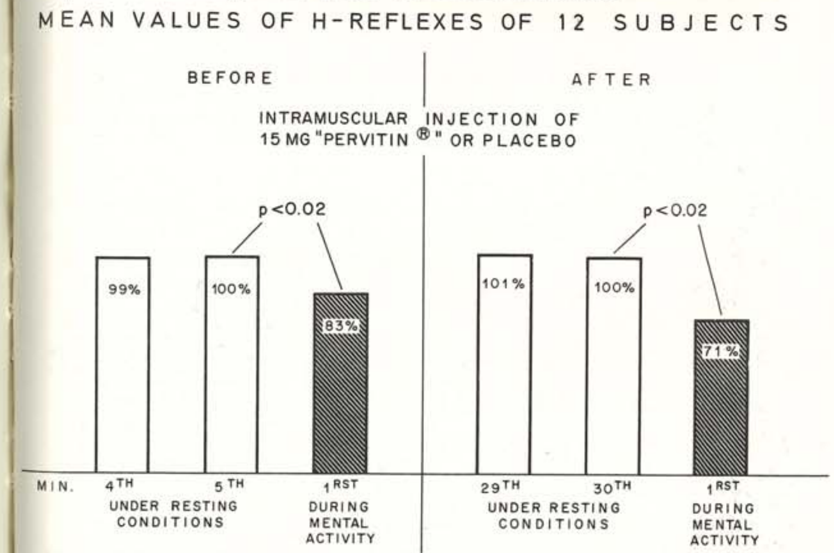


FIG. 4

Mean values of H-reflex of 12 volunteers who received Pervitin or placebo in the two last minutes before and in the first minute during the arithmetical task (= "mental activity"). The diminution of reflex excitability during the calculations is statistically significant.

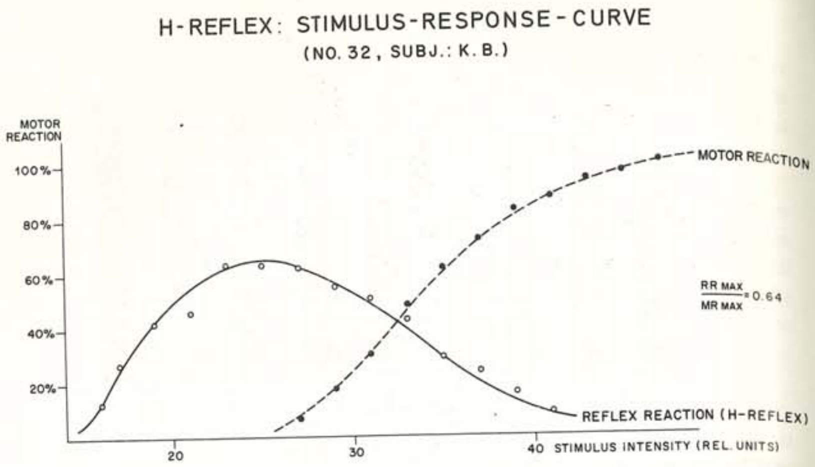

H-REFLEX: STIMULUS-RESPONSE-CURVE
(NO. 32, SUBJ.: K. B.)

FIG. 5

Stimulus-response curves of subj. K.B.– The height of the H-reflex (= reflex reaction) and of the M wave (= motor reaction) has been plotted against shock intensity.

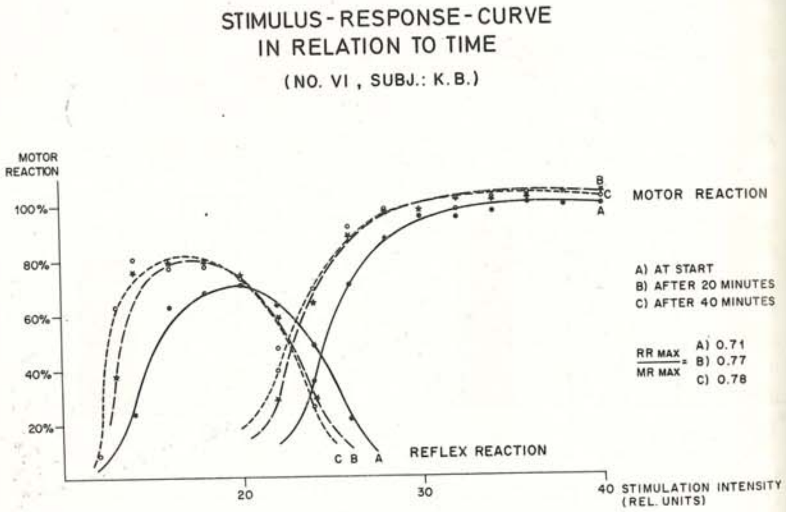

STIMULUS-RESPONSE-CURVE
IN RELATION TO TIME
(NO. VI, SUBJ.: K. B.)

FIG. 6

Stimulus-response curves of subj. K.B. showing the increasing amplitudes and the shift to the left of the curves during the course of the experiment.

SUBJECT	PERIODS			
	1	2	3	4
1 K.B.	0.94	0.94	0.96	0.94
2 S.M.	0.98	0.99	0.97	0.99
3 R.J.	0.93	0.87	0.88	0.90
4 B.D.	0.65	0.62	0.58	0.58
5 R.D.	0.77	0.76	0.70	0.73
6 H.J.	0.59	0.54	0.52	0.53
7 I.K.	0.98	0.92	0.89	0.89
8 G.Z.	0.90	0.88	0.90	0.90
9 M.G.	0.55	0.41	0.41	0.30

RATIOS OF MAX. H-REFLEX TO MAX. MOTOR REACTION UNDER RESTING CONDITIONS

IN FOUR PERIODS EVERY TWENTY MINUTES

TABLE 1

Ratios of maximal H-reflex to maximal M response (so-called H/M ratio) of nine female volunteers in four successive periods of one investigation (with intervals of 20 minutes).

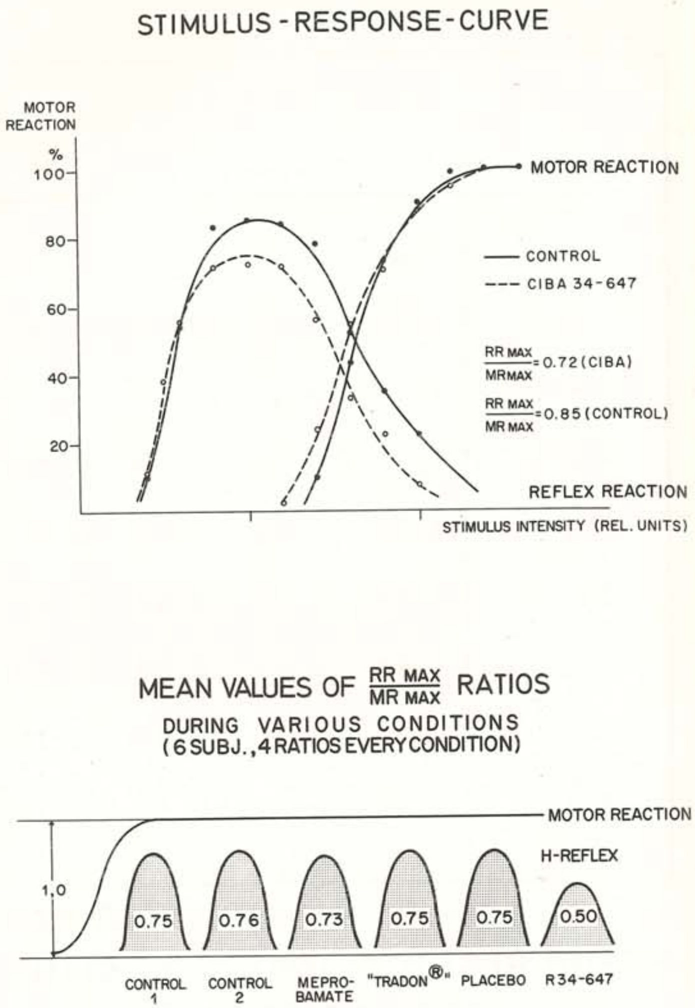


FIG. 8

Stimulus-response curves of volunteer K.B. a) control (without drug or placebo), b) under treatment with 40 mg of the gamma-Aminobutyric acid derivative CIBA 34'647-Ba (upper part).
Mean values of H/M ratios of 6 volunteers during various conditions. By analysis of variance, differences between the various drugs are significant, here only due to a decrease of the H/M ratio under CIBA 34'647-Ba (lower part).

