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THE TIMING OF MUSCULAR ACTIVITY AS REFLECTED IN MOTOR POTENTIALS RECORDED FROM THE HUMAN SCALP

by

J. GERALD JONES

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE TIMING OF MUSCULAR ACTIVITY AS REFLECTED IN MOTOR POTENTIALS RECORDED FROM THE HUMAN SCALP submitted by J. Gerald Jones in parial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

The purpose of this study was to determine whether dominant components of the motor potential recorded from the scalp, were coincident with the rise and fall of muscular activity in single movements, return movements, and continuous movements, in serial flexion and extension of the elbow.

Electroencephalographic recordings obtained from three right handed subjects through scalp electrodes were averaged by computer and related to EMG, force and displacement of the limb.

In the single movement, coincident events in the motor potential indicated the rise and fall of EMG and force.

Events in the motor potential of the return movement coincided with the rise of EMG and of force in the first phase, and the rise of EMG in the second phase. Other time relationships were not clear.

Dominant negative potentials were still evident, associated in time with change in direction, despite relatively high noise level in the motor potentials for continuous movement.

Relationships between events were clearer in some subjects than in others. This could have been caused by different characteristics in the performance of the task or by problems related to the location of scalp electrodes.

The general wave form of the motor potentials and the

EMG traces seemed to be related in a few samples of the single movement task, suggesting that other factors than time may be related between the motor potential and the EMG.

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CHAPTER I

STATEMENT OF THE PROBLEM

1.1 Introduction

It is a frequent experience of teachers of motor skills to have pupils who know what to do but who still cannot perform the task. After the information regarding the task has been received and understood, there seems to be a gap because subsequent attempts do not result in a satisfactory performance. Hebb (1968) and Greenwald (1970) have proposed that a perceptual image is required in the formulation of the plan of muscular action. This was proposed by James as long ago as 1890, but his ideas were challenged by conditioning theorists and fell into disrepute, apparently because they could not withstand rigorous experimental examination at that time. More recently neurological propositions by Eccles (1965), Hebb (1968), Konorski (1967) and Beritashvilli (1969) have revived these old ideas and expressed them in more objective terms. The argument can be reduced to feedback versus ideation in the learning of the skill. A mass of information is available on the importance of feedback in learning, much of its early development having been done by Hull (1931). There is little doubt that feedback plays an important part in the refinement of the performance, but it seems not to account for all the learning which occurs, since mental practice procedures can result in the acquisition of skill of naive subjects as well as improvement in those skills already established, (Jones, 1965; Richardson, 1965).

Support is also found in animal studies for the importance of central mechanisms in the work of Taub and Berman (1968). After reviewing their ten years of research on the influence of the removal of feedback by deafferentation, they stated the following:

> "...how could an animal learn to make use of deafferented limbs in the absence of vision.... Since the required information concerning the topography of their movements could not have been conveyed over peripheral pathways, it must have been provided by some central mechanism that does not involve the participation of the peripheral nervous system."

These authors go on to review literature which illustrates that mechanisms do exist which could include purely central feedback systems, returning information concerning future movements before the impulses that will produce these movements reached the periphery. This supports the idea of the fractional anticipatory goal response of Hull (1931) but still does not account for the formulation of the initial motor plan which determines what the output will be. This planning function is covered by Taub and Bermans (1968) second alternative, which is the possibility that behaviour can be learned and performed in the absence of all topographical feedback.

Hebb (1968) supports the idea of the lack of reliance on the afferent input and the concept that one can recall stored information and reform the image which was originally

"...a series of peripherally derived sensations."

After reviewing the different theories of learning, Greenwald (1970) concludes that the ideo-motor mechanism is the vital one in the initial stages of learning, where a response is selected on the basis of its own anticipated feedback. If this is so then what is recorded on the Rolandic area of the cerebral cortex as a motor potential may well be based on the anticipated feedback and may represent either the recalled image of a prior attempt, or a generalized image formed from sub-assemblies of second-order neurons (Hebb, 1968). The ideational portion of the function with its related potentials need not be related to the overt response, in that much behavioural evidence supports the idea of implicit rehearsal, and in fact, Vaughan _et al_. (1970) reports that "...potentials having the typical configuration of motor potentials were seen during the recording session without myographically evident contraction of the monitored extremity." These could be potentials related to unmonitored muscle action as he suggests, but there is also the possibility that they were a manifestation of mental practice of the task. After refinement of the technique, it may be possible to establish whether the overt performance is essential to the motor potential. If the muscular activity turns out not to be essential, then it would support the idea of the motor potential representing the plan of the performance.

Potentials from other areas of cortex associated with the performance of motor acts may also be of value in examining ideational components of motor planning. Sologoub (1969) examined electroencephalographs derived from many areas of the scalp and found a clear relationship between the rhythm of EEG wave forms and the rhythm of the task performed. These rhythms were clearest over parietal area 39 of Brodman and motor areas and they were sustained as the task became automated, whereas over other areas the rhythms became random. Sologoub's EEG wave forms were interpreted from the raw data, and therefore no clear components of the wave form could be seen, but it seems a distinct possibility that these waves were the same as Vaughan's motor potentials. Therefore these potentials may well be manifest in parietal as well as motor areas of the cortex.

Statements made by Nielson (1948), Penfield (1954) and Campbell (1965), although not supported by experimental evidence, express the common notion that the inferior parietal region of cortex is involved in body awareness and the planning of motor acts. Although this may not be totally true, it adds weight to the validity of examining potentials from the area and their relations to the planning and performance of motor skills

The work of Vaughan (1965, 1968, 1970), Gilden (1966) and Karlin (1970) show consistent components of the EEG potentials recorded above the motor cortex, and that these were related in time to the occurrence of muscular contraction. Research by Evarts (1966, 1967, 1968, 1969) on the function of single cells in the motor cortex in relation to muscle activity adds to this, and makes more reasonable the examination of EEG signals derived from above the motor cortex, before proceeding to other areas.

One of the components of muscular activity which is highly important in skilled acts is the timing of the beginning and ends of movements, and the timing of changes in direction. Accurate timing is not only essential for fast responses to external stimuli in those situations where fast reaction and fast movement are necessary, but also, in slower highly coordinated tasks where accurate time of the components of the multiphasic movement determine the degree of precision in the performance. Timing of muscular activity is the factor which also determines the rhythm of performance in a serial type task like running or rowing or swimming. Examination of this factor may also contribute to the understanding of man's ability to time rhythmic activity within a very small range of error (Von Sturmer, 1968; Ellis *et al*., 1968; Carlson and Feinberg, 1968). In order to use components of motor potentials to examine the timing of rhythmic activity, it is necessary to determine whether these components occur consistently with the onset and cessation of muscular contraction or with events in other parameters dependent upon the muscular activity.

1.2 The Problem

Scalp electrodes, will be used on normal human subjects to see whether dominant components of the motor potential occur coincident both with the rise and the fall of muscular activity. The same coincident potentials will also be looked for in tasks with two sequential movements and in continuous performance of alternating phases. Scalp electrodes will be used because they are considered necessary for further research on normal humans.

Vaughan (1965, 1968, 1970), Gilden (1966) and Karlin (1970) clearly demonstrated a negative component of the motor potential occurring with a small latency after the onset of muscular activity. These signals were obtained through scalp electrodes in sharp ballistic-type tasks except for the work reported by Vaughan in 1970, where the animals were trained to open and hold a switch for a short period of time. Only in the 1970 study was a coincident potential also obtained for the cessation of the muscle action. So far as can be interpreted from the published material, this task was more of an isometric than an isotonic task (see definition of terms, page 7). The records in that study were obtained from the cortex of the monkeys whereas in the experiments on humans they were taken from the surface of the scalp. Either or both of these differences could have accounted for the occurrence of the potential coincident with the cessation of the EMG (muscle potential) in the latter case and not in the former.

1.3 Definition of Terms

Electroencephalograph (EEG). The trace displayed on paper or an oscilloscope, of the electrical recording of the activity of the brain. The usual method of recording is via surface electrodes or needle electrodes inserted through the scalp.

Electromyograph (EMG). The trace displayed on paper or an oscilloscope of the electrical recording of the activity of one or more muscles. The usual method of recording is via surface electrodes or needle electrodes inserted into the belly of the muscle.

Evoked Potential (EP). Change in voltage, usually recorded in wave form, which is used to represent the response of the brain to an external stimulus.

Isometric Contraction. Muscular force exerted against a non-moving resistance so that the limb remains stationary, and the muscle remains the same length.

Isotonic Contraction. Muscular force which results in shortening of the muscle, and movement of the limb concerned.

Motor Potential (MP). Designated by Gilden et al. (1966) and Vaughan et al. (1965) as a characteristic cerebral wave form associated with voluntary motor activity. For characteristics see Chapter II, page 21.

Noise. Irrelevant electrical signals in which the signal of interest is often embedded.

Phase Shift. The lead or lag of one wave relative to another wave (or to a time point) where both are supposed to occur simultaneously.

<u>Pyramidal Tract Neurons (PTN)</u>. Cells of the cerebral cortex which project fibres through the pyramids of the brain stem into the spinal cord.

1.4 <u>Limitations</u>

(A) The tasks used in this research are suitable to examine the time relations among the parameters concerned only so far as the subject is able to perform the movements accurately and reliably.

(B) Since the task is so simple and of very low information load, relations among the parameters cannot be generalized to complex motor tasks, or those which involve processing of large amounts of information.

(C) The extent to which the records taken from the scalp can be used is dependent on the consistency of the relationship between the topography of the cranium and that of the cortex.

(D) The study was limited by the accuracy and reliability of the equipment used. This was particularly important in this experiment where so many pieces of very sensitive equipment had to operate correctly at the same time.

(E) This research is limited by the number of subjects and the population from which they are drawn.

From the results one therefore cannot generalize, but the study should be looked upon as an initial experiment in a series which was designed to examine whether certain phenomena occur and whether further research in this direction is feasible.

(F) The research is also limited by the extent to which the subjects were able to establish the basal state and perform the tasks as directed while following the sweep hand of the clock.

CHAPTER II

REVIEW OF LITERATURE

Only in the last few years has research been done relating external measures of brain function to motor performance. Much of this has been directed towards the investigation of information input through the different sensory modes. The main work on externally measured brain output in relation to motor performance has been done by Vaughan and his associates, (Vaughan *et al.*, 1965, 1968, 1970; Gilden *et al.*, 1966). In addition one Russian study reports findings on the matching of alpha rhythm to rhythmic muscular activity (Sologoub, 1969). Beyond this work most other research has used animals to relate cortical cell function to the overt performance.

In this chapter relevant work relating the function of motor cortex and muscular performance, which provides a context for this study, will be reviewed.

2.1 Single Cell Activity and Muscular Performance

Several research workers from 1965 onward (referred to in this chapter) have been trying to relate the function of cells in the motor cortex to the activity of the muscle and other characteristics of the overt performance.

In a series of studies on monkeys, Evarts (1966) implanted microelectrodes in the motor cortex of the animals and related the firing of the cells recorded to the characteristics of simple arm movements. He reported that in a simple button-pressing task, the arm movements were preceded by responses in pyramidal tract neurons, and that the latency of the PTN (pyramidal tract neuron) response after the stimulus was related to the latency of the movement. Since the PTN activity preceded the peripheral EMG (electromyograph) response associated with the movement, the firing of the cortical cells could not be dependent on feedback from the muscular activity. In a further study (1968) Evarts examined the question; "Is the discharge of PTNs related to the force exerted by the moving part, or does PTN activity more nearly parallel the displacement which results from this force." In this experiment the animal was trained to make alternate 30° flexion and extension movements of the wrist for a fruit juice reward. During training both the magnitude of the load and the direction in which it acted were varied, and the monkeys learned to make displacements of the required duration independent of these variations. The right hand was trained and the recordings were derived from the contralateral precentral gyrus. Force and position transducers were used to record the degree of muscular force produced and the displacement of the wrist. Muscle potentials were obtained from both flexors and extensors of the wrist using needle electrodes implanted into the muscle. Examination of changes in the behaviour of the PTNs when the load was varied showed that the magnitude of the force generated was an important factor in whether the recorded PTN actually fired at all and in the frequency of the discharge. It was also shown that as the force changed, so also the frequency of firing of some PTNs changed. In all cases these changes occurred before the muscular events and therefore could not be attributed to rapid feedback from the muscle. Concluding the report on the study Evarts states the following:

> "For the majority of PTNs discharge frequency was related primarily to the force (F) and dF/dt and was only secondarily related to the direction of displacement.
>
> Some PTNs which were unrelated to force were related to the direction of displacement, but not to the fine details of the displacement in the way that other PTNs were related to the fine details of the applied force."

Further examination of the results showed that most PTNs of the precentral motor cortex are more strongly related to dF/dt than to force. Evarts states the functional consequence of this as follows; "A strong representation of dF/dt prevents saturation and acts to extend the operating range of the PTN, allowing it to play a role over a very wide range of output force levels."

In reviewing his previous work Evarts (1967) takes to task his own research question which asks whether the discharge of PTNs is related to force or to displacement. He concludes that the question is "...trivial and sterile", since movement must a priori be related to force and in voluntary action one cannot separate force, direction and duration.

As an extension of his work Evarts reported another study (1969) in which monkeys had to maintain the position of a lever for 10 secs for a reward. During the task the load and direction opposing the maintenance of the position was varied, and the PTN response recorded. The task was practised to a stereotype level. It was found that the PTN activity varied in relation to the pattern of muscular contraction and the amount and direction of force exerted during maintenance of the position. Together with Evarts previous findings these observations indicate that the output of cells of the precentral motor cortex is related to the muscular activity causing the action rather than the joint displacement or steady joint position resulting from the muscular activity. The additional finding is reported; "... that a given PTN may be active during many different movements - more intensely in some and less intensely in others. A PTN which is strongly involved in shoulder movements may be weakly involved in wrist movements - presumably because movements of the wrist depend on the coordinated activity of the muscles of the upper extremity as a whole." (1969).

From Evarts work it may be concluded that the activity of those cells which were shown to be associated with muscular activity was correlated with gross characteristics of the overt performance. But this population of neurons from which recordings were taken constituted only 1/3 of the cells initially entered. It may well be that the augmenting and inhibitory effect of other cortical cells will not show as simple a relationship with the performance, and therefore in grosser type recordings taken from the scalp the finer details of the performance may be confused with other functions. The work of Preston and co-workers (1967) is related to this, in that it concerns the function of the motor cortex in inhibiting postural mechanisms so that volitional movements may be initiated.

In this series of studies Preston _et al_. (1967) concern tnemselves with analysis of the pattern of influence exerted on segmental motoneurons by volleys initiated from pyramidal cells, and transmitted to the periphery via the pyramidal tract. All but the pyramidal tract was severed at the brain-stem level. From their early work they suggest "that differing magnitude of cortical inhibition in the different motoneuron populations might be related to their role in maintaining antigravity posture. For the motor cortex to play a role in the initiation of volitional movements it is necessary that the tonic antigravity postural mechanisms be arrested to permit volitional movements to occur." They found, in the cat and the baboon that those muscles involved in antigravity function received inhibition from motor cortex, and that the difference in inhibition between the two animals was related to the different muscular requirements in their two postures. They compared the inhibition of the forearm with that of the hind limb and found that the motoneurons innervating the intrinsic musculature of the baboon hand receive only a facilitatory effect from the motor cortex in the pyramidal preparation. Also in the primate, they found that in elbow movements cortical inhibition was found in the flexor motoneurons rather than the extensors. Since these experiments used external stimulation of the cortex conclusions drawn from them must be guarded, but they nevertheless suggest that with gross type recordings from the scalp, neural activity which is recorded may represent inhibitory components as well as facilitatory ones. Some of them would therefore be associated with nonactivity of muscle and others with contractile muscle action. This would mean that the relationship between motor potentials and EMG or force traces would not be a simple function, or, that certain components of the MP would be related to these other parameters and other components not related. This work, along with that of Creutzfeldt (1966) and of Evarts (referred to previously) would suggest that positive deviations of the motor potential may well represent the inhibition of postural muscular action or signals concerned with the arresting of the movement.

2.2 Outlets from the Motor Cortex Other than Pyramidal Tract

Most of the work reviewed so far relates to the large cells of the motor cortex which have their outlet to the periphery through the pyramidal tract. But in recordings from the surface of the cortex or the scalp, the activity of other cells which do not have a direct outlet will be picked up. Where averaging techniques are used to eliminate non-time-locked responses the activity of the so-called extra-pyramidal cells may well be recorded since their signals also play onto the final common pathway to the muscle. Denny-Brown (1967) reviews much of his work which includes the effects of ablation of the cortex and sectioning of different pathways and states "The pyramidal system appears to require a substrate of extra-pyramidal activity without which it is ineffective. Its highly selective function also requires a direct pathway to the spinal segments, though it is related to extra-pyramidal function at all levels." Denny-Brown also states that through inhibitory effects each area 6 of Brodman appears to have a direct control over extra-pyramidal effects of both hemispheres through motor centres at the pontine level (Denny-Brown, 1967, p. 441).