investigation consisted in 4 determinations of the reflex excitability at intervals of 20 minutes. The first test was used for selection of the volunteers and to accustom them to the method of investigation. The second test served as a confirmation of the specific behaviour of the reflex excitability in each volunteer. Two hours before the 3rd and 4th tests each person received 2.0 g Meprobamate and 60 mg "Tradon" – an imino-oxo-oxalidine derivative – resp. Before the 5th investigation placebo was administered and before the 6th 40 mg of a derivate of the gamma-Aminobutyric acid (CIBA 34.647-Ba), a myotonolytic drug.

We found that, apart from expected individual variations, a) the different drugs have significantly drugs have significantly different effects ($p<0.005$) and b) the drug effect is significantly different from one individual to the other ($p<0.005$). Differences of the ratios RR_{max}/MR_{max} between the four periods, however, were not statistically significant, i.e. the factor 'time' without influence. – The last slide (No 8) shows, in the upper part, the alteration of the stimulus-response-curve and of the ratio under treatment with CIBA 34'647-Ba, illustrated by the findings in one volunteer. The lower part of the diagram demonstrates schematically the ratios of the stimulus-response-curve (mean values) in the 6 investigations. It is evident that the statistically significant difference between the various drugs is due only to a decrease of the ratio under the influence of the gamma-Aminobutyric acid derivative.

We summarize our results.

1) By the usual method of determining reflex excitability employed, (besides the oscillations around a certain mean value) one often observes a gradual increase of the mean value with time.

2) Since a drug may produce alterations of the same kind, it is difficult or impossible to distinguish these two effects and to determine whether and to what degree the increase in motoneuron excitability is due to the drug.

3) A diminution of the H-reflex amplitude during a mental-emotional activity, especially at its beginning, was confirmed. – This fact shows that psychic events may generally influence motoneuron excitability and that factors of this kind must be taken into account when testing reflex excitability.

4) These influences can be more or less eliminated, if reflex excitability is determined not by constant stimuli, but rather by increasing the stimulus intensity step by step. The ratio 'Maximal Reflex Reaction/Maximal Motor

Reaction' represents a measure for the motoneuron excitability and remains relatively constant under the circumstances investigated.

5) It was confirmed statistically that in healthy subjects the derivative of gamma-Aminobutyric acid CIBA 34'647-Ba markedly decreases the excitability of the alpha-motoneurons.

REFERENCES

ANGEL, R.W., and HOFMANN, W.W. (1963) : The H-reflex in normal, spastic, and rigid subjects. *Arch. Neurol.* (Chic). 8, 591-596.

BIRKMAYER, W., W. DANIELCZYK, and G. WEILER (1967) : Zur Objektivierbarkeit des myotonolytischen Effektes eines Aminobuttersäurederivates (CIBA34'647-Ba). *Wien, Med. Wochenschr.* 117. 7-9.

HOFMANN, P. (1910) : Beiträge zur Kenntnis der menschlichen Reflexe mit besonderer Berücksichtigung der elektrischen Erscheinungen. *Arch. Anat. Physiol. Abt.* 1910, 223-256.

Uber die Beziehungen der Sehnenreflexe zur willkürlichen Bewegung und zum Tonus. *Z. Biol.* 68, 351-370 (1918).

(1922) : *Untersuchungen über die Eigenreflexe (Sehnenreflexe) menschlicher Muskeln.* Berlin. Springer 1922.

LLOYD, D.P.C. (1943) : Neuron patterns controlling transmission of ipsilateral hind limb reflexes. *J. Neurophysiol.* 6, 293.

SHERRINGTON, Ch. (1906) : *The integrative action of the nervous system.* New Haven, Yale University Press 1906.

ZSCHOCKE, S., and G. BRUNE (1965) : Klinische und elektromyographische Studien über die pharmakologische Beeinflussung der Spastik. *Verh. dtsch. Ges. inn. Med.* 71, 662-665.

ELECTROMYOGRAPHIC KINESIOLOGY IN THE ANALYSIS OF WORK SITUATIONS AND HAND TOOLS

E.R. TICHAUER

Research Professor of Biomechanics
Institute of Rehabilitation Medicine
New York University Medical Center New York, N.Y., 10016, U.S.A.

Introduction

Man, when engaged in a work situation, is restricted to a motions inventory limited by constraints imposed by the physical characteristics of the working environment, including machinery and tools. The rational study of man as the monitoring link in a man-task system must by needs involve the conjoint consideration of muscular activity together with biomechanical correlates such as displacement, velocity and acceleration of moving limbs and/or objects handled. However, it is almost a tradition, albeit unfortunate, that since the commencement of the "Scientifica Management Movement", man in industry has been studied almost exclusively from the point of view of speed of motion as an index of performance efficiency. This led to the development of industrial motion and time study (1). The early efficiency experts, with the notable exception of Gilbreth (2), tended to overemphasize the need for the industrial worker to perform with high speed but did not concern themselves to any great extent with the effort required to maintain levels of productivity demanded by economic conditions.

It is the purpose of this paper to show how electromyographic kinesiology can be developed into a discipline contributing a new dimension to the scientific study of man at work. Indeed, this fast developing discipline may well become the tool of choice of rational workplace design ensuring that man moves effectively and at acceptable levels of physical well-being while performing at the same time at a rate of productivity which is economically desirable, so that the worker in industry shall become neither physically nor economically impaired or disabled.

This research is supported in part by the Social and Rehabilitation Service, Department of Health, Education and Welfare, under the designation of New York University as a Rehabilitation Research and Training Center.

Early Developments

The theory as well as the commonly employed techniques of electromyography are described in the comprehensive fashion by Basmajian (3). The same publication traces both the conceptual and scientific development of myography from Borelli (4) the founder of the iatro-mathematical school of medicine (and hence the father of physical medicine) through Duchenne (5) and Denny-Brown (6) to Inman, Saunders & Abbott (7).

Already some of the earliest electromyographic research dealt with such topics as the *Electromyographic Investigation of Position and Manner of Working in Typewriting* by Lundervold (8), *Man's Posture* by Joseph (9), weight lifting (10), and gait analysis (11, 12). However, the aforementioned studies were principally concerned with the development of electromyographic methodology per se and with the study of man only rather than with a more comprehensive analysis of the man-task system. Furthermore, the mainstream of electromyographic research concerned itself with clinical and medical aspects so that the application of electromyographic to work study proper received but little attention until 1963 when Tichauer (13) began to investigate changes in the kinesiology of the upper extremity when this limb performed as part of an arm-tool aggregate in connection with pliers and other implements commonly employed in the electronics industry.

It was observed that straight pliers as commonly employed in industry lead to ulnar deviation of the wirst resulting in restriction of range of pronation and supination, with associated lack of precision of manipulation and poor quality workmanship. In some industries there was also a tendancy to associate (albeit without objective proof) such ailments as tenosynovitis and carpal tunnel syndrome with a tool-enforced ulnar deviation (14) and it was decided that it would be more beneficial to bend the pliers instead of the wrist (Figure 1).

Subsequently, the biomechanical and electrophysiological correlates of this task situation were investigated on a simulated workplace at the Institute of Rehabilitation Medicine of New York University. Wrist positions analogous to the one in industry were enforced by constructing a dynamometer which was operated in one task situation by means of a T-handle (wrist straight) and in another situation with a straight screw-driver handle (ulnar deviation) (Figure 2). The device employed embodies an electrogoniometer which registers, by way of direct on-line signal conditioning, the angular displacement, velocity and acceleration of the dynamometer shaft simultaneously with the integrated biceps electromyogram of the operator.

It was found that, even at work loads which would be considered as very light indeed in industry, ulnar deviation as brought about by the screw-driver handle lead to a reduced range of supination, substantially depressed velocity and acceleration "signatures" and considerably increased levels of myoelectric activity. More effort was required to perform the task under paced conditions. Under self-pacing conditions, it was observed that the same task was performed at a much slower rate with even more depressed velocity and acceleration patterns while myoelectric activity tended to increase in proportion to the number of work cycles performed. Thus, the straight handle (e.g., ulnar deviation) did indeed reduce work tolerance (Figure 3).

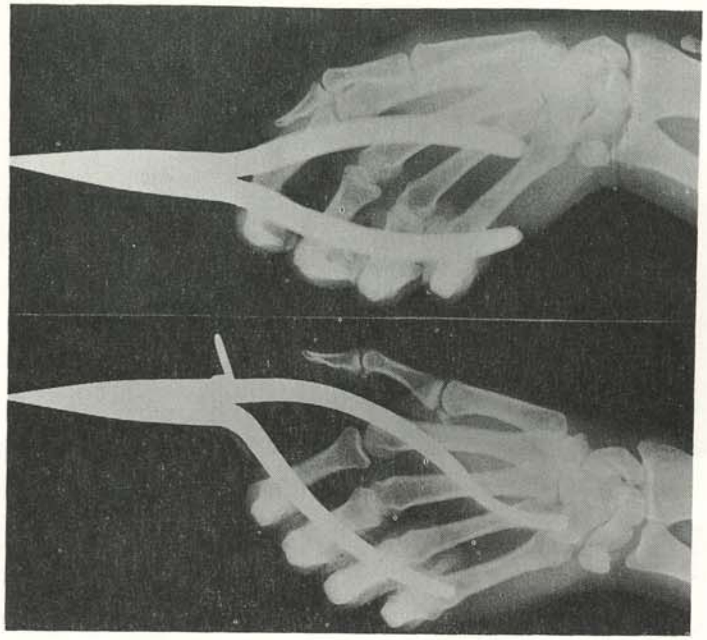


FIG. 1

An anatomically design of pliers (bottom) avoids excessive ulnar deviation. Conventional pliers forcing the hand to deviate towards the ulna while in working position are shown at top. Ulnar deviation limits range of pronation and supination and demands increased force and hence myoelectric activity to perform these maneuvers. From (13)

It was also noted that the highest level of myoelectric activity did not coincide with the peaks of velocity and acceleration but rather occurred when the tool was rotated at constant and volontarily sustained rates of angular displacement. It is suggested that the aforementioned and similar techniques

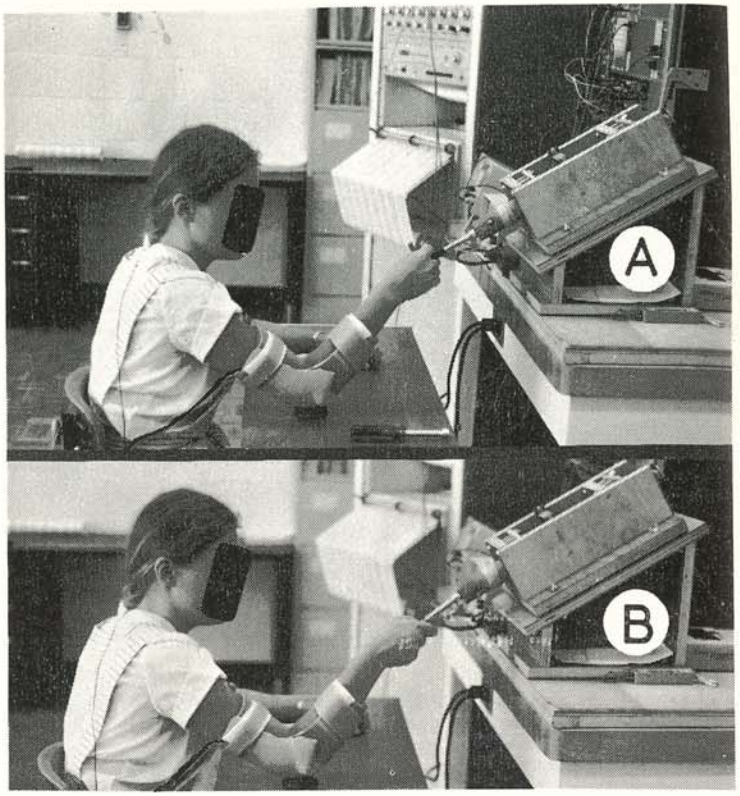


FIG. 2

Kinematometer measuring rotation of the forearm-tool aggregate
in pronation and supination.

A : Device connected to hand by means of a T-handle which keeps the wrist straight.
B : Hand engaged with instrument through a straight screw-driver handle which causes the wrist to be deviated towards the ulna.

The instrument records angular displacement, velocity and acceleration during pronation and supination at any instant, simultaneously with a surface myogram taken over the biceps muscle.

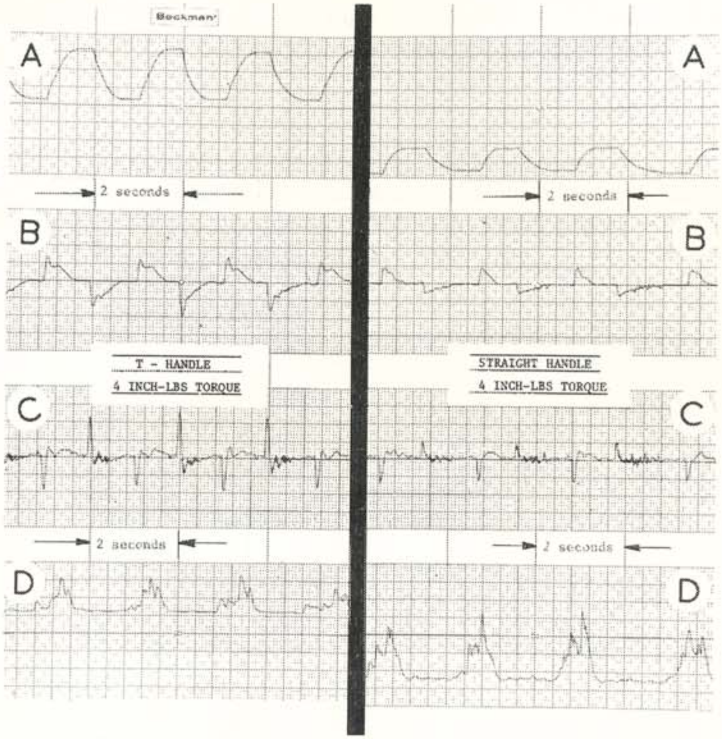


FIG. 3

Recording produced by subject shown in Figure 2 after 15 works cycles under self-pacing conditions.