Lawrence and Kuypers (1965) investigate the contribution of pyramidal and extra-pyramidal pathways in freely moving animals. The pyramidal tracts of their monkeys were interrupted at the medullary level. After seven weeks of recovery all monkeys with histologically-demonstrated bilateral interruption of the pyramids were able to perform all gross body movements with a great degree of skill, but independent finger movements never returned and all movements remained slower and fatigued more rapidly than in normal animals.

In support of this, the work reviewed by Glickman and Schiff (1967) on neocortical regulation of motor sequences, which includes studies using partial ablations of the cortex suggest that many basic "...manipulatory or consumatory patterns are "coded" in the brainstem but depend on the neocortex for proper ordering and elicitation." Glickman and Schiff also quote the work of Lewis and Brindley (1965) who showed that section of the medullary pyramids results in small changes in latency and threshold, but not in the basic form of movements evoked by electrical stimulation of the cortex. They also refer to Goldberger's work, who, after combined spinal cord and cortical lesions states; "...residual voluntary motor function seemed to depend upon the integrity... of the extra-pyramidal tracts of the spinal cord. These tracts may have a more important function in the control of motor activity than has previously been recognised." Glickman and Schiff make the final statement that "The traditional cortico-spinal paths, with their fine grained topographic organization may serve primarily to provide the subtle facilitatory influences critical for extremely precise motor control."

From the above mentioned evidence it is to be expected that recordings taken from the scalp above the motor cortex will represent the activity of all cells of that region, including pyramidal and those which play on extra-pyramidal pathways and as a result should be associated with both the overall pattern of movement derived from non-direct pathways, and the speed and precision derived from the pyramidal tract neurons. The assumption made is that the record derived from the scalp above the precentral gyrus represents the activity of all cells which are associated with characteristics of the muscular activity. On the basis of selective ablation studies and cell counts reported in Walberg (1953) it is quite evident that not more than 30 to 40% of PTNs originate in the precentral gyrus. Many of the PTNs arise in the parietal lobe, and temporal and occipital cortex seem to contribute some. Nevertheless, the evidence from the studies of Evarts, previously cited in p. 12 and that from the studies of Vaughan and co-workers seems to indicate that all the functions of the cortical motor cells are represented in the precentral gyrus. So it seems that the other pyramidal tract neurons with somata located in areas other than the precentral motor area either serve another function or are just augmenting the function of the large Betz cells in the motor cortex.

2.3 Populations Versus Single Neurons

Freeman (1963) stated; "The interpretation of single cell recordings is severely limited in correlations with molar behaviour by problems of population sampling. The realm of effective use of EEG data lies not in the analysis of the cellular mechanism of the cortex, but rather in synthesis of the framework within which analyses can be carried on." Since not all cells operate at the same time during overt activity the time pattern which relates the firing of cells will be important in the prediction of the muscular outcome. It is therefore reasonable to undertake research relating the function of whole populations of neurons to the characteristics of motor performance. Later in his review, Freeman indicates his belief that one pair of electrodes will suffice to provide "...almost all the information on the function of the cortex that the EEG is able to convey relevant to behaviour". Although this is an overstatement of the case his point is well taken that examination at the cellular level may not give the best correlation with molar activity.

In order to use the techniques of cellular recording and yet relate to gross motor performance Humphrey et al. (1970) recorded simultaneously from several individually selected neurons of the motor cortex of monkeys during simple arm movements. Their task was similar to the one used by Evarts (1967) where the animal flexed and extended the wrist against variable resistance. The firing rates for all cells sampled were summed for each point in time and were correlated with displacement, velocity, force and dF/dt, these dependent variables being measured on the task apparatus. As the animals performed the required movements five electrodes were inserted into the cortical area centred at the forearm region of the contralateral motor cortex. Not only did they find that the rate of firing of the population sampled correlated significantly with the characteristics of the performance, but also, as the number of units recorded was increased the mean percentage prediction error was reduced. From these experiments it can be seen that as the sampled population increased in size the correlation with performance parameters increased. Humphrey used only from one to five cells in his recordings. It is reasonable to assume that if the population had been increased still further the prediction error would have been further reduced. Although Humphrey's integrated records may have allowed inclusion of extra parameters, they give some support for recording from larger populations of neurons.

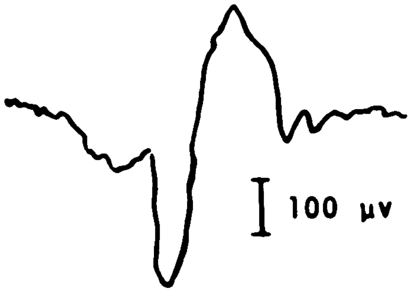
2.4 Topographical Relation Between the Cranium and the Cortex

One of the difficulties in taking scalp recordings to represent a particular population of underlying neurons is the fact that the cortex does not lie in a constant relationship to the topography of the cranium. As a result a particular point on the cranium may overlie a given population of cells in one subject and a somewhat different population in another subject. However, Schaltenbrand and Bailey (1959) state, in their stereotaxic atlas of the human brain, that if the upper end of the Rolandic fissure is taken approximately 1 cm. posterior to the midpoint between the nasion and inion the error is not likely to be greater than 1.5 cms. in either direction. Where the interauricular line crosses this division is the vertex. Vaughan (1968) found that if a line from the vertex to a point 2.5 cms. anterior to the tragus were used to represent the inclination of the central sulcus, the maximum amplitude of motor potentials concerned with the function of the hand was obtained in a zone 2-5 cms. lateral to the midline. In another study Gilden _et al_. used an electrode placement a little more lateral to this (3 ins. from the midline) and obtained similar recordings (1966).

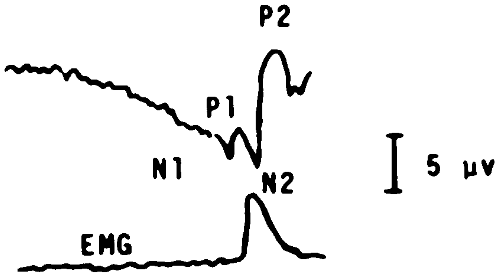
In a series of studies Woolsey _et al_. (1952) mapped the motor cortex of monkeys and, in effect, supported the above method of location of the hand and arm area of the motor cortex. The elbow flexion and extension areas were located a little way apart, but not so far that one electrode could not pick up the activity of cells in both areas. This is supported by the multi-cellular work of Humphrey _et al_. (1970) who sampled cortical cells from an area 2 mm by 3 mm. The microelectrodes which they used were so close together that an overlap of flexion and extension areas is suggested. From this it is reasonable to assume that since the electrical field will have spread more widely in transit to the scalp, scalp recordings through one electrode may be used to sample the activity of cells concerned with the actions of both flexion and extension.

2.5 Characteristics of Scalp Motor Potential (MP)

In a series of articles by Vaughan _et al_. (1965, 1966, 1968, 1970) relationships were examined between characteristics of motor performance and potentials recorded from the area of scalp presumed to be above the motor cortex. They used the 10-20 system of electrode placement in order to locate C3 and C4 above the motor cortex. The directions of Schaltenbrand and Bailey (1959) were followed in order to locate the specific area required. The scalp potential recorded is almost identical to the transcortical recordings taken from monkeys. Referring to the potentials recorded through cortical electrodes in monkeys Vaughan states the following; "This MP is comparable in all respects to the MP obtained in man." In the study reported in 1968 Vaughan found similar wave forms from 6 subjects, each recorded from the scalp during the performance of the same task. The monkey motor potential and the human one are shown below for comparison.



Monkey MP (Vaughan, 1970)



Human MP (Vaughan, 1968)

Although the configuration of the motor potential is the same, the amplitude of the different components, when taken from the scalp, is much smaller hence requiring greater amplification.

From the human motor potential recorded from the scalp, shown above, the following four main components can be seen:

(1) A slow negative shift of about 5 microvolts which begins variably between 0.5 and 2.0 secs. before the onset of the EMG. This component is labelled N1 and has been previously demonstrated by Walter (1964) to be associated with the preparation to act.

(2) A small positive wave, P1, (not always present) of variable amplitude beginning 25 to 100 msecs. prior to the EMG.

(3) A sharp negative going phase, N2, which occurs either as an increased negativity of N1 or as a falling phase of P1. This deviates down to approximately -20 microvolts below the baseline. In almost all cases the EMG begins during the falling phase of N2.

(4) A positive wave, P2, this occurs towards the end of muscle action and does not terminate until after the end of the EMG; this is associated with the termination of muscle action as indicated in the EMG. The amplitude of P2 varies around 15-30 microvolts.

The analog wave forms obtained by Vaughan (1965, 1968, and 1970) and by Gilden (1966) clearly show that certain aspects of the MP are associated with some of the components of the muscular action.

Karlin (1970) recorded potentials above the vertex during a discrimination task where one response was to raise the finger from a noiseless key and the other was to give no overt response. He found that late positive components of the potential, similar to P2 of the motor potential, were significantly increased when the overt response was withheld. This could be interpreted as electrical activity inhibiting the firing of pyramidal tract neurons, similar to that found in the work of Creutzfeldt _et_ _al_. (1966) and of Jasper and Stephanis (1965).

2.6 The Relation of Components of MP to Muscular Performance

Considering the basic wave form of the motor potential obtained by Vaughan and co-workers as reported in this chapter, P1 could be the inhibition of any postural function, which would need to be eliminated before the required motor act could be performed. This possibility is supported by the work of Preston and of Evarts (see Section 2.1) and would be a positive going phase.

Also on the basis of the previously reported literature, it would be expected that when muscular activity is occurring, pyramidal tract neurons will be fired and a negative going wave will be recorded. The biophysical work reported by Hubbard (1969) on the generation of electrical fields, supports the idea of a negative field at the cortex surface being associated with the firing of PTNs. This is also adequately demonstrated in the records of Creutzfeldt (1966) and Jasper and Stephanis (1965).

Based on the same kind of evidence it is reasonable to expect that as an action is stopped, inhibitory synaptic activity in the cortex will take place, this electrical field being recorded at the surface of the cortex (or on the scalp) as a positive going wave.

These characteristics of the motor potentials were recorded by Vaughan (1970) during a prolonged muscular contraction. It is anticipated that similar phenomena may be displayed during the tasks performed by the subjects in this study.

Since Vaughan (1970) demonstrated a negative shift in the baseline during a given level of muscular work, it may well be that different intensities of muscular force will be associated with different displacements of the baseline. Also it may be shown that as force is increased so the negative shift will increase.

The work of Gilden (1966), Karlin (1970) and Vaughan _et al_. (1965, 1968, 1970) has demonstrated the occurrence of a negative going aspect of the MP at the beginning of the muscular activity. In these studies this relationship has varied very little on the time base. Since this is so, the negative going phase (or a criterion point on it) may be useful in predicting the timing of the beginning of motor acts. But if these acts follow closely on one another, the late components of one MP may be confused with the early components of the next. Allison (1962) showed that when the scalp potential was evoked by an external stimulus the test response was never completely obliterated even though interstimulus intervals between pairs were reduced down to three milliseconds. "The first components always being discernable." If the same holds true for motor potentials, then it may be possible to use the first component of succeeding responses to indicate the timing of voluntary movements, even when the different components of the task are relatively close together.

2.7 Chapter Summary

The hypotheses at the beginning of Chapter III are stated with the basic objective of examining the time relationships between dominant components of the motor potential and the rise and fall of muscular activity and the force generated by these contractions.

The rationale for the parameters used in this study is based to a great extent on the literature reviewed in this chapter.

If extensions of this work are to be conducted on humans without medical supervision then the measurement of cerebral function must be obtained from the scalp using surface electrodes. Research using this form of transduction to examine the relationships between cortical function and parameters of motor performance has been reviewed.

Since the active tissue producing the performance is muscle, the most closely related parameter indicating the motor response is the EMG. Without muscle activity no force would be applied and no displacement occur in the task. Therefore, as in the research of Evarts, Vaughan and others reported in this chapter, EMG will be one of the parameters measured.

It is possible for opposing muscles to overlap in their action and as a result produce no overt manifestation of their activity, therefore, to assess their effectiveness in the resulting movement, two performance parameters were measured. A force measurement was included in the work of Evarts and of Vaughan as reported above. This is important since it represents all muscular activity contributing to the performance, whereas EMG cannot be guaranteed to do this unless all muscles which can possibly contribute are monitored. Displacement of the limb indicates when the force applied by the muscles has become effective in producing movement, and hence discriminates between isometric and isotonic contraction. Angular displacement of the limb is therefore used in this study, as in the research of Evarts, but is of less importance than EMG or force since it can only have a third order relationship with the motor potential, via the muscular activity and the force generated by it.

CHAPTER III

PROCEDURES

The procedures used in this experiment are supported in the main by the literature reviewed in Chapter II. Those techniques not covered in the review follow logically from the problem, which is outlined in Chapter I.

3.1 The Motor Task

As in the studies of Vaughan (1965, 1968, 1970) it was necessary to choose a task which would provide the necessary data and yet be relatively invariate so that processsing in the computer would make the relevant wave forms stand out rather than obscuring them. Easy isolation of the body parts was necessary, so that the muscles used could be determined and the electrodes readily located above the active parts. So that the computer function could be started reliably by the rising phase of the EMG, the muscles had to be capable of generating a sharp initial signal in the chosen task. A task which made low demands on the information processing capacity of the subject was necessary so that a stable EEG was obtained and so that concentration on the performance of the task was possible.

The basic movement chosen was flexion and/or extension of the elbow as explained in Section 3.1.2. This movement was used in five different tasks performed in order from the simplest to the most complex.

3.1.1 The Basic Position

All subjects began the task seated in a chair with eyes fixed on the sweep hand of the laboratory clock. The subject's tongue was resting on the floor of his mouth, the jaw relaxed and the lips together. The non-performing arm was resting easily on the lap and the right arm (when not in motion) was resting on the elbow platform and lever handle in a totally relaxed state (see Fig. 20). The task was performed while maintaining the above general position in every experimental condition.

3.1.2 The Movement

A serial and coherent movement was used; that of flexion and extension of the right elbow from a starting position with the upper arm raised laterally to the horizontal, the elbow flexed to an angle of 90° and the hand pronated. The right hand gripped the handle of a lever which was swept from left to right, and from right to left in the horizontal plane against the resistance of a friction drum. The flexion and/or the extension movement was initiated sharply from the starting position, such that the movement of the lever was not delayed while muscular force was built up to overcome the friction of the friction drum. When the lever started to move the force was maintained to keep the movement at a constant speed throughout the excursion.

Each excursion covered a sweep of approximately 18 inches. The subject was asked to stop and totally relax the arm at the end of each movement, which commenced as the sweep hand of the clock passed each mark on the clock face. The intervals indicated by the marks were three seconds in duration. The subject was told that if he wished to move his position in any way, swallow or.blink the eyes, he was to stop the movement and totally relax the performing arm. Also he was asked to try and do as many repetitions as possible before stopping, and to try and maintain the basal condition. A few practice trials were given to the subject to enable him to reproduce on the oscilloscope, the sample wave form provided by the administrator.

3.1.3 Tasks 1 and 2

Tasks 1 and 2 involved single separate movements, for each task starting at six second intervals and lasting for approximately one second. The subject tracked the sweep hand of the clock one full turn, and when it reached the vertical began the task as previously instructed.

Task 1 consisted of extension movements and Task 2 flexion movements, hence Task 2 returned the arm to the starting position for Task 1. The subject performed 4 sets of 100 movements in each direction without counting, but maintaining full attention by tracking the sweep hand on the clock face and making a movement as it passed each mark.

3.1.4 Task 3

Task 3 involved two movements; extension, moving the arm from left to right, immediately followed by flexion, moving the arm from right to left. For the remainder of the dissertation, this task will be referred to as the "return movement". The subject was instructed not to tense the arm excessively as the change of direction was made, to totally relax between trials and to try to make all movements the same length. The subject performed 4 sets of 100 return movements without counting, starting each trial as the sweep hand on the clock face passed each mark.

3.1.5 Task 4

Task 4 was a return movement as for Task 3 but in the opposite direction. The subject was instructed to try to give a mirror image of the performance of Task 3.

3.1.6 Task 5

Task 5 was a continuous task with alternating movements, performed without rest until the required number of trials had been completed. In order to control for the effects of extraneous eye movements the subject was asked to track the sweep hand of the clock until the task was completed. The subject performed 4 sets of 100 movements.

3.2 The Motor Task Apparatus

A lever was designed to move left and right in a horizontal plane against the resistance provided by an adjustable friction drum. A hand grip, formed to take the shape of the fingers, was mounted at the end of the lever. Above the friction drum at the proximal end of the lever was attached a sponge covered platform on which the subject rested the elbow (see Fig. 21). A laboratory clock which the subject observed, had a 9 inch diameter face and took 15 seconds to sweep the 360 degrees. The normal clock face was covered with white paper on which high contrasting marks were placed to represent 3 second intervals. The clock was placed 10 feet away, and directly in front of the subject.

3.3 Measurement of Dependent Variables

The rationale underlying the selection of dependent variables is covered in Section 2.7 at the end of the review of literature, and the method of relating these variables is covered in Section 4.3 before considering the resultant relationships in the different tasks.

3.3.1 Angular Displacement of the Arm

A variable potentiometer CRL B16 1/5 was inset into the platform above the pivot point. The bottom arm of the potentiometer was attached to the lever and moved with it. The top arm was fixed to the mounting at the back of the apparatus and remained stationary. As the arm moved the voltage conducted by the potentiometer was linearly related to the angle of displacement of the arm (for calibration see Appendix E). The change in voltage conducted by the potentiometer was suitably amplified through a Honeywell Accudata 113 amplifier. After amplification the wave form was monitored on a Tektronics 2 channel oscilloscope, 3603, written out on a Honeywell strip chart recorder, Visicorder 1912, as a permanent visual record, and recorded on magnetic tape on a Hewlett Packard 3911 instrumental tape recorder for later analysis.

3.3.2 Force Generated by the Movement

Attached to each side of the lever was a Newark strain gauge, gauge factor 2.02, which was wired as part of a Wheatstone Bridge. The change of electrical potential produced by the bridge gave an indication of the changes in force being applied to the lever (for calibration see Appendix D). The varying voltage from the strain gauges was amplified and recorded on a similar system to that described for angular displacement immediately above.

3.3.3 Muscle Potentials

During performance of the movements, muscle potentials (EMG) were recorded from the long head of biceps brachialis (flexor); and from the triceps (extensor). Basmajian (1962) reviewed electromyographic research and reported that the long head of biceps acted throughout the movement of flexion and showed more activity than the short head during slow flexion of the forearm. On the action of extension of the elbow Basmajian stated that "...the medial head (of triceps) is always active and appears to be the prime extensor of the elbow."

Silver electrodes 10 mm in diameter (separated from the skin by an electrode cup containing conducting jelly) were used to transduce the electrical potentials generated by the muscles.

A series of pilot studies was conducted to check the performance of the electrodes and to find the frequency range on the amplifier filters giving the clearest muscle signals. The frequency range selected was 15 to 500 cycles per second. This setting gave a sharp rise in the EMG from the base-line up to 150 microvolts (the voltage level chosen to trigger an analog signal averager, described later).

The EMG signals for both flexor and extensor actions were amplified by Honeywell Accudata 135 EMG/EEG amplifiers. These have an input impedance of 10 megohms and a frequency response of 0.05 cps to 5,000 cps, thus being capable of amplifying the EMG signals without distortion.

3.3.4 Motor Potentials

Vaughan *et al*. (1965, 1968, 1970) described potentials recorded from the scalp and from the surface of the cortex which were associated with the occurrence of muscular activity. These they called motor potentials. The object of this study is to relate components of these motor potentials to the time of occurrence of the rise and fall of the EMG and force waves. For the recording of these scalp potentials it was necessary that the electrodes were small for easy application and adjustment, and that they could be applied to the surface of the scalp so that any future application of this work can be conducted either in clinical or field situations without medical attention. The characteristics required of the electrodes to perform the above function can be seen in Appendix K.

The scalp electrodes used in this study were made by the experimenter to the same specifications as those used by Skov and Simons (1965) for in-flight monitoring of EEG.

The actual scalp location was determined using a tape measure and the position marked with a skin pencil. A small amount of hair was removed to accommodate the plastic electrode insert which was 1/4 inch in diameter. The surface of the skin was abraided with a number 7 dental bur and the electrode insert glued in place using medical collodion. After measurement of electrode impedance the electrode cap was glued in place over the small plastic insert. Leads were attached to the electrodes and to the Honeywell EEG/EMG preamplifier, which in turn was coupled to the main Honeywell console. The EEG was amplified by a Honeywell Accudata 135 amplifier at a frequency range of 0.05 to 50 cycles per second. After amplification the EEG waveform was recorded on paper along with the other dependent variables by the Honeywell stripchart recorder, and on magnetic tape by the Hewlett Packard 3911 tape recorder. Using the preamplifier and Accudata 135 amplifier provided 200,000 times amplification. Using full amplification of the two stages gave a full-scale reading of 1 volt for a 5 microvolt signal. This was more than adequate for recording on magnetic tape and for analysis in the DEC PDP8I analog computer.

3.4 Subjects

Three graduate male students aged between 20 and 30 years were chosen from the population available at the University of Alberta, Faculty of Physical Education. The selection of subjects was based on availability, freedom from any obvious perceptual-motor problems and being right handed.

3.4.1 Number of Subjects

The choice of using only three subjects, a significant departure from most studies in physical education, was based upon the following rationale. This research is basically to establish whether in any human, it is possible to predict the onset and end of muscular activity from dominant aspects of the motor potential. If this prediction was supported it would then be possible to conduct a study with several subjects, to establish the variability between subjects hence producing not only a tool for further research, but also a diagnostic instrument for the assessment of the status of patients with motor performance deficiencies.

With electrodes applied externally to the scalp as in this study, the experimenter can never be sure that the recording is being taken over the desired cortical area, even though the motor cortex is more reliable than other cortical areas in its relationship to dominant topographical points on the cranium (Cunningham, 1967; Woolsey, 1952). The use of three subjects gave more chance of recording motor potentials (presumably generated by the cortex) which were related to components of the task. It also provided the opportunity of comparing the variability among three subjects as an indication of what might be found in future.

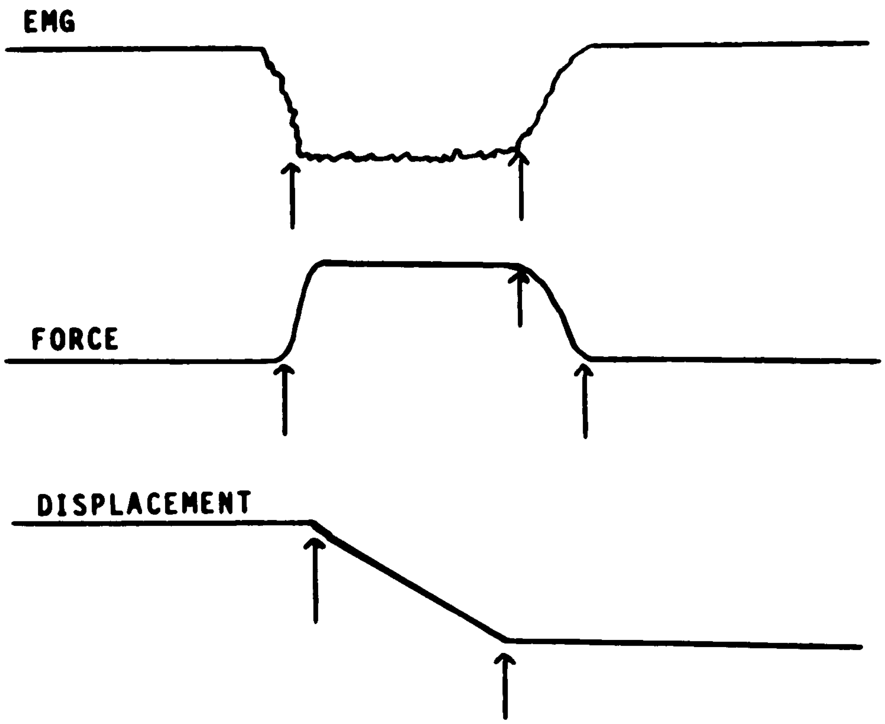
3.4.2 Handedness of Subjects

Vaughan (1965, 1968, 1970), Gilden (1966), Karlin (1970) and others have demonstrated that scalp potential recordings are clearer and less transient on the contralateral side of the motor cortex from the performed movement. Consequently handedness tests for clear right hand dominance, as described by Provins (1956) were considered necessary. Results of these handedness yests are shown in Appendix A.

3.5 Measurement of the Data

3.5.1 Occurrence of Coincident Wave Forms

In examining the time relationships among traces, major potentials in the EEG were looked for in association with the rise, fall and end of force, the rise and fall of the EMG and the beginning and end of displacement. The arrows in diagram show where dominant motor potential spikes were looked for in the different phases of EMG, force and displacement.



The shape of the EEG was also examined to see if its general form followed that of either force trace or EMG.

3.5.2 Latency Between Relevant Wave Forms

Where dominant wave forms on the different traces were related, latencies were measured between these components and mean latencies and range of latencies were determined. The criterion points for the measurement on the different wave forms were as follows:

(A) On the EEG; after scrutinizing the wave form it was decided to use the peak of positive or negative components since the rest of the trace was extensively influenced by noise.

(B) On the EMG; the time of the steepest rise in the rectified EMG was used since this would be above any muscular noise generated by general muscle tension, but would indicate the activity related to performance of the task.

A general idea of the time of steepest fall in the EMG could also be detected, but this was not clear enough for a definite allocation of a time point.

(C) On the force trace; the time points chosen were those indicating greatest rise in force and greatest fall in force, since these were likely to be related to the steepest rise and fall in EMG.

(D) Displacement of the lever; although this parameter was of secondary interest since it could show, at best, a third order relationship with the motor potential, time points were examined indicating the beginning and end of movement.

3.6 Experimental Design

Based upon the problem and the task specifications essential to answering the problem, the following design was established.

The investigation consisted of varying a single factor with five levels, Tasks 1 through 5 as described in Section 3.1 of this chapter. Since all subjects participated in all levels of the experimental factor, the design adopted can be described as a complete block, repeated measures; or, a treatments by subjects design.

3.7 Order of Presentation of Tasks

The order of presentation adopted for this investigation was that of sequential order from Task 1 through Task 5 for all subjects. The reasons for adopting such an order are as follows. One of the objectives of the study was to determine whether some component of the motor potential could be used to predict the onset of muscular activity, not only in discrete spaced movements, but also in serial movements more closely spaced.

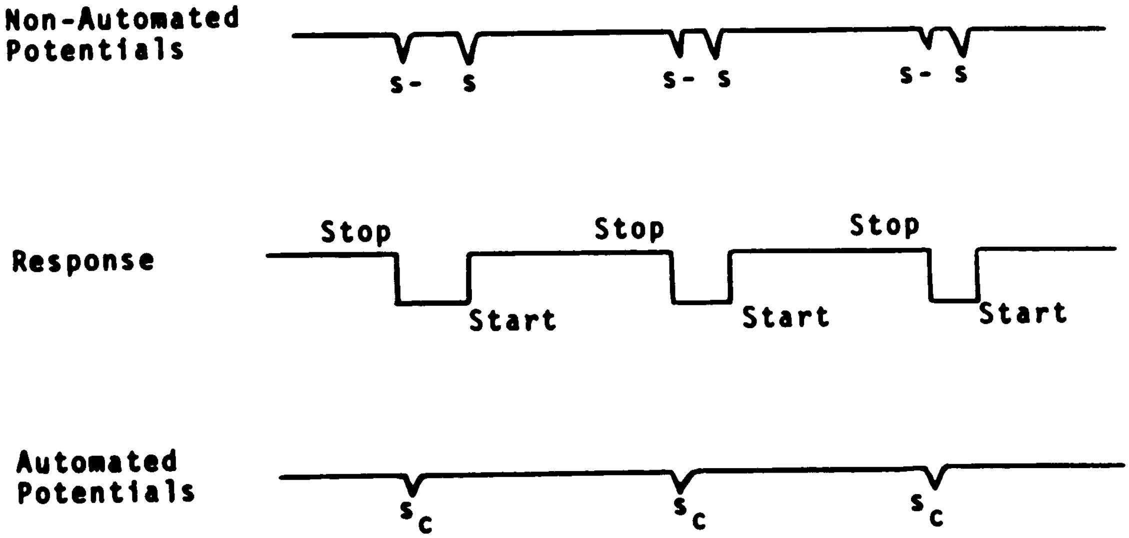
Vaughan (1965) found a motor potential associated with the initiation of discrete movements at three second intervals. The tasks used by Vaughan were sharp dorsiflexion of the foot, dorsiflexion of the wrist, various movements of the hand and movements of the face and tongue. Before proceeding with serial movements it was necessary in this study to demonstrate a similar relationship between the motor potential and the flexion and extension movements of the elbow performed as discrete tasks. It was therefore logical to start with the simplest task and proceed to the more complex.

Another reason why the increasing order of complexity was used, was to see if automation of the task would be demonstrated. One of the manifestations of automation is the serial chaining of the components of the task as suggested by Greenwald (1970). In this, the situational stimuli (as demanded by the experimental condition) are replaced by response produced stimuli. These response produced stimuli could be a result of feedback from the overt performance or short loop feedback from the plan of performance which is being fed out to the muscles. In the application of serial chaining to this experiment the following may be stated. As indicated by Vaughan in the study reported in 1970, waves coincident with both the rise and the fall of muscle activity may be manifest. If both these components occur for each movement and if they are negative going spikes then the non-automated potentials as indicated below can be expected for a serial task. If serial chaining takes place after continued practice then automated potentials as indicated below may take their place. This would indicate that the spike associated with stopping has become the spike which is also associated with the beginning of the movement which immediately follows (see diagram on page 42).

3.8 Pre-Experimental Preparation

3.8.1 Preparation of Equipment

Before the subject arrived all apparatus was turned on



and warmed up for 30 minutes. Amplifiers were preset to the gain and frequency response found most suitable in pilot studies. Each channel of information was positioned appropriately on the strip chart recorder and calibration spikes were recorded; 25 microvolts for EEG, 1 millivolt for EMG1 and EMG2, and 2 millivolts for force and displacement channels.

3.8.2 Preparation of the Subject

The handedness determination was carried out prior to the experiment. One or two days before the experiment the subject was given instruction on the basic task. These instructions included information on the basic position, details of how the movement was to be performed and the specific requirements of the experimental variations. Examples of the noise effect of extraneous movements on the recordings were shown to the subjects, along with normal traces (see Appendix C).

When the subject arrived in the laboratory he was reminded of the requirements of the task and the different variables which could cause artifacts in the recordings. The examples (Appendix C) were again shown to the subject. Instructions to the subject were read from the sheet which he had previously studied.

3.8.3 Location of EEG Electrodes

In order to sample the activity of appropriate populations of neurons in the motor cortex, careful placement of electrodes was essential. The technique used for location of the place on the scalp above the elbow area of the cortex on the left hemisphere was based on the recommendations of Vaughan *et al*. (1968), who plotted the median motor potential amplitudes for different movements. Reference was also made to the homunculus drawn on a cross-section of the hemisphere by Penfield and Rasmussen (1950); and to Cunningham (1967) who outlines a practical method of electrode location. First, the nasion (the bone junction where the forehead joins the nose) and the inion (the protruberance at the extreme occipital pole of the cranium)were located and the distance between these measured. At the half distance between these two points a mark was made on the scalp with a skin pencil. A line was then taken from the tragus (the bone junction immediately anterior to the ear) on one side of the head to that on the other. Where the mid-point of this line crossed the nasion-inion mid-point was marked, and considered to be the vertex of the skull. This measurement technique is the same as that used in the 10-20 international system, now commonly used in hospitals and recommended by Cooper (1969). From the vertex a point was located 3 cms laterally over the left hemisphere, on the vertex-to-tragus line. 1 cm anterior to this point was taken to be the scalp location directly over the elbow area of cortex.

3.8.4 Measurement of Electrode Impedance

After application of the electrodes as indicated in Section 3.3.4, the skin-to-electrode impedance was measured. For this a variable frequency sine-wave generator and an AC impedance bridge were used. So that the current passed did not reach a level of any danger to the subject it was monitored on an oscilloscope and was held at 25 millivolts. This current level is recommended by manufacturers of EEG equipment (IMA Electronics, 1971). The impedance was measured in the frequency range 5-60 cycles per second. These are the approximate frequency components of the results reported by Vaughan (1965, 1968) and Karlin (1970) in their studies on motor potentials. Cooper (1969) recommends that this impedance be not in excess of 5 K ohms. It was found in the EEG Department of the University of Alberta Hospital that if the impedance was brought down to approximately 2 K ohms less noisy recordings were consistently obtained. This criterion was therefore used in this study. After the measurement of skin-to-electrode impedance the electrode caps were glued firmly in place using collodion.

3.8.5 Attachment of EMG Electrodes

As indicated in Section 3.3.3 EMG recordings were taken from the long head of biceps brachialis and from triceps. On biceps the electrodes were attached approximately 1 inch apart on the belly of the lower 2/3 of the muscle. Redox electrode jelly was put into the electrode cups which were attached to the arm using Beckman two-sided electrode stickers. The extensor electrodes were similarly attached to the medial side of the triceps muscle level with the insertion of the deltoid.

Since the EMG electrodes are large compared with those for EEG, and since the muscle potentials are also larger, the problem of impedance is not vital to the measurement, therefore no impedance measures were taken of the EMG electrodes.

3.8.6 Positioning of the Subject

After the application of the electrodes the subject was seated in a padded upright chair looking away from the recording equipment and towards the experimental clock. The subject was given the general instructions concerning the task and was reminded to avoid those actions which contributed to noisy recordings. The room lights were dimmed and the subject given one or two trials after the position of the arm on the task apparatus was checked. During these few trials the signal levels were checked for each of the dependent variables and any adjustments made to the recording equipment.