A : Angular displacement (2 cms on ordinate are equal to 180 degrees of forearm rotation).
B : Velocity signatures.
C : Acceleration signature.
D : The integrated surface myograms of the biceps muscle.

It can be seen that straight handle (ulnar deviation) is conducive to the generation of twice the level of muscular activity in order to produce one half only of physical work output. 4 inch pounds of torque are the approximate equivalent of the force needed to turn the door knob.

can be usefully applied for the purposes of achieving a physiologically optimal alignment of forearm, hand and tools or other machine controles in order to avoid trauma and to achieve efficiency and well-being at the workplace.

Lifting Tasks : Stress conditions within the human body when lifting are essentially analogous to those of a crane (figure 4) (15).

Thus the true stress to be supported by the vertebral column, the sacrospinalis muscle and other structures cannot be represented simply by the weight of an object lifted. The true workload must be expressed in "inch pounds of torque" (or equivalent) multiplying the weight of an object handled combined with the weight of the body segments involved in the lifting process, with the distance of the center of mass of this aggregate from an anatomical reference point, e.g., the lumbo-sacral joint. Hence, lifting

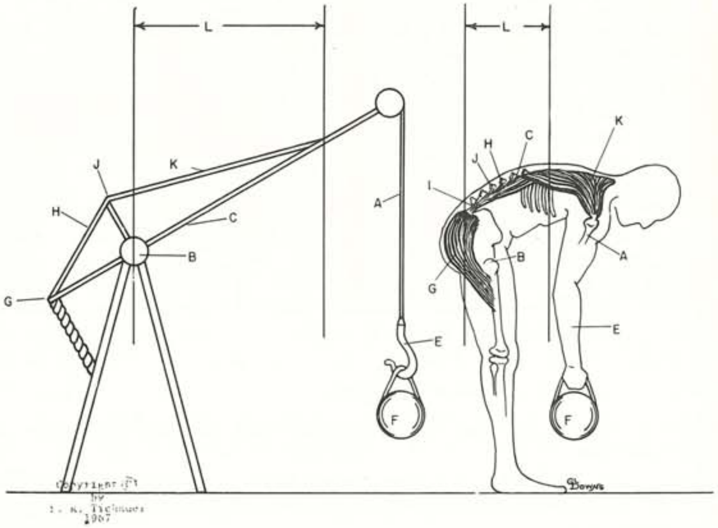


FIG. 4

In load lifting the structural elements of man are analogous to the structural elements of a crane. The same mathematical techniques can be applied to predict performance of either of them. Homologous components are labelled with identical letters. L equals distance from the center of mass of combined body load aggregate to the joints of the lumbar spine. From (15)

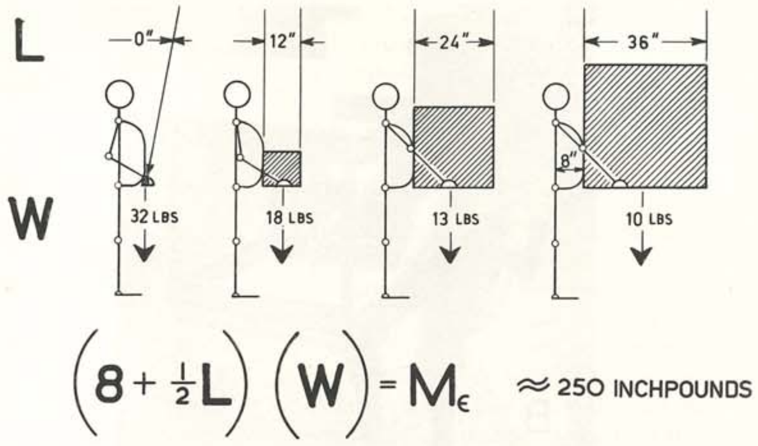


FIG. 5

The „moment concept" applied to the derivation of biomechanical lifting equivalents. All of the loads represented in the figure produce approximately equal bending moments on the sacro-lumbar joint (approximately 250 inch pounds).

8 = approximate distance in inches from the interzygapophyseal joints of lumbar spine to front of abdomen (i.e., a constant for each individual).

L : length of inches of one side of a cube of uniform density lifted during the standard task.

W : the weight in lbs the cube handled.

M_e : the biomechanical lifting equivalent (here approximately 250 inch pounds).

loads must always be evaluated in terms of moments and derived "biomechanical lifting equivalents" (Figure 5).

This is of special importance in todays electronic industries, largely dedicated to the building of delicate apparatus which has to be packed into protective and bulky containers for shipping. The effects of the "bulk/weight ratio" of a parcel on the severity of a lifting task can best be evaluated by using a double-differentiating hip joint goniometer in combination with surface electromyography over the sacrospinalis. Here again a goniometer developed from Rubenstein's earlier instrument (16) as ancillary apparatus permits the direct and simultaneous read-out of angular displacement, velocity, and acceleration of the femur about the hip joint (Figure 6).

This method was employed to evaluate changes in work stress caused by bulkier containerization. First, a load deemed acceptable for handling by women in industry under continuous working conditions, viz. 32 lbs, in the shape of a small metal ingot was lifted. Then the subject was handed a

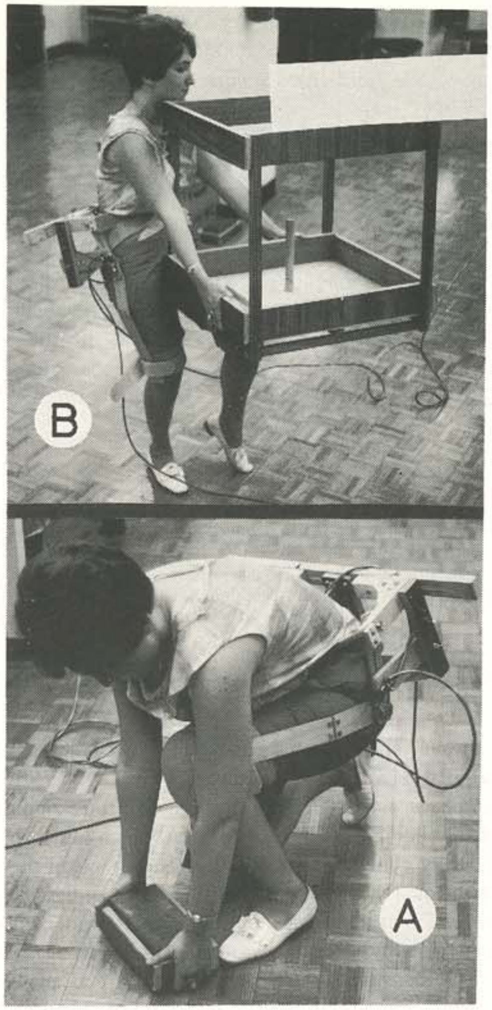


FIG. 6

A shows the lifting of a 32 lbs metal ingot while biomechanical and myoelectrical correlates are measured by means of a hipjoint kinematometer. B shows a much bulkier but lighter "load", exerting however a greater moment of torque on the lumbar spine when lifted.

30″ X 30″ X 30″ box frame weighing 10 lbs and the two lifting processes were compared. It was found that the process of lifting the ingot was relatively fast : the cycle time was approcimately 2 seconds from a standing position down to the floor through pickup and return to a standing position, putting the ingot down and rising to normal standing position again. Velocity peaks were observed at the beginning and at the end of the lifting movement and at no time during the entire work cycle was the velocity of lift constant.