3.9 The Experiment

3.9.1 Single Movement (Tasks 1 and 2)

The specific instructions concerning Tasks 1 and 2 (see Appendix C) were read to the subject, the experimental clock was started, the strip chart recorder and the tape recorder were switched on and the subject quietly told to begin when he was ready.

During each series of trials the experimenter counted the number of sweeps performed as they were recorded on the paper, watched for abnormalities in the performance of the subject and monitored the EEG and EMG1 on the two channel oscilloscope. It also proved necessary to monitor the strip chart write-out in order to watch for abnormalities in the performance of the DC amplifiers. On several occasions base-line drift occurred in the displacement and force recordings, making adjustments to the amplifiers necessary.

After each 50 sweeps the subject was stopped if he appeared disturbed in any way. A rest of 1 minute was allowed and then the experiment began again as before. The subject was stopped after every 100 sweeps, allowed to remove the performing arm from the apparatus and allowed to relax for 2 minutes. The above procedure was continued until the subject had completed 4 sets of 100 sweeps of extension and 4 sets of 100 sweeps of flexion. This completed Tasks 1 and 2. The subject was then allowed to stand, leave the task apparatus and move around as far as the electrode leads would allow.

3.9.2 Return Movement (Task 3)

After a 5 minute rest the subject returned to the task apparatus, assumed the basic position and prepared himself to begin the new task.

The specific instructions concerning Task 3 were read to the subject and this phase of the experiment was begun as for the single movement. During the performance the experimenter monitored the subject and the various pieces of equipment making adjustments where necessary, counting the number of sweeps and watching for abnormalities in the data recorded on the paper. Rest periods were provided as for the single movements.

The return movement in Task 3 started with the lever at the left side of the sweep, moved to the right and without rest returned to the left.

After completion of this task the subject was again given 5 minutes of rest.

3.9.3 Return Movement (Task 4)

The Task 4 movement started at the right side of the sweep, moved to the left and without rest returned to the right.

The specific instructions concerning Task 4 were read to the subject, an additional statement being made that he should try to make the performance a mirror image of Task 3. The rest of this phase of the experiment was conducted as for the previous phase.

3.9.4 Continuous Movement (Task 5)

The Task 5 movement started at the left side of the sweep and continued moving to right and left without pause until the set of sweeps was completed. The specific instructions concerning Task 5 (see Appendix C) were read to the subject before beginning this phase of the experiment. The subject was reminded of the shape of the force waveform required and asked to maintain concentration for the remaining portion of the experiment.

After the final task was completed the electrodes were removed from the subject, the appropriate skin areas were thoroughly cleaned and the subject thanked for his cooperation.

3.10 Treatment of Data

3.10.1 Examination of Visicorder Write-Out

The five channels of data written out by the Visicorder were examined for gross abnormalities, especially of the EEG trace. A record was made of the numbers of the sweeps which appeared to be abnormal so that during averaging they could be eliminated from the sweeps which were processed.

3.10.2 Examination of Tape Recorded Data

Samples of the data recorded on the magnetic tape were examined using an oscilloscope to check for adequacy for averaging and for voltage level.

3.10.3 Averaging of Recorded Data

A DEC PDP8I laboratory computer was used to obtain averages of prescribed numbers of sweeps for the different tasks. The averages were first displayed on the computer oscilloscope and then written out on graph paper using a Hewlett Packard X-Y plotter.

3.10.4 Recording of Events and Calculation of Statistics

Tables were collated of the coincidence of dominant components of the motor potential with different aspects of the EMG and force traces.

Means were calculated of the latencies between the motor potential components and the steepest rise and fall of EMG and force traces. The range of these latencies were also determined. These statistics were calculated wherever time points could be allocated to the different components of the wave forms.

In addition the motor potential, EMG and force traces were examined for general consistency of shape.

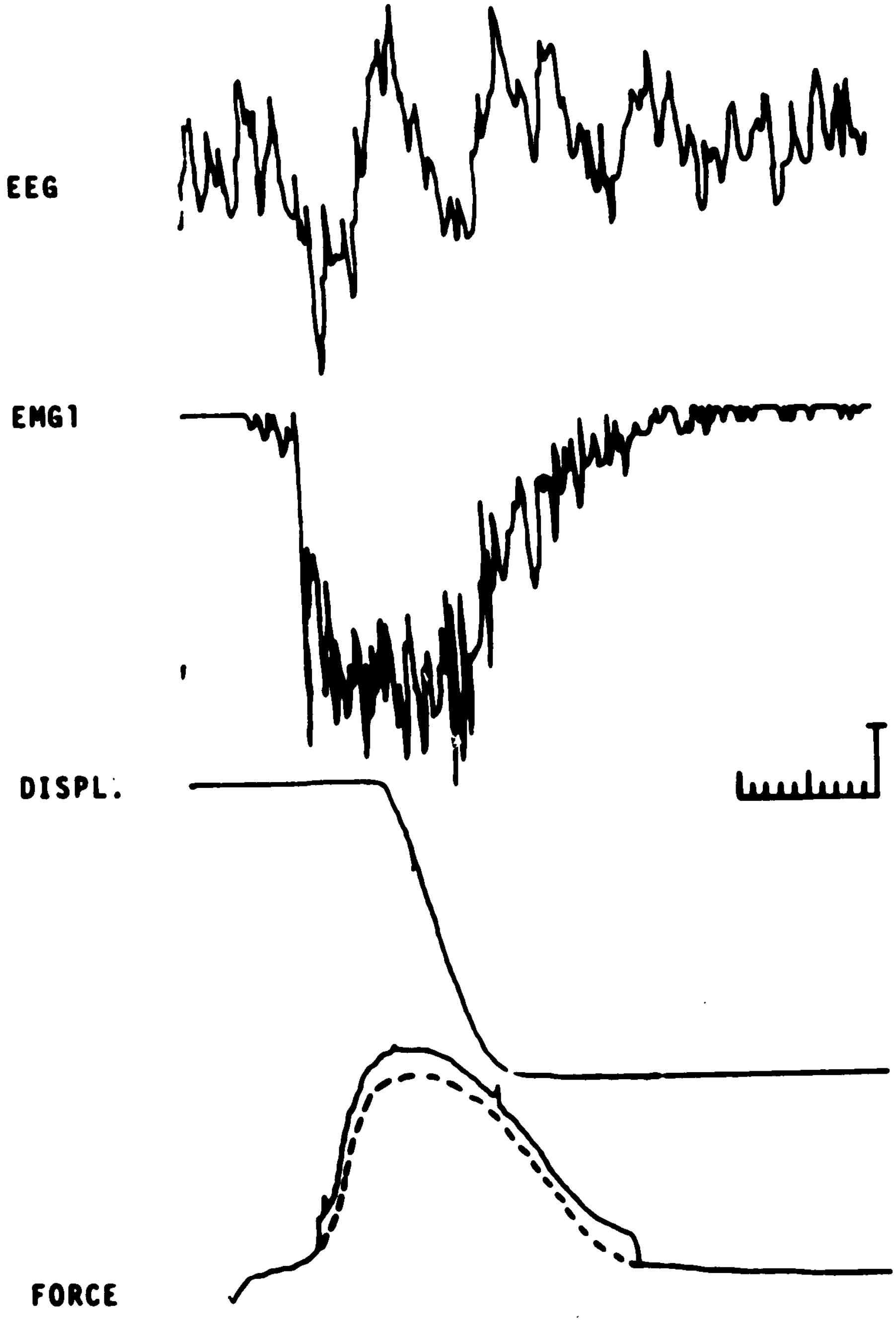


Fig. 1 Subject 1, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

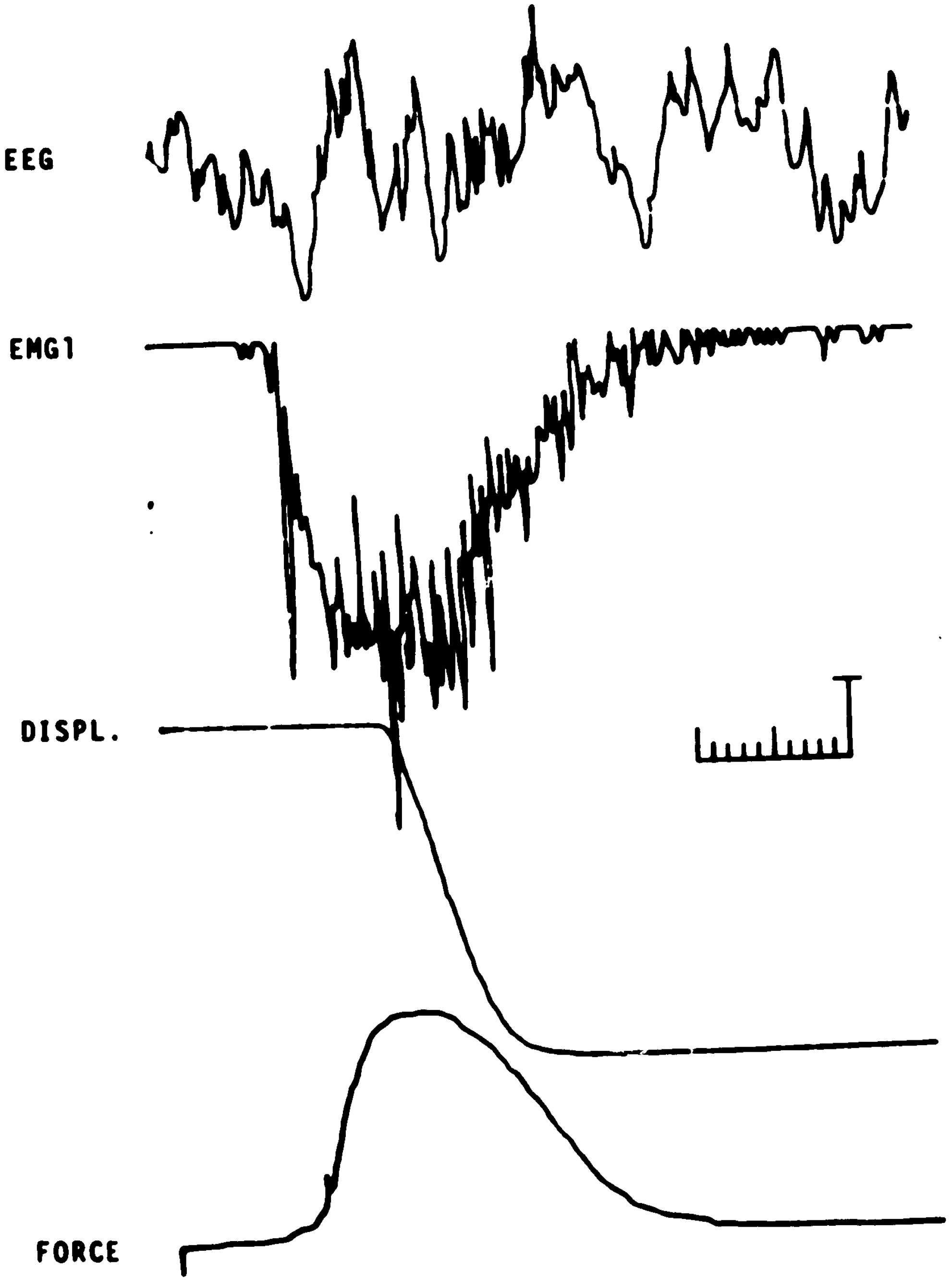


Fig. 2 Subject 1, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

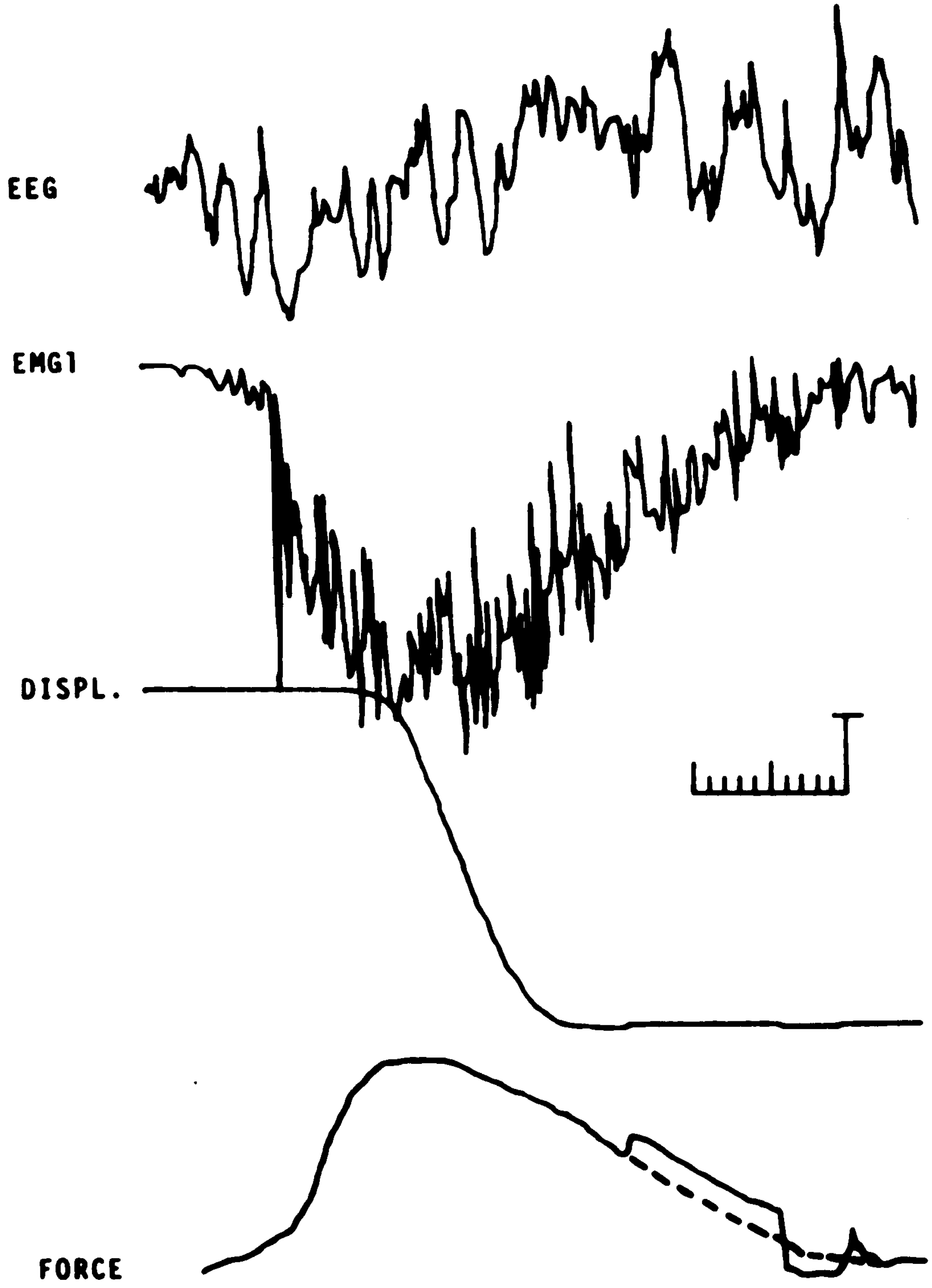


Fig. 3 Subject 1, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

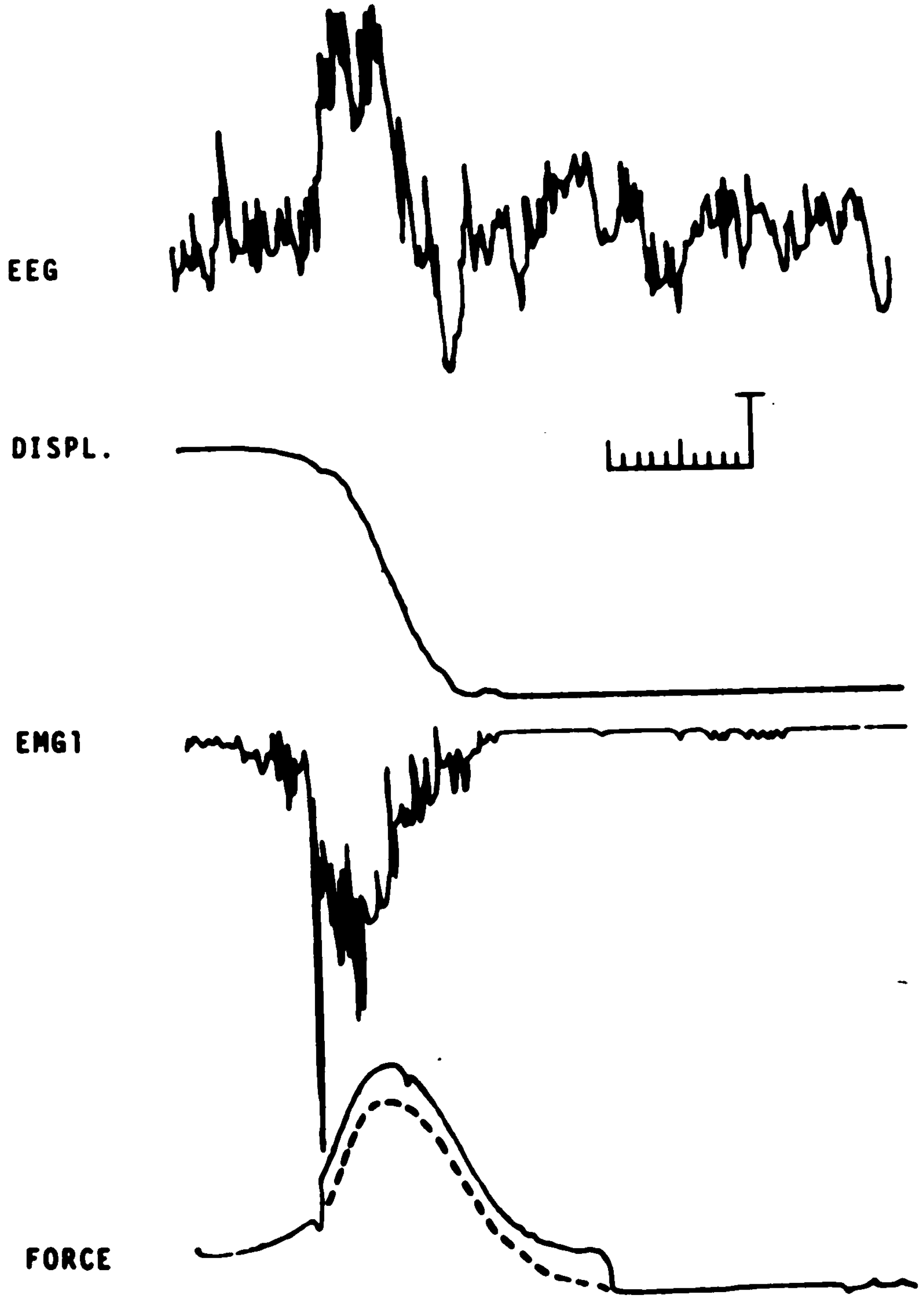


Fig. 4 Subject 2, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

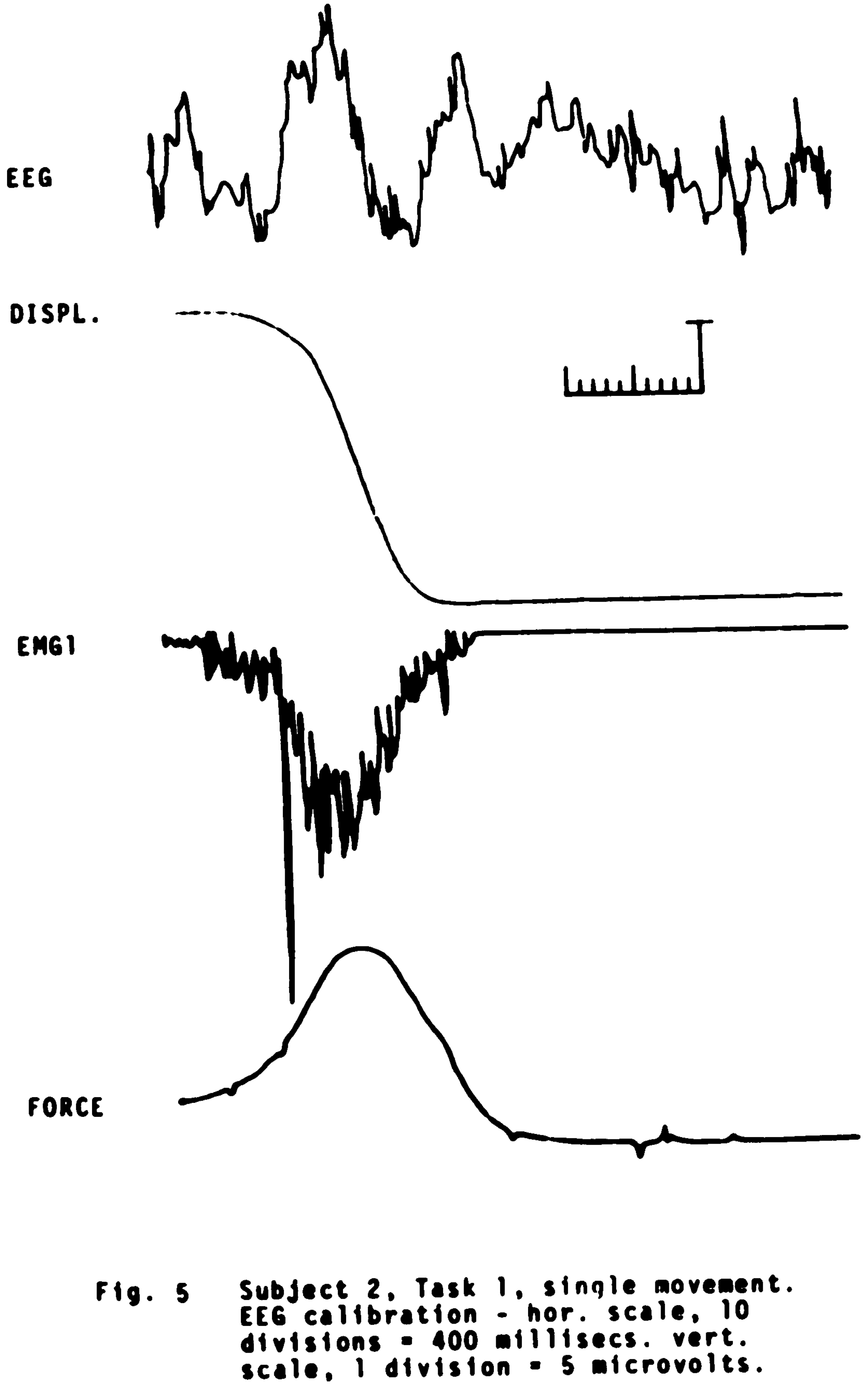


Fig. 5 Subject 2, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

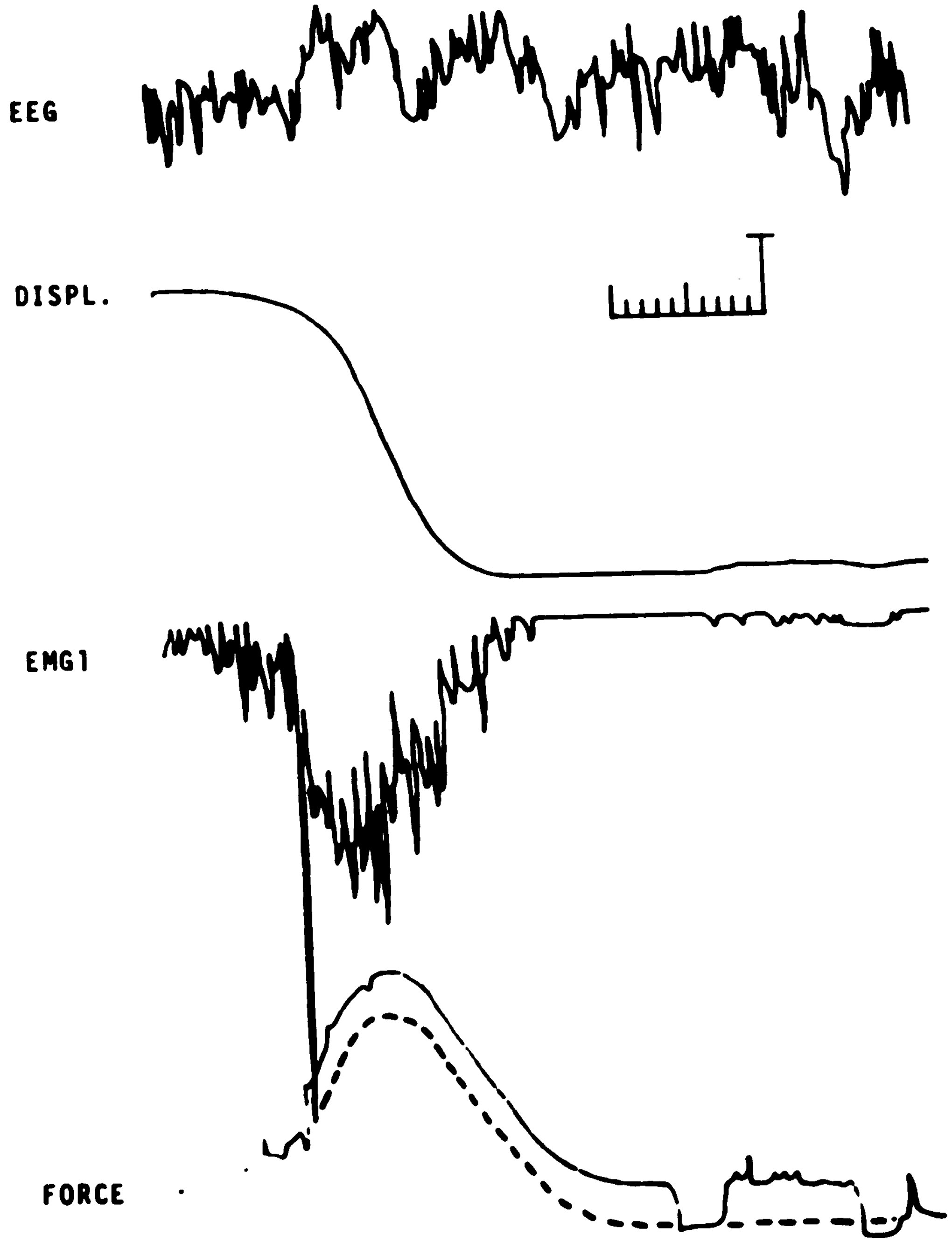


Fig. 6 Subject 2, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

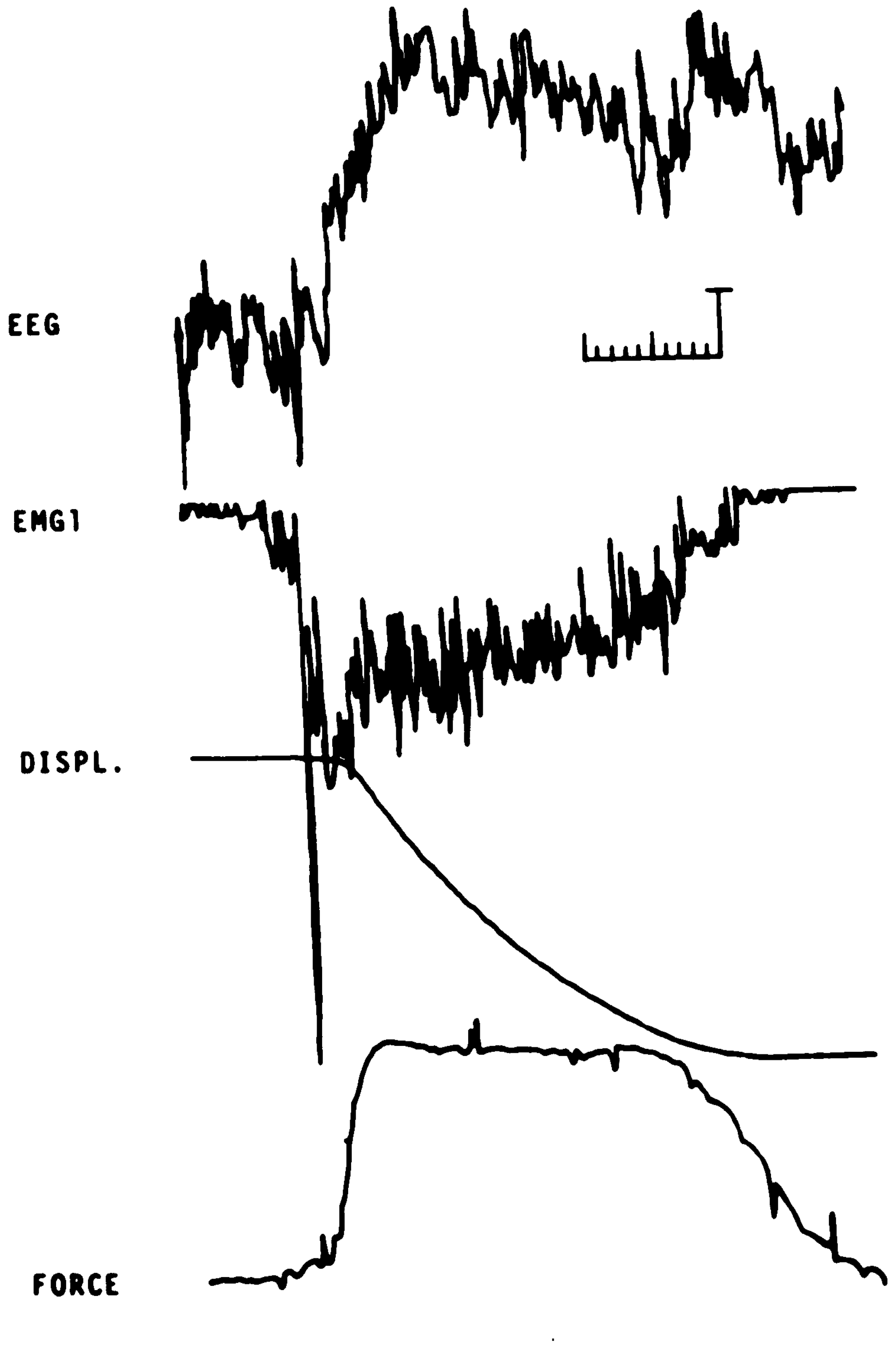


Fig. 7 Subject 3, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

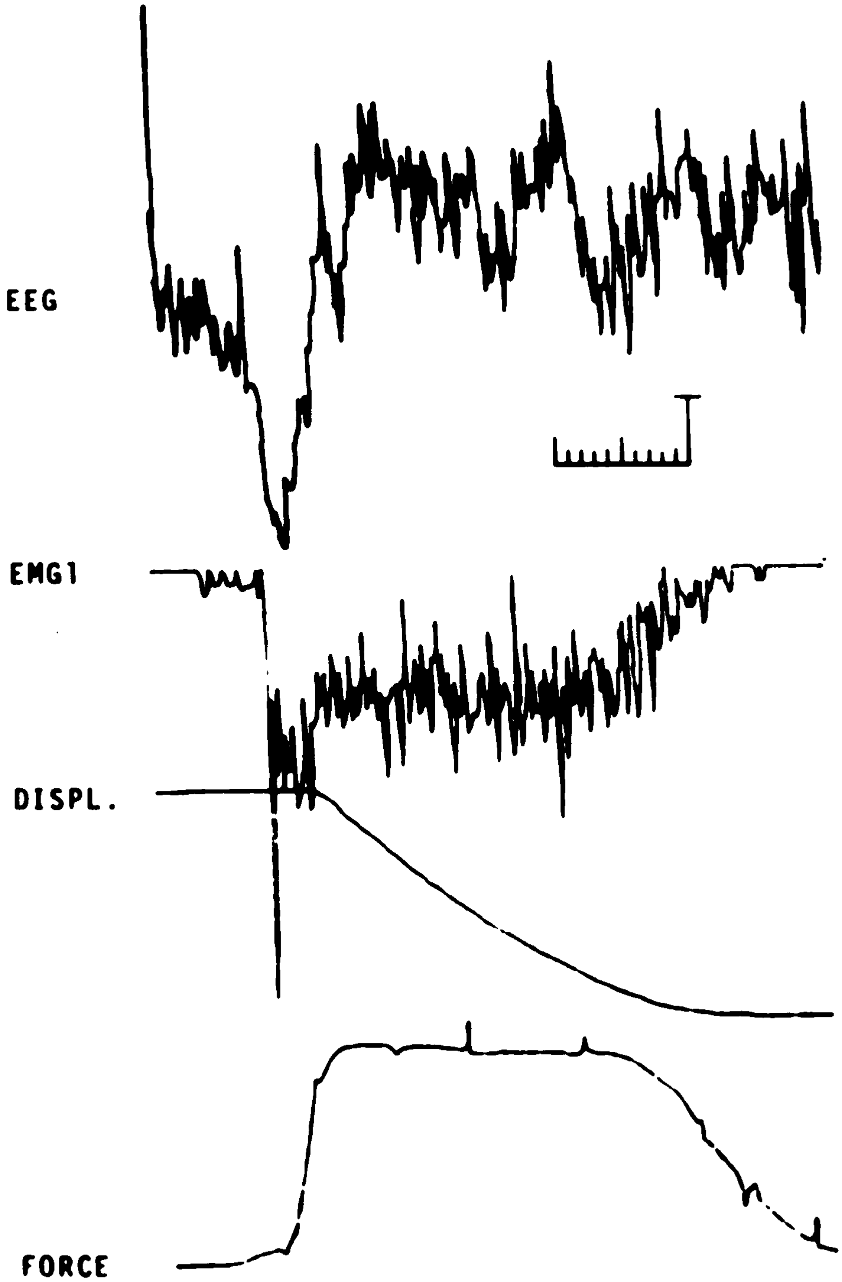


Fig. 8 Subject 3, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