The integrated myogram showed that sacro-spinalis activity and hence stress on the lumbar spine commenced approximately when the angular displacement of the femur above the ortho-axis of the hip joint changed in direction from flexion to extension, that the height of the integrated myogram was maximum when the torso was bent forward at an angle of approximately 45 degrees and moving relatively slowly, and that a second and lesser peak of myoelectric activity was reached shortly before the load was put down again. Then the torso was flexed at an angle of approximately 60 degrees to the vertical and flexion of the thighs about the hip joint was relatively fast. After this, electro silence returned fairly rapidly.

When the empty crate weighing only 10 lbs was handled, the general pattern, phasing, and activity of the surface myograms with respect to its biomechanical correlates was essentially the same as in the case of the 32 lbs ingot, so that it can be said that the lighter but bulkier object constituted a biomechanical lifting equivalent of the heavier but much smaller metal article. However, when the empty crate was weighted to only 15 lbs, a dramatic change occured, the lifting process now took two and a half times as long, the area under the integrated myogram as well as the peak of the recording increased considerably and the "velocity signature" showed distinct segments of almost constancy of angular velocity. Otherwise, the basic pattern of phasing was unchanged.

Finally, when the box was further weighted 30 lbs thus approaching the weight of the ingot (32 lbs) the effect of the increase became even more noticeable. Now the lifting time was about three times the original, the peaks of the velocity curves were much depressed and, in fact, myographic as well as mechanical correlates displayed clear and strong bursts of effort shortly before putting the now bulky load down.

It could be deduced from the height, duration and pattern of the surface myogram over the sacro-spinalis that physical work stress acting on this muscle during the handling of a bulky load may be considerably greater than when a dimensionally smaller object of equal weight is being handled (Figure 7).

This methodology shows definite potential for development into a

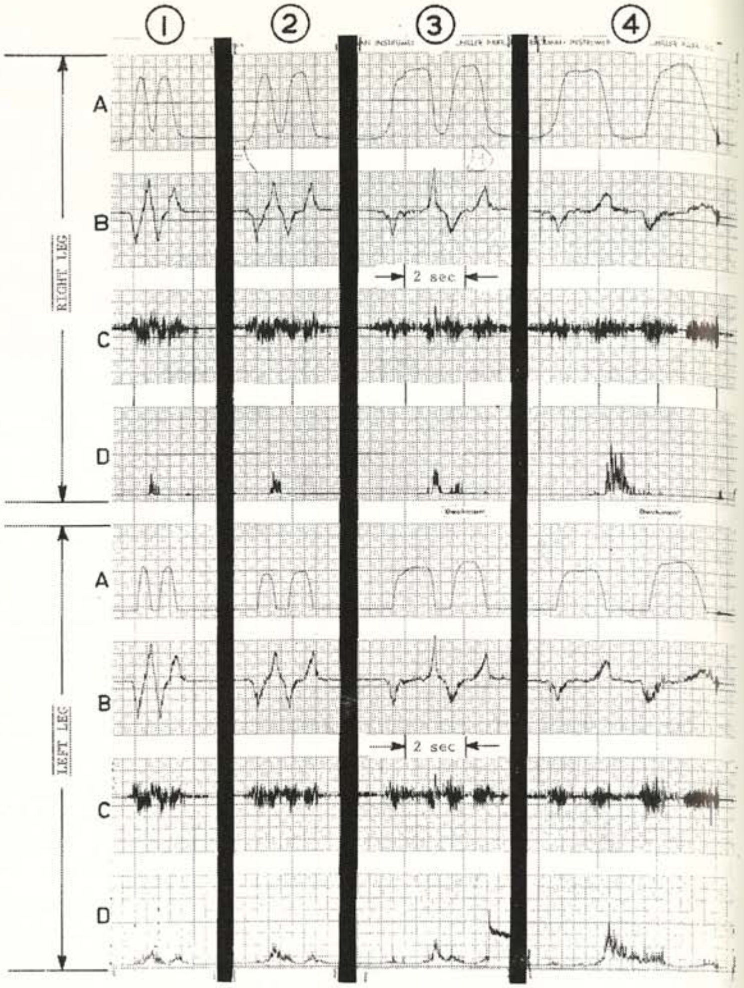


FIG. 7

Recording of the biomechanical and myoelectric correlates recorded during the lifting task described in Figure 6.
1 : Recording of the ingot lifted.
2 : Recording during lifting of the empty crate.
3 : Recording during lifting of crate of half weight.
4 : Recording during lifting of crate of full weight (32 lbs)
A : Angular displacement of hip joint (2 cms on ordinate = 120 degrees rotation of hip joint during trunk flexion)
B : "Velocity signature".
C : "Acceleration signature".
D : The integrated surface myogram taken over the sacro-spinalis muscle at level of L4. For further explanation see text.

procedure suitable for the assessment quantitative of the work tolerance of males, females and juveniles engaged in lifting operations.

The importance of this can be considerable just at the present time when the ergonomic problems resulting from recent trends in miniaturization and containerization have added a serious and perhaps sinister overtone to the age-old jocular question : what is heavier, one pound of lead or one pound of feathers ? The feathers, of course, they are so much bulkier. How much heavier they are, however, can best be found out by employing the analytical processes of electromyographic kinesiology.

Performance Measurements in Man-Machine Aggregates

Electromyographic kinesiology is one of the most elegant tools to be employed in the evaluation of man-task systems. Often it is possible only through the application of this procedure to determine if the system functions according to the specifications of the original design, and if man monitors machine or machine monitors man. The proper application of electromyographic technique often provides clues useful in the elimination of either physical discomfort of the operator or economic inefficiencies of the system. A case history involving small drill presses may serve as a good example (17).

It was observed that, during the performance of a drilling task, taller women operators were complaining about frequent shoulder pains and abdominal discomfort while other female employees of smaller body build did not complain at all, but considered the particular job in question to be an easy task (Figure 8).

An analysis of the work situation shows that, under conditions of existing chair heigt, the taller women were sitting so high that the elbows were down while the smaller individuals could assume a working posture where the upper arm was flexed forward, Thus, the smaller ones could pull the lever which actuates the machine downward easily by simply contracting the latissimus dorsi muscle.

To perform the same task with the arm already in downward posture, the taller individual had to flex the torso forward about the lumber joints, by means of contraction of the rectus abdominis and other muscles of the abdominal wall. Frequent and continuous contraction of these muscles tends to produce a continuous oscillation of surging and declining pressure within the abdominal cavity which gives rise to a "phrenic referral" from the diaphragm to the shoulder causing pain there. Likewise, continuous forward and backward movement of the torso caused a great level of activity in the