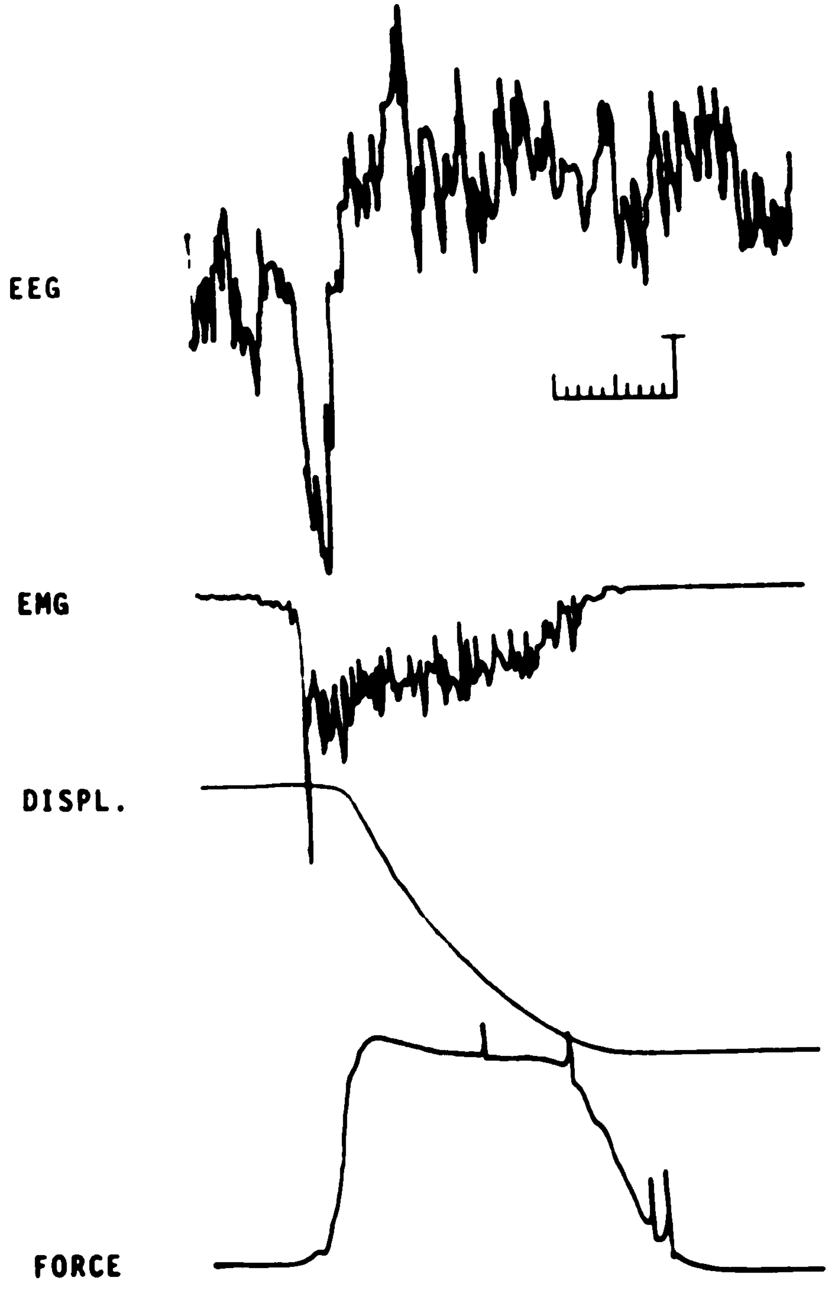


Fig. 9 Subject 3, Task 1, single movement. EEG calibration - hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.

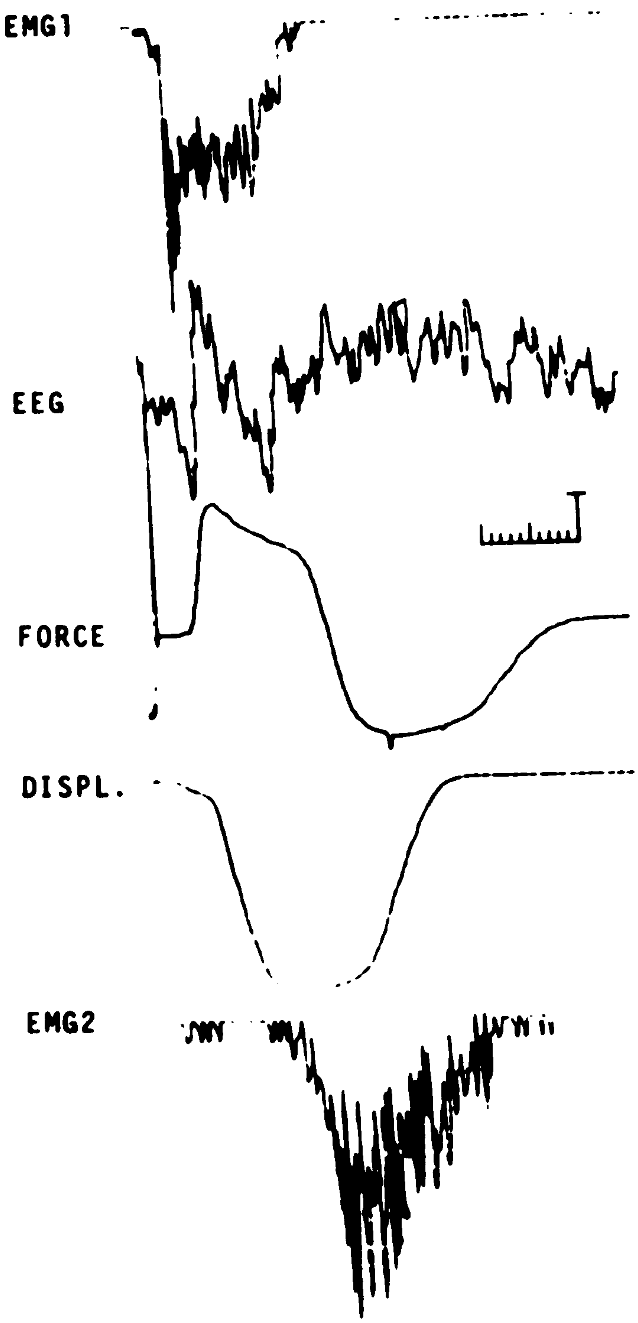


Fig. 10 Subject 1, Task 3, return movement. EEG calibration - hor. scale, 10 divisions = 480 millisecs. vert. scale, 1 division = 5 microvolts.

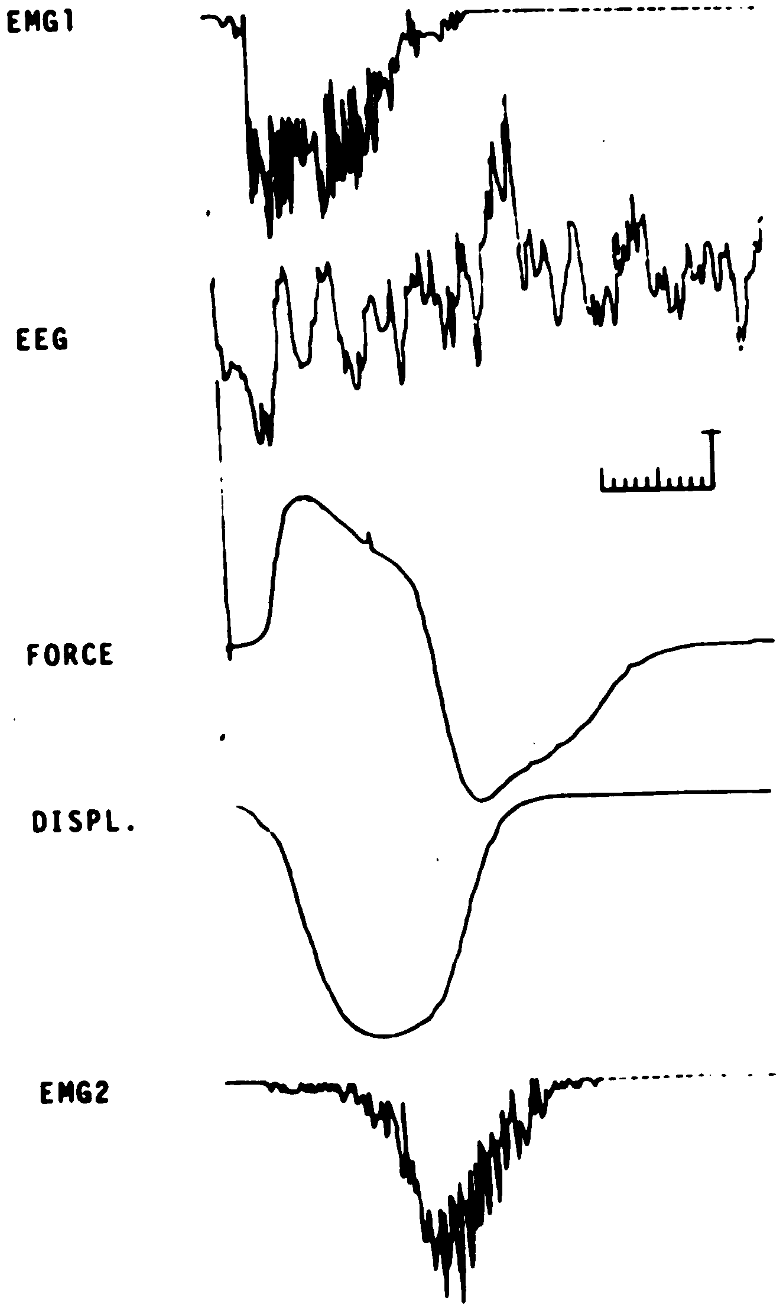


Fig. 11 Subject 1, Task 3, return movement. EEG calibration - hor. scale, 10 divisions = 480 millisecs. vert. scale, 1 division = 5 microvolts.

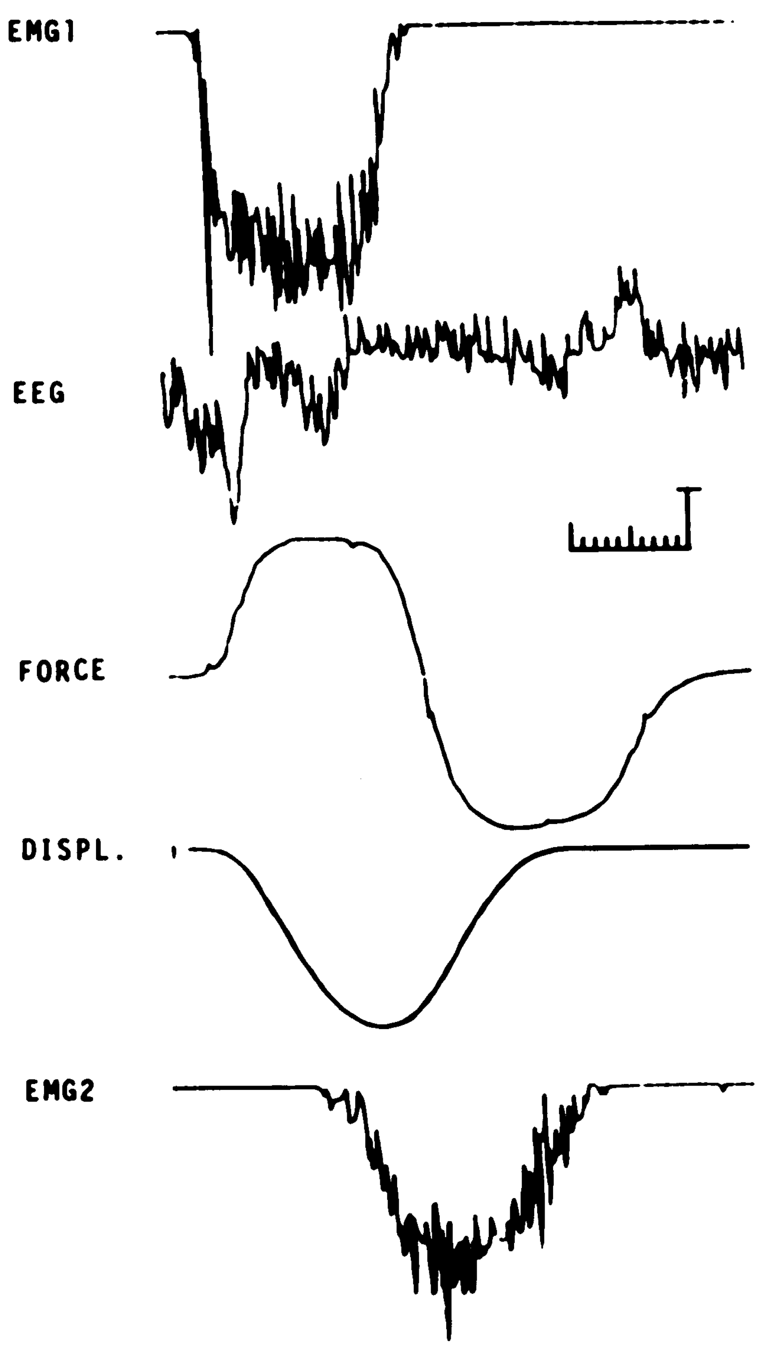


Fig. 12 Subject 3, Task 3, return movement. EEG calibration - hor. scale, 10 divisions = 480 millisecs. vert. scale, 1 division = 5 microvolts.

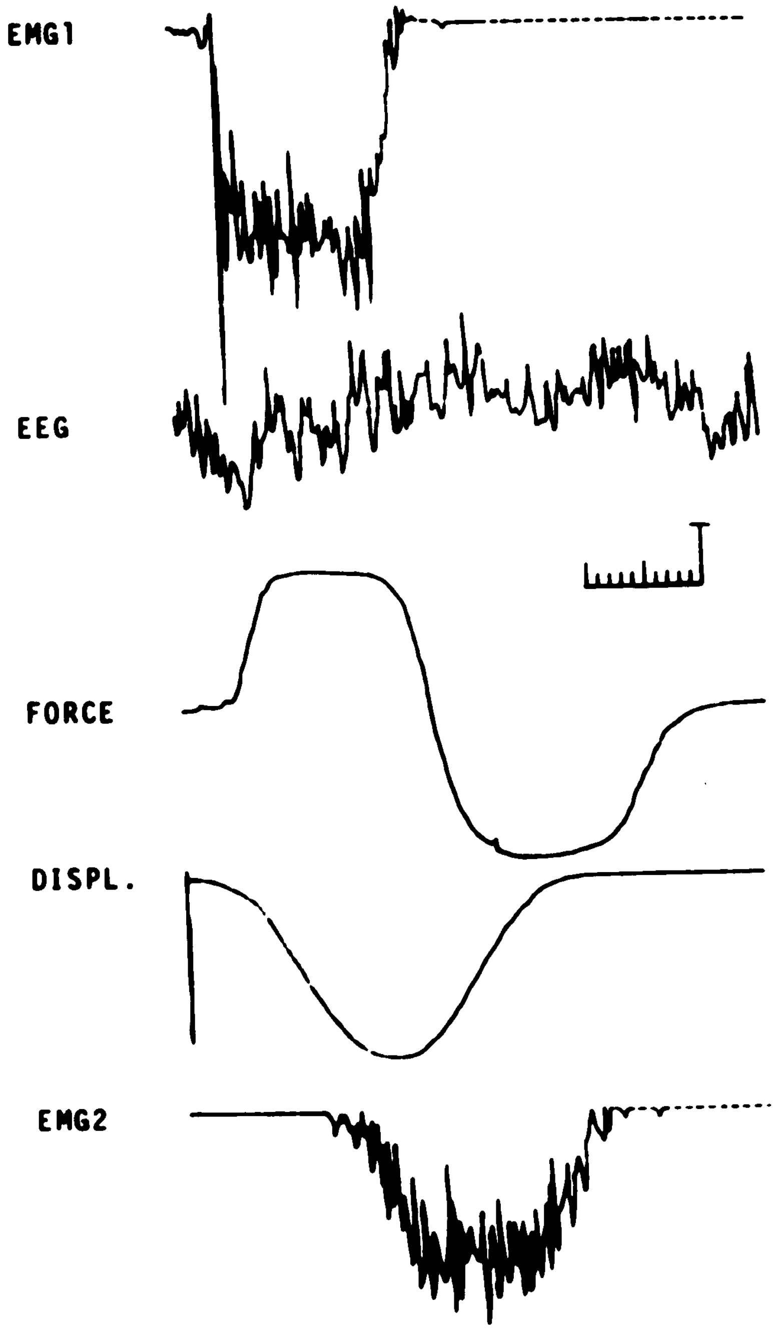


Fig. 13 Subject 3, Task 3, return movement. EEG calibration - hor. scale, 10 divisions = 480 millisecs. vert. scale, 1 division = 5 microvolts.

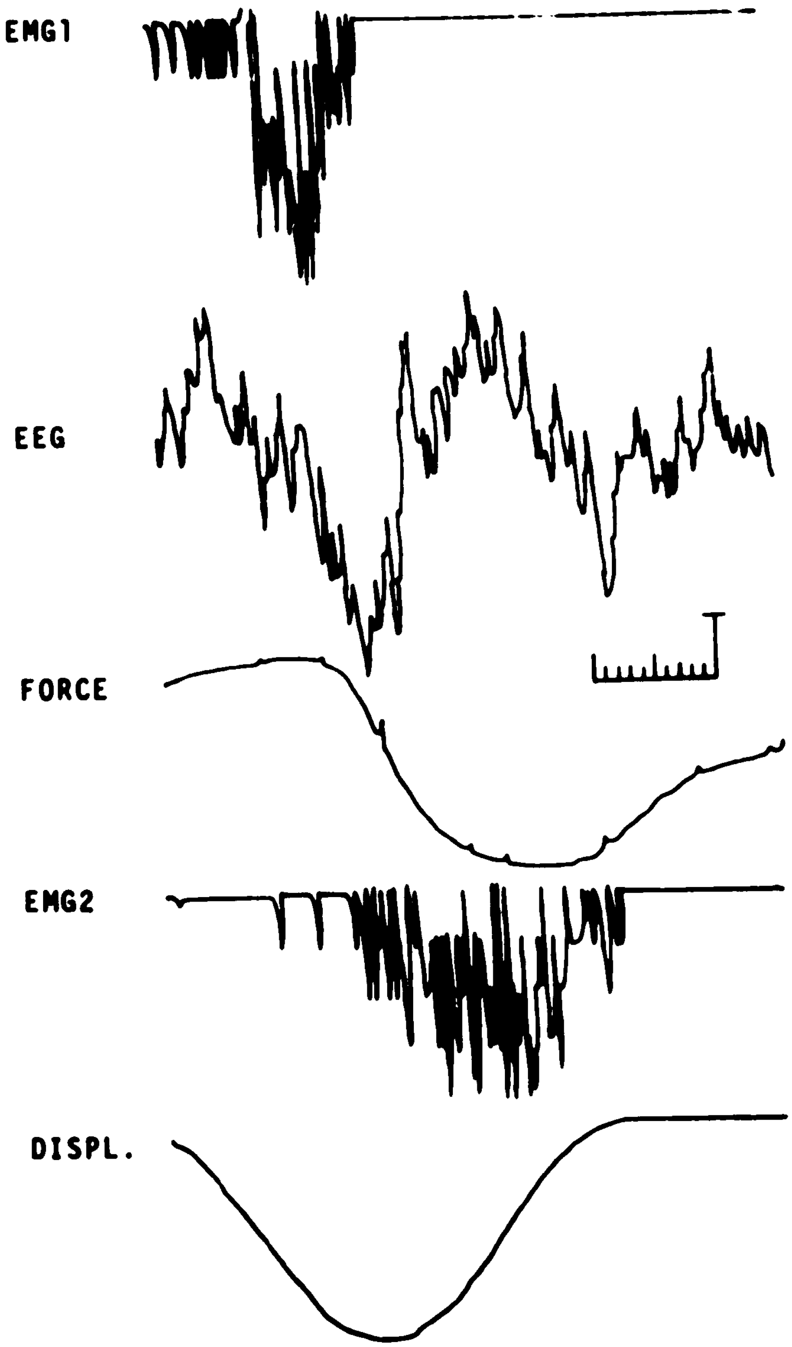


Fig. 14 Subject 2, Task 3, return movement. EEG calibration - hor. scale, 10 divisions = 480 millisecs. vert. scale, 1 division = 5 microvolts.

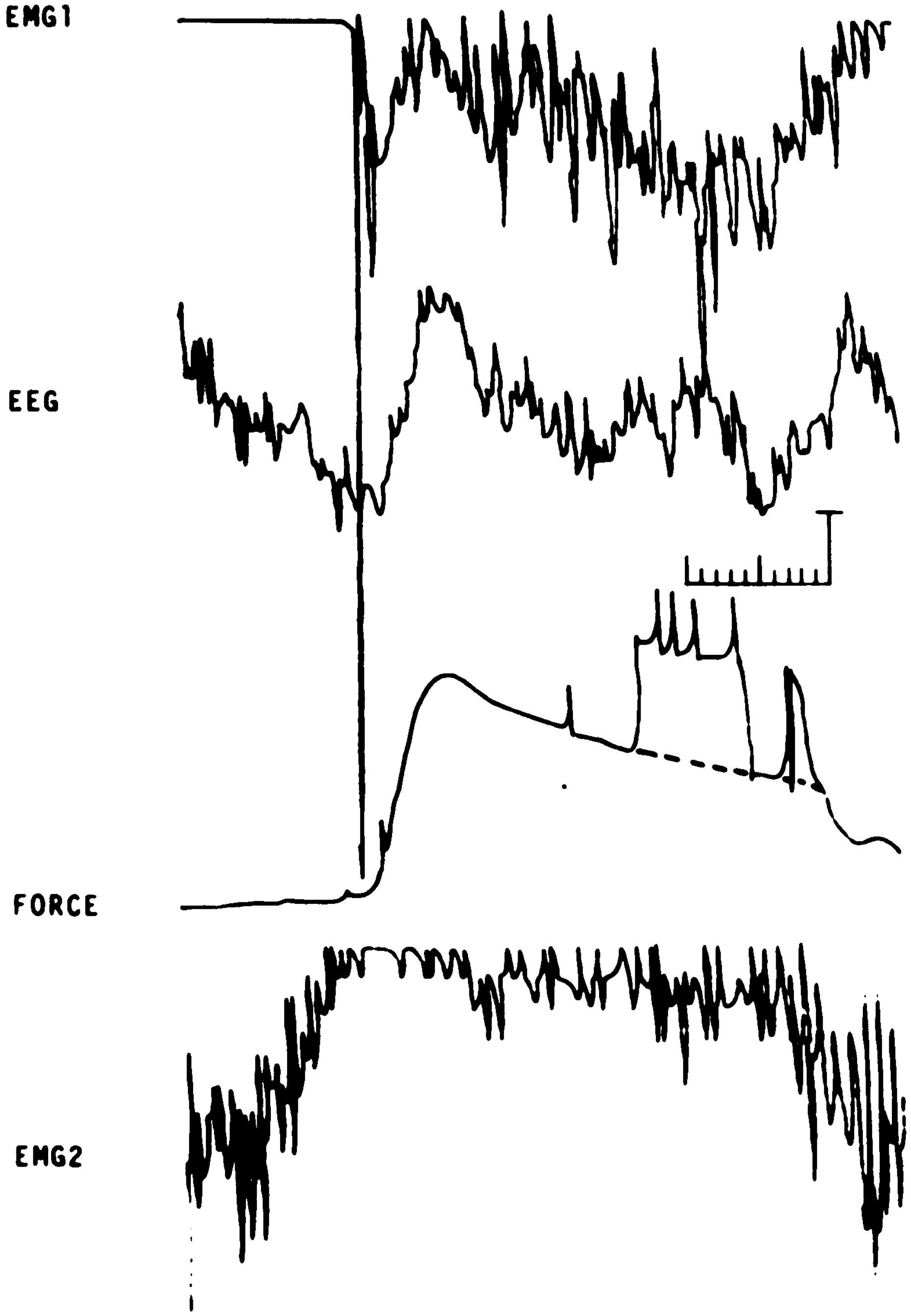


Fig. 15 Subject 2, Task 5, continuous movement. EEG calibration - hor. scale, 10 divisions = 320 millisecs, vert. scale, 1 division = 5 microvolts.

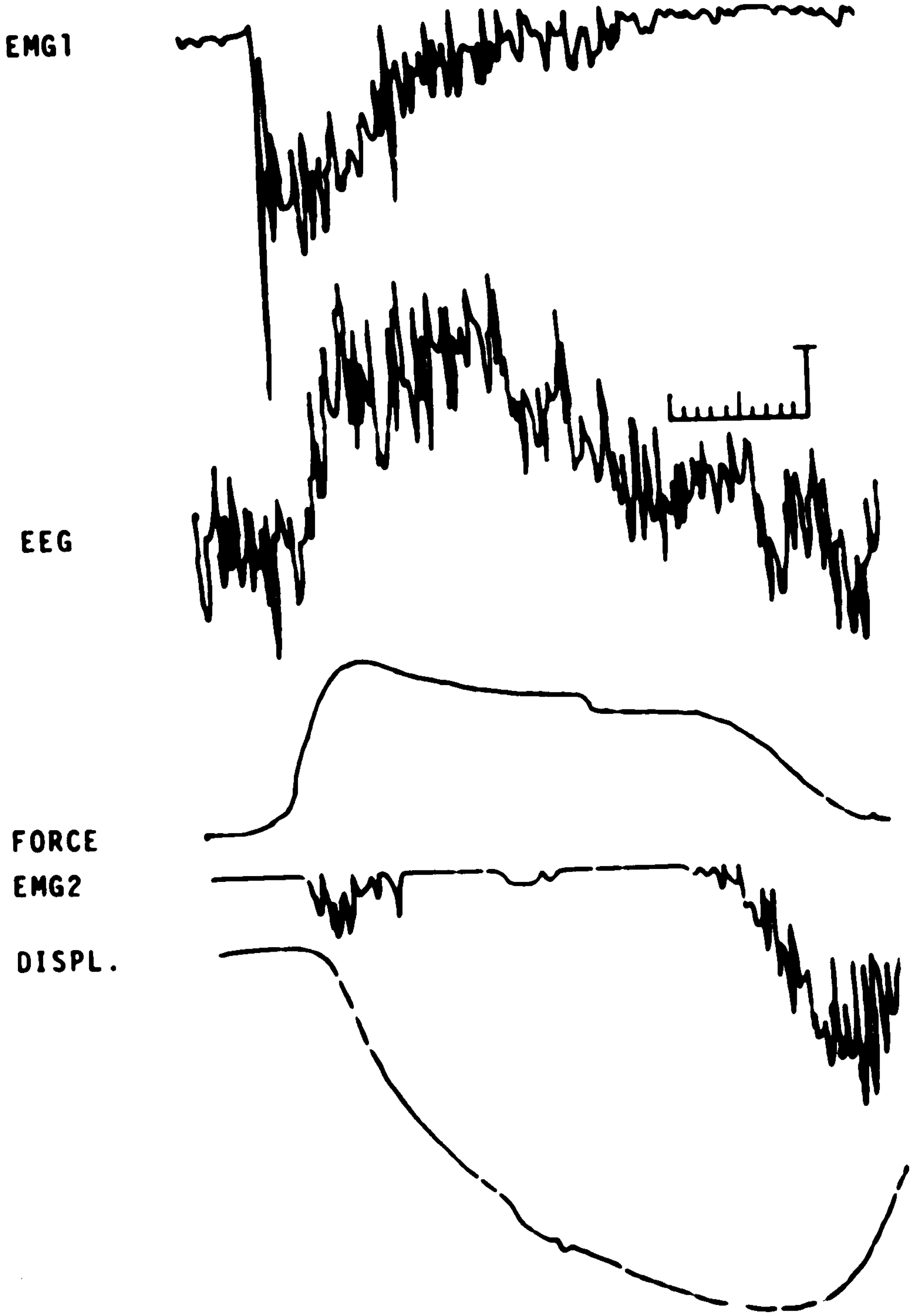


Fig. 16 Subject 3, Task 5, continuous movement. EEG calibration - hor. scale, 10 divisions = 340 millisecs. vert. scale, 1 division = 2.5 microvolts.

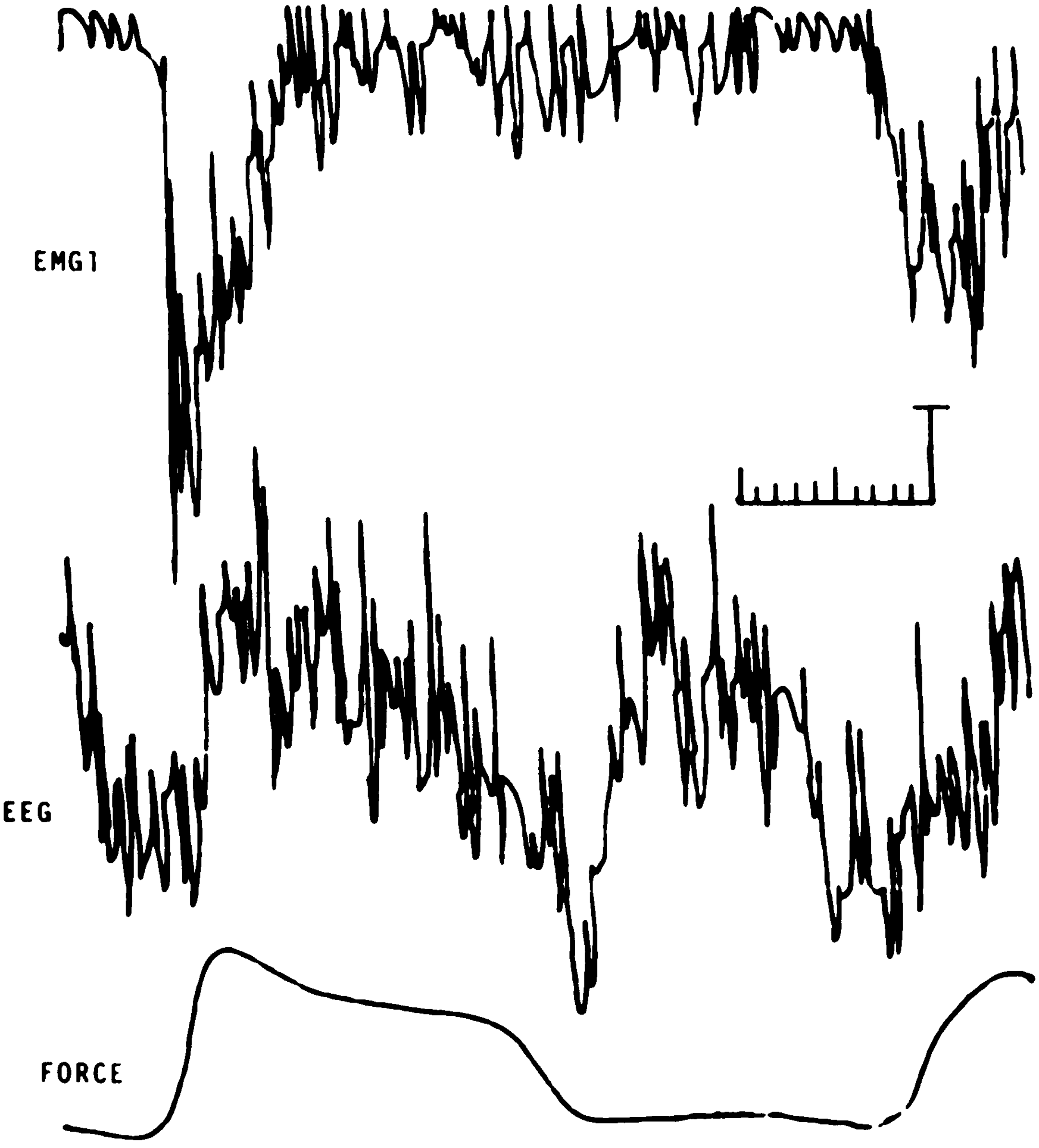


Fig. 17 Subject 3, Task 5, continuous movement (double epoch time). EEG calibration - hor. scale, 10 divisions = 680 millisecs, vert. scale, 1 division = 2.5 microvolts.

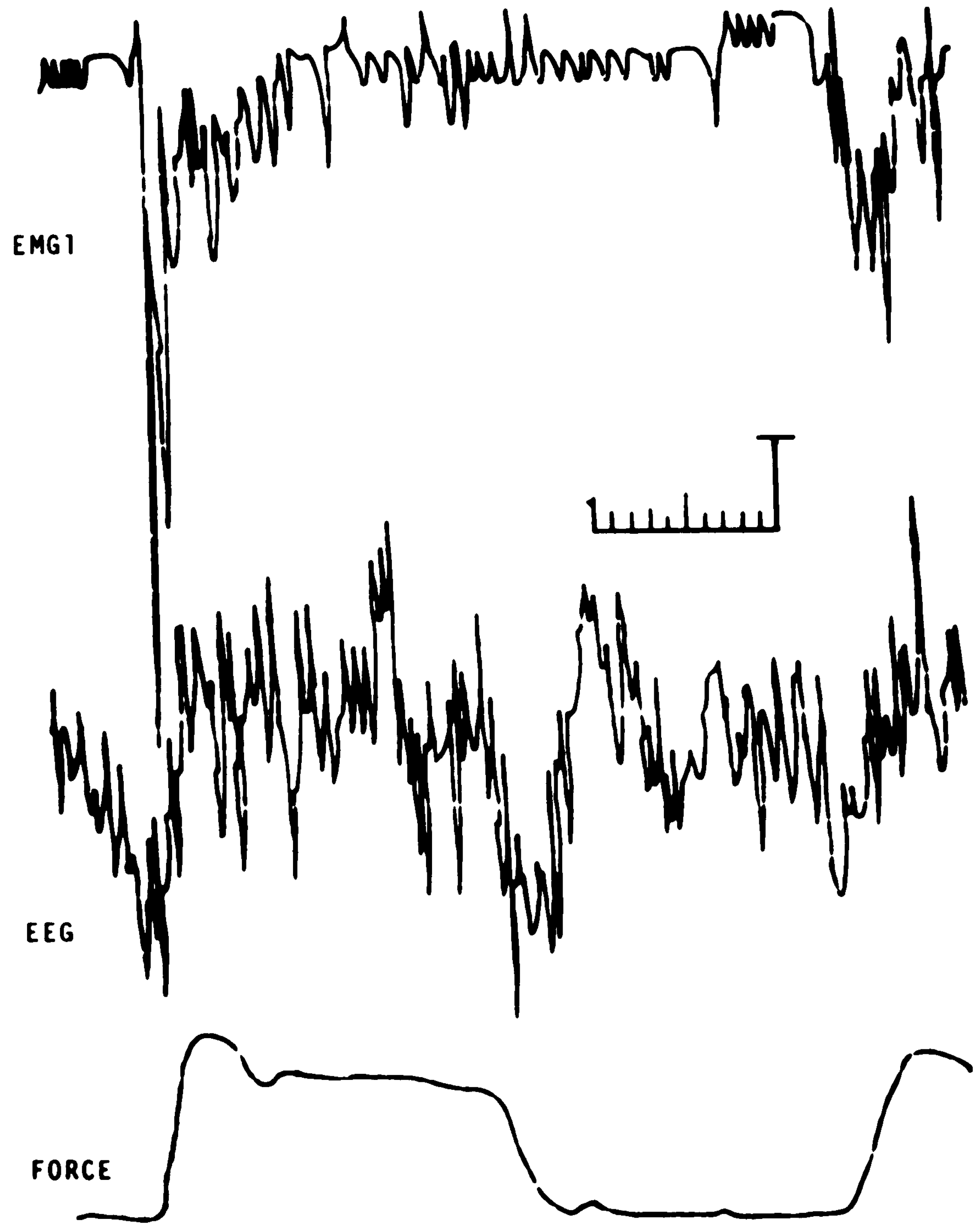


Fig. 18 Subject 3, Task 5, continuous movement (double epoch time). EEG calibration - hor. scale, 10 divisions = 680 millisecs, vert. scale, 1 division = 2.5 microvolts.