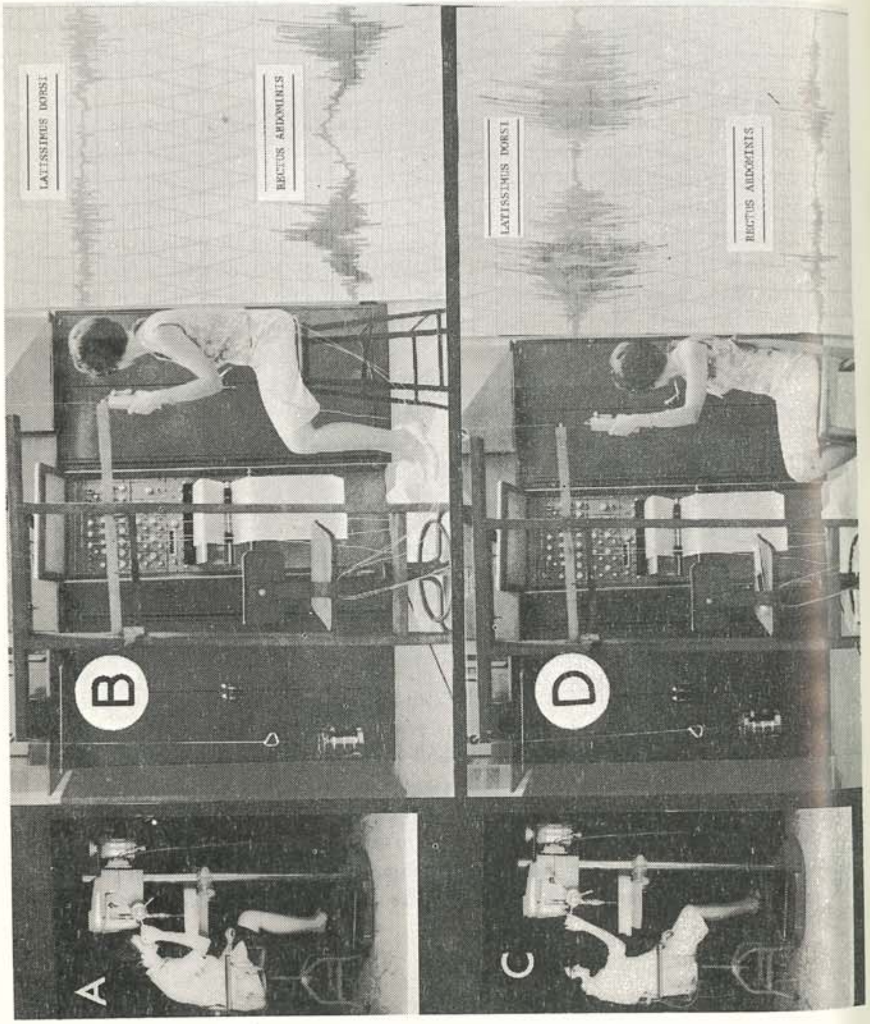


FIG. 8

When chair hight and body hight are not matched then muscular activity during the performance of a task may not proceed as originally intended.
A : Tall woman located in front of drill press.
B : Same task simulated in laboratory shows poor utilization of arm but high activity in rectus abdominis muscle.
C : Small woman can assume proper working position in front of machine.
D : Task simulated in laboratory by lowering of chair to produce proper skeletal configuration now shows good and sustaines myoelectric activity in latissimus dorsi and comparative electro-silence over rectus abdominis. Adapted from (17).

lumbar spine and its associated structures also giving rise to frequent complaints about discomfort and pains in the lumbar region. These circiumstances frequently give rise to absenteeism from the workplace, which lowered performance efficiency. Furthermore, many of the employees experiencing discomfort engineered lateral transfers within the enterprise or, failing this, they resigned. This caused frequent staff rotation leading to training and retraining problems connected with the continuous need to procure new staff.

In order to demonstrate to management that it would be necessary to introduce adjustable chairs into the interprise so that seat height could be adapted to individual needs, the task was studied in depth in the myographic laboratory,(Figure 8D) where a biomechanical equivalent of the machine was simulated and the operation performed under controlled conditions. Surface electrodes were placed over the rectus-abdominis and latissimus dorsi muscles. The purpose of the investigation was to achieve optimal configuration of the musculo-skeletal system during work as a pre-condition for the operators ability to perform both economically and under conditions of physical comfort.

It was clearly demonstrated that, when the seating surface of the chair was adjusted too high with respect to the machine, the myograph registered strong activity of the muscles forming the abdominal covers, while the latissimus dorsi was only little exercised during the operation. On the other hand, after seat height was lowered so as to produce adequate forward flexion of the arm, a complete change in the myographic picture was observed.

Now, there was a strong, forceful and purposeful latissimus dorsi activity with relative electro silence over the abdomen. It was also found that the latter type of electromyogram was always associated with trouble free and comfortable performance, whereas the operators positioned so that they produced the former type of record in the great majority of cases began to complain after a few days of discomfort in the shoulder and the back.

On the basis of myographic experimentation it was decided to make instruction in the proper adjustment of the work chair part of each operator's induction training program and this lead to a dramatic reduction in the incidence of the aforementioned complaints (17).

Conclusion

Three case histories have been presented, each showing in its own way the usefulness of electromyographic kinesiology to the analysis of work situations and the assessment of work tolerance of individuals as well as of groups. It is postulated that this discipline should form a basic tributory to the professional tool kit of both physician and engineers in industry. Myoelectric signals evaluated conjointly with biomechanical and physiological correlates may well form in the future the basis of a more rational approach to work measurement. The quantitative estimation of physical work stress intrinsic to a specific task, and, finally, the objective assessment of the activity tolerance of individuals as well as groups with respect to specific work situations.

This paper was written to demonstrate by way of technical communication that electromyographic kinesiology has a discipline as much to offer in the quest of making the industrial working environment a safer and healthier place for man the most important natural resource available to himself.

Acknowledgments

The development of new methodologies is never the result of the activities of a single researcher. Thus, the author is deeply indebted to M. O'Dorney for the development and M.Montreuil for the construction of circuitry and devices employed in some of these investigations. Messrs. N.Ehrlich and G.Sarkar produced the recordings of myoelectric signals and their biomechanical correlates. S.Seegmiller pervormed much of the background search of relevant literature and Mrs. W.Hart contributed in the preparation of the manuscrit. The aforementioned are members of the Bioengineering Unit of the Institute of Rehabilitation Medicine of New York University Medical Center.

Thanks are also due to E.Lowman, M.D., H.A.Rusk, M.D., and Mr. E.J. Taylor for encouragement and warm support in this continuing research.

REFERENCES

1. TAYLOR, F.W. : *Scientific Management.* Harper Brothers, New York, 1947.
2. GILBRETH, F.B. : *Motion Study.* Van Nostrand, New York, 1911.
3. BASMAJIAN, J.V. : *Muscles Alive.* Williams & Wilkins, Baltimore, 1967.
4. BORELLI, A. : *De Motu Anamalium.* Rome, 1679.
5. DUCHENNE, G.B.A. : *Physiology of Motion.* W.B. Saunders Co., Philadelphia, 1966 (translated by E.B. Kaplan).
6. DENNY-BROWN, D. : On the Nature of Postural Reflexes. *Proc. Royal Soc.* 104B : 252-301, 1929.
7. INMAN, V.T., SAUNDERS, J.B. de C., and ABBOTT, L.C. : Observations on the Function of the Shoulder Joint. *J. Bone & Joint Surg.* ,26 : 1-30, 1944.
8. LUNDERVOLD, A.J.S. : *Electromyographic Investigations of Position and Manner of Working in Typewriting.* A.W. Broggers Boktrykkeri A/S, Oslo, 1951.

9. JOSEPH, J. : *Man's Posture : Electromyographic Studies.* Charles Thomas, Springfield, 111., 1960.
10. FLOYD, W.F., and SILVER, P.H.S. : Function of Erector Spinal in Flexion of the Trunk. *Lancet*, Jan. 20, 1951, pp 133-138.
11. HIRSCHBERG, G.G., and NATHANSON, M. : Electromyographic Recording of Muscular Activity in Normal and Spastic Gaits. *Arch. Phys. Med.* 33 : 217-225, 1952.
12. HIRSCHBERG, G.G., and DASCO, M.M. : The Use of Electromyography in the Study of Clinical Kinesiology of the Upper Extremity. *Am. J. Phys. Med.* 32 : 13-31, 1953.
13. TICHAUER, E.R. : Some Aspects of Stress on Forearm and Hand in Industry. *J. Occupational Med.* 8(2) : 63-71, 1966.
14. TICHAUER, E.R. : The Biomechanics of the Arm-Back Aggregate under Industrial Working Conditions. The American Society of Mechanical Engineers, publication no 65 – WA/HUF – 1, 1965.
15. TICHAUER, E.R. : Ergonomics of Lifting Tasks Applied to the Vocational Assessment of Rehabilitees. *Rehabilitation in Australia,* October, 1967, pp. 16-21.
16. RUBENSTEIN, L. : Continuous Radio Telemetry of Human Activity. *Nature,* 193 (4818) : 849-850, 1962.
17. TICHAUER, E.R.,: Gilbreth Revisited. The American Society of Mechanical Engineers, Publication No 66 – WA/BHF – 7, 1966.

CONSCIOUS CONTROL OF MOTOR UNITS BY THALIDOMIDE CHILDREN ; AN ELECTROMYOGRAPHIC STUDY ; A 16 MILIMETER SOUND, BLACK AND WHITE FILM[1]

T.G. SIMARD and H. LADD

Département d'Anatomie, Université de Montréal, and
Department of Psychology, Loyola College and
Rehabilitation Institute of Montreal, Montreal, Canada

Summary

Based on the results of previous research with normal subjects (Fruhling M., Simard, T.G. and Basmajian, J.V., 1968), this study attempted to establish the level of motor control of thalidomide patients by electromyography. The patients were of 4 1/2 to 7 years old with at least one anatomical defect. The right romboid muscle was used. Conscious control of motor units was studied sequentially establishing gross electrophysiological activity, inhibition, isolation and maintenance of a single motor unit. Visual and auditory signs of the motor responses were employed ; first, without instructed body movements, second, during directed right upper limb movements. The results indicate that gross motor units control and inhibition were established in general whereas only 30 per cent of the patients could isolate and maintain single motor unit activity. The maintenance of finest activity during movements was more difficult to establish than with normal subjects. This was achieved by only 18 per cent of the patients in contrast to 50 per cent in normal individuals. The levels of control achieved in motor unit training in thalidomide patients are discussed. The specific problems involved in subject cooperation, conceptualization of the experimental task and self control are considered with respect to the thalidomide syndrome including child-parent relationships and emotional, social and intellectual development.

[1] This film is available on a rental – or – purchase basis in English, French or German. For information concerning prices and delivery, write to : Chairman, Department of communication arts, Loyola of Montreal, Montreal, Quebec, Canada.

This study was performed at the Rehabilitation Institute of Montreal. Financial support was received from the Medical Research Council of Canada. (Grant MA-2643 to T.G.S. and 604-486 to Rehabilitation Institute of Montreal.)

RECIPROCAL INHIBITION AND COCONTRACTION

Hal T. WEATHERSBY

Department of Anatomy, Southwestern Medical School
Dallas, Texas 75235. U.S.A.

Summary

The concept that a muscle is reciprocally inhibited during contraction of its antagonist was tested using an ink writing electromyograph and self-retaining fine wire electrodes. Selected bi-functional muscles were used noting the activity when the muscle was performing one of its functions at the same time that the antagonist of its other function was contracting.

There was considerable activity in the tibialis anterior muscle when the foot was dorsiflexed and everted. However, during inversion and plantar flexion no potentials were recorded. Using the peroneus longus muscle, the antagonist of tibialis anterior, there was activity during simultaneous plantar flexion and inversion of the foot. The biceps brachii muscle played no appreciable part in flexing the fully pronated forearm or in supinating the fully extended forearm. However, the muscle was not completely inhibited until the full extent of the antagonistic motion was reached. Other muscles are currently being studied.

Cocontraction seems to be a normal function of certain muscles in selected actions.

ELECTROMYOGRAPHY OF TONGUE MUSCLES

D.P. CUNNINGHAM* and J.V. BASMAJIAN

Department of Anatomy, Queen's University, Kingston Ontario

Summary

From fine-wire electrodes inserted into genioglossus and geniohyoid muscles bilaterally, simultaneous EMG recordings were made during various functions of the tongue. A total of twenty-six adult subjects were examined. During swallowing of saliva or water, a pattern of activity has been found which varies between subjects and even between swallows by the same subject. However a general pattern is recognizable with clear differences between the swallowing of saliva and the swallowing of water. Even during the brief span of a swallow, the muscles show rapid variations in their contributions from moment to moment.

---

* Supported by a grant from the Medical Research Council

ELECTROMYOGRAPHY OF ANTERIOR ABDOMINAL WALL IN THE DIAGNOSIS OF ACUTE SURGICAL DISEASES OF ABDOMINAL ORGANS

A.V. LIVSHITZ

Institute of Surgery by A.W. Wischnewsky,
Moscow, U.S.S.R.

Summary

Of great importance for the diagnosis of acute diseases of abdominal organs, including acute appendicitis, is the determination of rigidity of the anterior abdominal wall muscles. Such rigidity is a manifestation of enhanced viscemotor reflex from the "diseased" abdominal organ to the anterior abdominal wall, the extreme degree of this reflex being the defence of abdominal muscles.

It is well known from everyday practice that the evaluation of rigidity of abdominal muscles by means of palpation is difficult and subjective.

Accordingly, a method has been developed for objective evaluation of the functional state of abdominal muscles by means of electromyography.

Using plate-type electrodes and a portable two-channel electromyograph of his own design, the author has studied the electrical activity of abdominal muscles in 100 normal subjects and in 200 patients with acute surgical diseases of abdominal organs.

The electrical activity was studied under conditions of relaxation, voluntary contraction, and stretching of the muscles by palpation and in tests for a number of symptoms of acute abdomen and acute appendicitis. Also investigated was the electrical activity of the anterior femoral muscles because of their closeness to the internal oblique and transverse abdominal muscles.

It was found that in normal persons the electrical activity of abdominal muscles was well defined only during voluntary contraction, being symmetrical and represented by asynchronous oscillations of biopotentials.

In contrast to this, in patients with acute appendicitis a persistent electrical activity was noted under all physiological conditions (relaxation, voluntary contraction and stretching), predominantly in the right iliac region both in the presence and absence of a clinically pronounced rigidity. The right femoral muscles were also electrically active.

With appendicular colic, the electrical activity differed from normal only in that it was somewhat increased in the right iliac region during voluntary contraction, as compared with all other abdominal wall muscles.

With intestinal colic, the electrical activity of abdominal muscles was normal.

With retrocecal appendicitis, palpation of the right iliac region led to the appearance of high-amplitude oscilations in the area of right lumbar triangle, these oscillations being much greater than in the case of right-sided renal colic. At the same time, no electrical activity was observed in the area of left lumbar triangle.

To elucidate the nature of defence reflex, the electrical activity of abdominal muscles was investigated during appendectomy operation. It was shown that mechanical stimulation of parietal peritoneum and visceral organs (intestine, vermiform appendix) brings about a reflectory increase in the electrical activity of abdominal muscles. This activity decreased following anesthesia or division of the mesoappendix.

„SILENT PERIOD" BEFORE THE ACT IN RAPID VOLUNTARY MOVEMENT

Michio IKAI

Laboratory of Physiology, School of Education,
University of Tokyo, Hongo, Tokyo, Japan

Summary

It has been observed in trained subjects in skilled act that the tonic impluses disappears for some extent immediately before the ordinary synchronous discharge to the muscle in rapid voluntary movement, in various sport activities, such as "starting" in sprint running, "hitting" in Kendo Japanese fencing, as well as "batting" in baseball. To reveal the mechanism of this phenomenon "silent period before the act", a series of experiment was conducted in trained and untrained subjects. While the subjects keeps a slight voluntary contraction as the background of motor unit activity for experiment, he is asked to respond with a rapid voluntary contraction of the muscle as quick as possible to a stimulus of visual (neon lamp) or acoustic (shot). The silent period was easily obtained in extensor muscles, particularly brachial triceps muscle. The latency of this silent period was found to be around 50 msec at minimum. When the subject reacts involuntarily by pistol shot, the synchronous discharge appears in 50 msec as same as the latency of silent period. It is supposed from these findings that some inhibitory discharge could arrive to the spinal motor neurones through the efferent spinal gamma route to prepare the efficient phasic discharge through alpha route to the acting muscle.

ABDOMINAL EXERCISES
AN ELECTROMYOGRAPHIC STUDY

Marcel HEBBELINCK

Laboratoire de l'Effort,
Université Libre de Bruxelles, Belgium

Summary

Action potentials were recorded by surface electrodes from the upper and lower part of the m. rectus abdominis and the m. obliquus abdominis externus, as 5 healthy male adults performed a series of 21 abdominal exercises. The abdominal exercises were common exercises as found in the physical education literature. The electromyographic analysis and motion study permits the comparison and grouping of different exercises.

STRUCTURE AND ACTIVATION OF THE MYOCARDIUM CARDIAC ELECTROMYOGRAPHY

L. Gomez OLIVEROS, G. Ramirez ORTIZ and F. Torrent GUASP

Department of Anatomy,
University of Madrid, Madrid, Spain.

Summary

The authors try to show successive and independent contraction of two ventricular muscular layers in charge of an expulsive systolic function and a diastolic expansive one, respectively. For this purpose, strain gages directly applied on the epicardic and endocardic surfaces, have been used.

The authors try to prove as well the existence of a mechanism of ventricular activation serving a double contractile system producing the systolic contraction and the diastolic expansion of the heart in an active and independent way. To achieve this end, they have directly recorded the cardiac muscle potentials by means of an EMG-like Bronk needle. In this way, a real cardiac electromyography (EMKG) has been performed.


medelec
MS6 MODULAR EMG
4 BEAM DISPLAY
FIBRE-OPTIC RECORDER
LOW NOISE AMPLIFIERS
FULL RANGE OF PLUG-INS
SOLID-STATE RELIABILITY

medelec

MS4
PORTABLE EMG

This portable EMG has been acclaimed for its comprehensive facilities, its compact size and solid state reliability.

Now it is even better value with Conduction Time Indicator built-in and several detail improvements ; all at no extra cost!

Full facilities are provided for EMG, motor and sensory conduction time recording and muscular Strength - Duration curve plotting.

Photorecording with either Polaroid or 35mm cameras enables high quality records to be kept.

The unit is supplied with full electrode kit, plastic cover and operating handbook.

MEDELEC LTD., WOKING, SURREY, ENGLAND.
Telephone: Woking 5627 & 65805 Cables: Medelec Woking

---

medelec

MUSCLE TESTING STIMULATOR S3C

This self-contained, constant current stimulator is signed for use as an adjunct to EMG investigations incipally for the derivation of Strength/Duration curves. lses at 1 and 10 per second and variable intensity are oduced at the standard durations. Audible pulse monitoring provided. Output currents are read continuously from the ont panel meter without switching.

ecification: Stimulus intensity : 0 - 50mA
Stimulus duration : 0.03, 0.1, 0.3, 1, 3, 10, 30, 100mS
Repetition rates : 1 and 10 per second
Output impedance : >100KΩ
Size : 30 x 18 x 18cm

MEDELEC LTD, WOKING, SURREY, ENGLAND
Telephone: Woking 5627 & 65805 Cable: Medelec Woking

medelec

NERVE TESTING STIMULATOR FS1

The FS1 is a battery operated constant current stimulator intended for use in nerve testing to establish early prognosis in facial paralysis of lower motor neurone origin. The meter gives a steady reading of current and an audible pulse monitor of output. The 100mS pulse may be used for direct muscle motor point stimulation, when the short pulse will produce no response with denervated muscle. A mercury battery with long life and world wide availability is used.

Specification:			
	Stimulus duration	:	1 and 100mS
	Stimulus intensity	:	0–15mA
	Output impedance	:	>100KΩ
	Output voltage	:	90 volt max
	Repetition rate	:	1 per second
	Size	:	19 x 12 x 8.5cm

MEDELEC LTD, WOKING, SURREY, ENGLAND

Telephone: Woking 5627 & 65805 Cable: Medelec Woking

---

medelec

This company specialising in electrophysiological quipment has been for many years in the forefront of rogress in Electromyography.

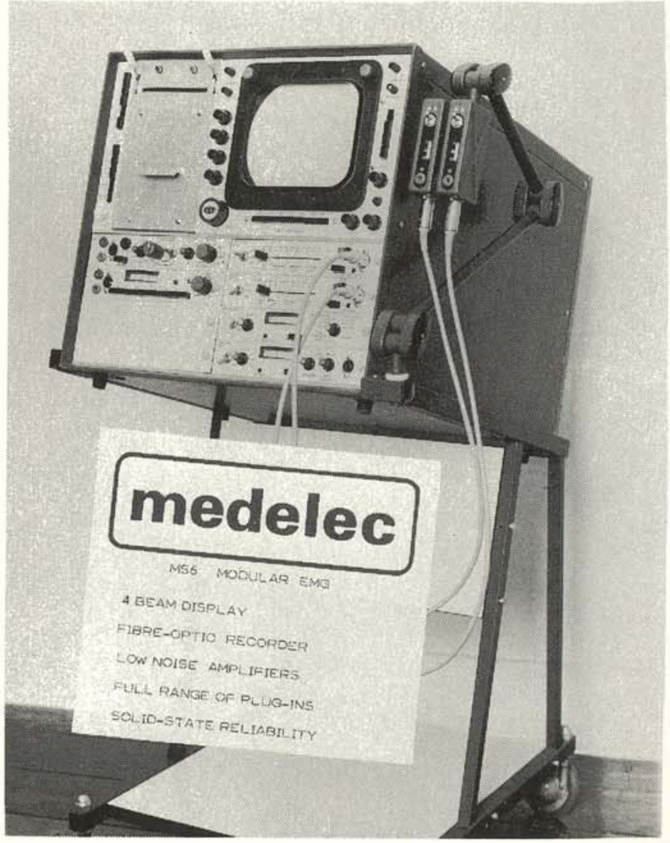
The range includes EMG, EEG, Electrocardioscopes, pecial and general purpose stimulators plus a service roducing special purpose equipment to customers pecification.

We are represented throughout the world and a list f current agents is given below.

ustralia	Philips-Stanford
elgium	Medico Electronic P.V.B.A.
hina	Uniscien Co. Ltd.
rance	Henri L. Michael & Co. Inc.
reece	"Electratha" PH Athanassoulas & Co.
olland	Elther N.V.
dia	X-Ray and Electromedicals
an	Dehkadeh & Co.
rael	Be Pex Ltd.
aly	Amplimedical s.p.a.
ortugal	Alves & Ca. (Irmaos)
outh Africa	Protea Electro-MedicalServices
pain	Electronica Medica e Industrial S.A.
weden	Thorin & Thorin AB
hailand	Philips Electrical Co. of Thailand Ltd.
urkey	A.B. Ticaret Ltd. Sirketi,
nited States	Teca Corporation, NY.
ew Zealand	N.Z. Distributors Ltd.

MEDELEC LTD. WOKING, SURREY, ENGLAND

Telephone: Woking 5627 & 65805 Cables: Medelec Woking


medelec
MS6 MODULAR EMG
4 BEAM DISPLAY
FIBRE-OPTIC RECORDER
LOW NOISE AMPLIFIERS
FULL RANGE OF PLUG-INS
SOLID-STATE RELIABILITY

D/1969/0081/28

Printed in Belgium
by Nauwelaerts, Printing Dept. Louvain