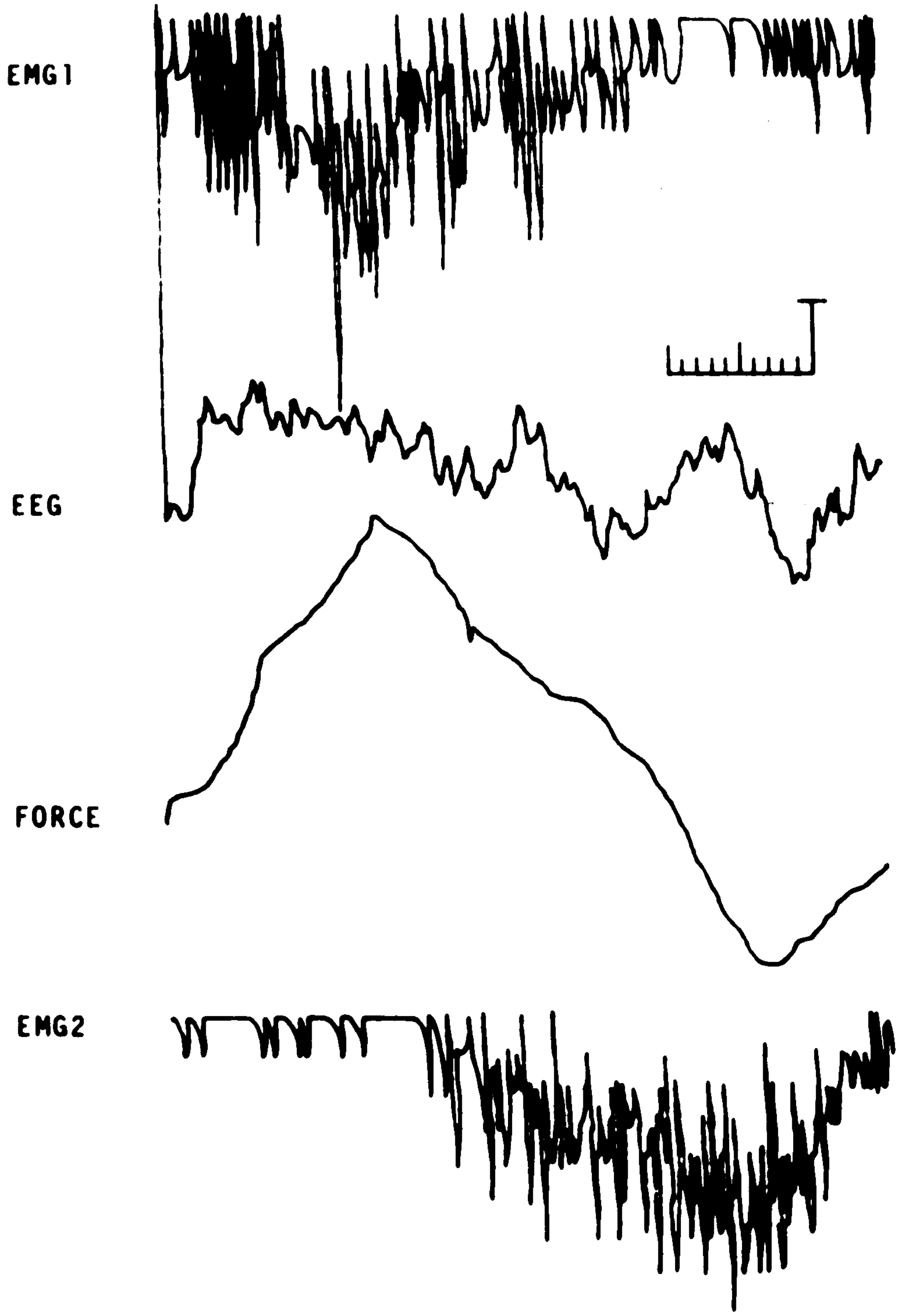
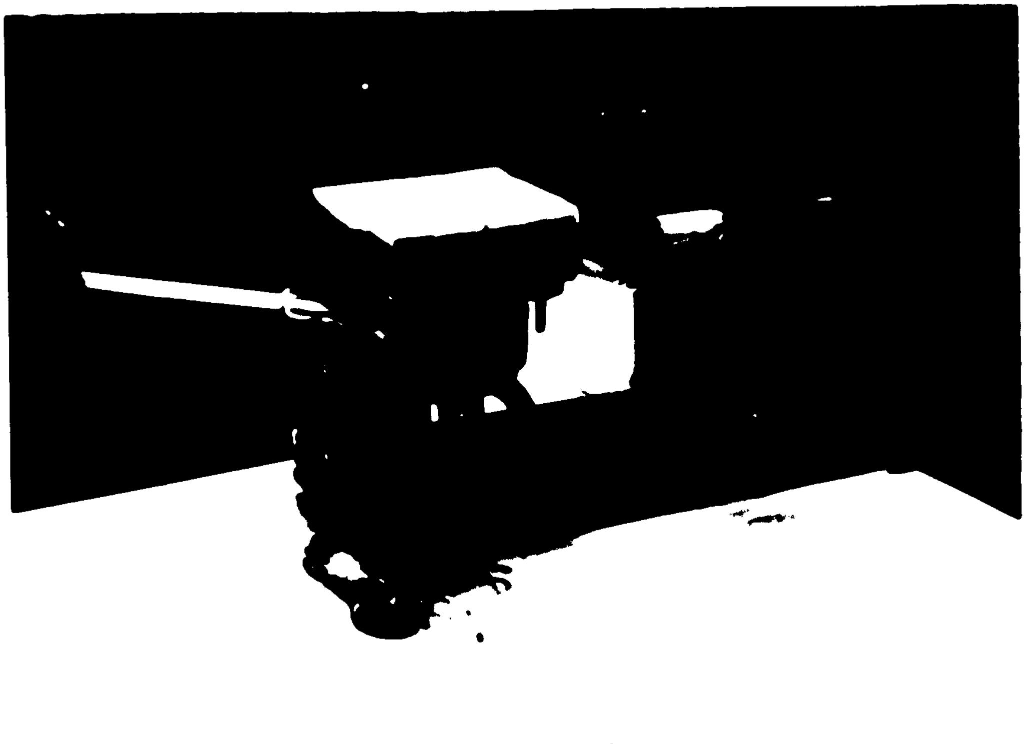


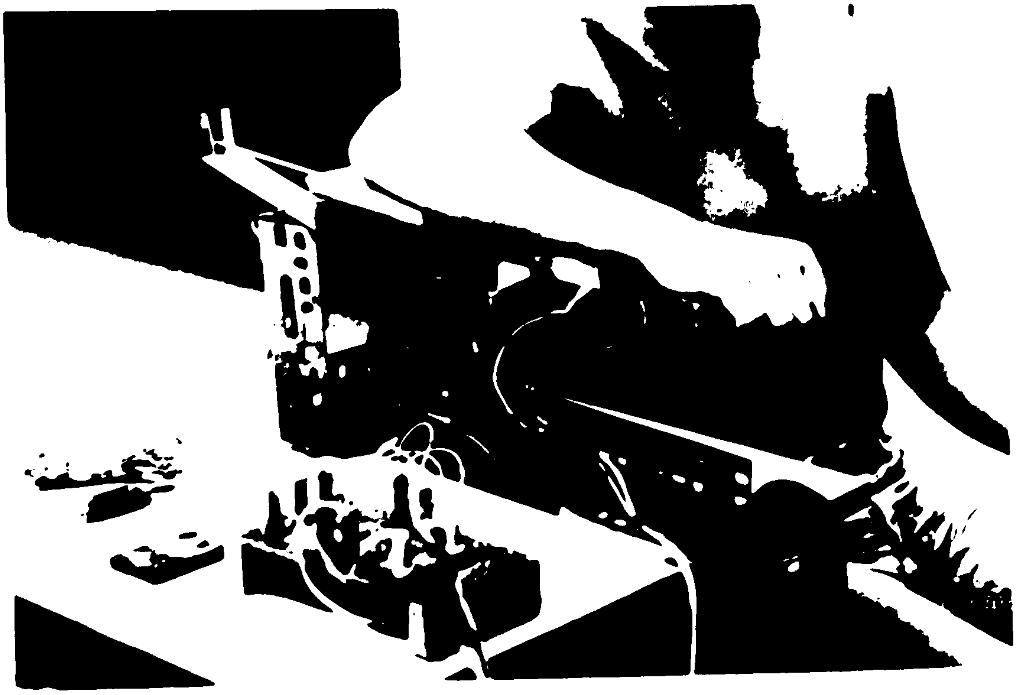
Fig. 19 Subject 1, Task 5, continuous movement. EEG calibration - hor. scale, 10 divisions = 320 millisecs, vert. scale, 1 division = 5 microvolts.

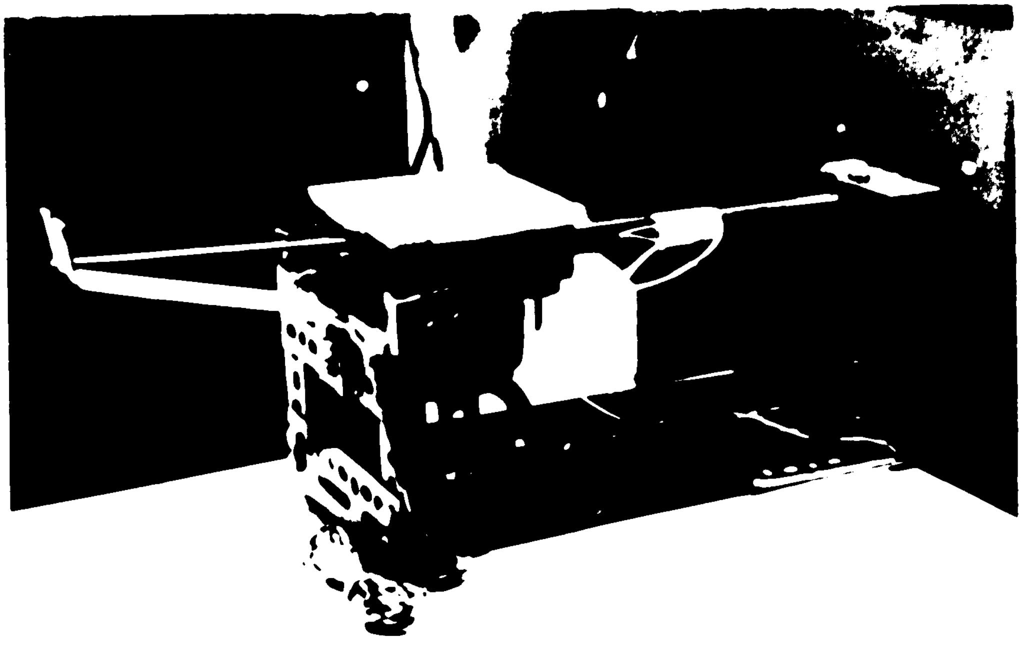
Fig. 20

Fig. 21



Task apparatus, elbow resting on platform above friction drum, and strain gauges shown on side of lever.





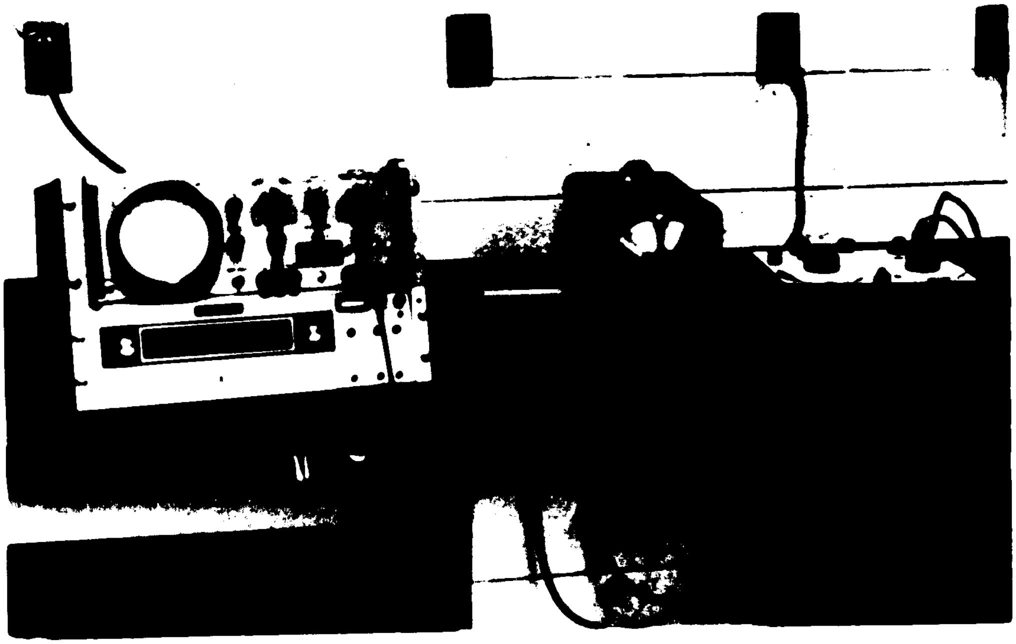


Fig. 22 Impedance measuring equipment

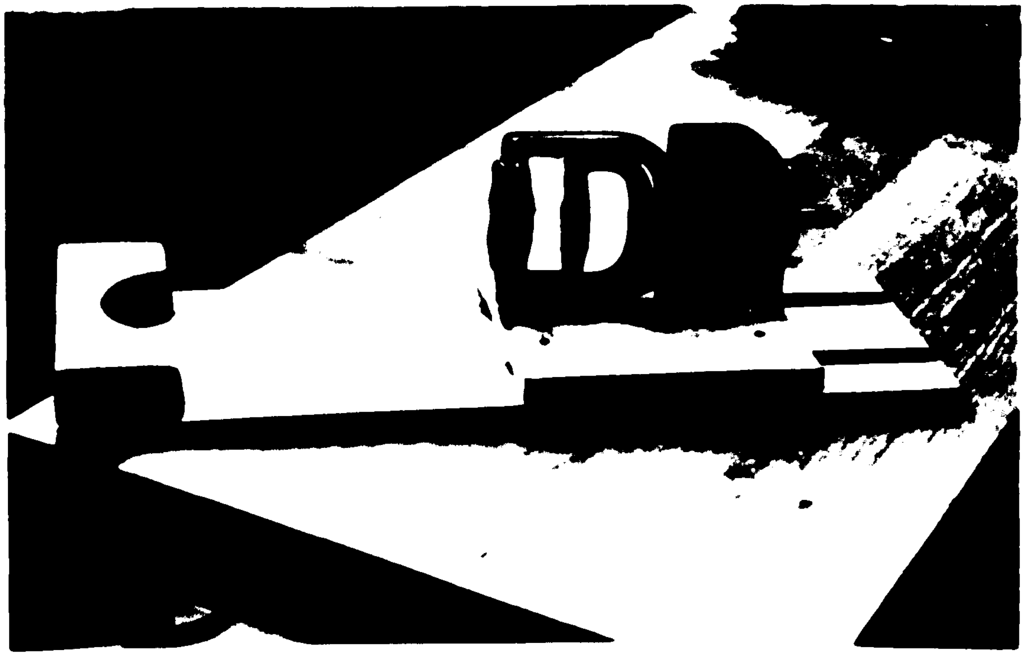
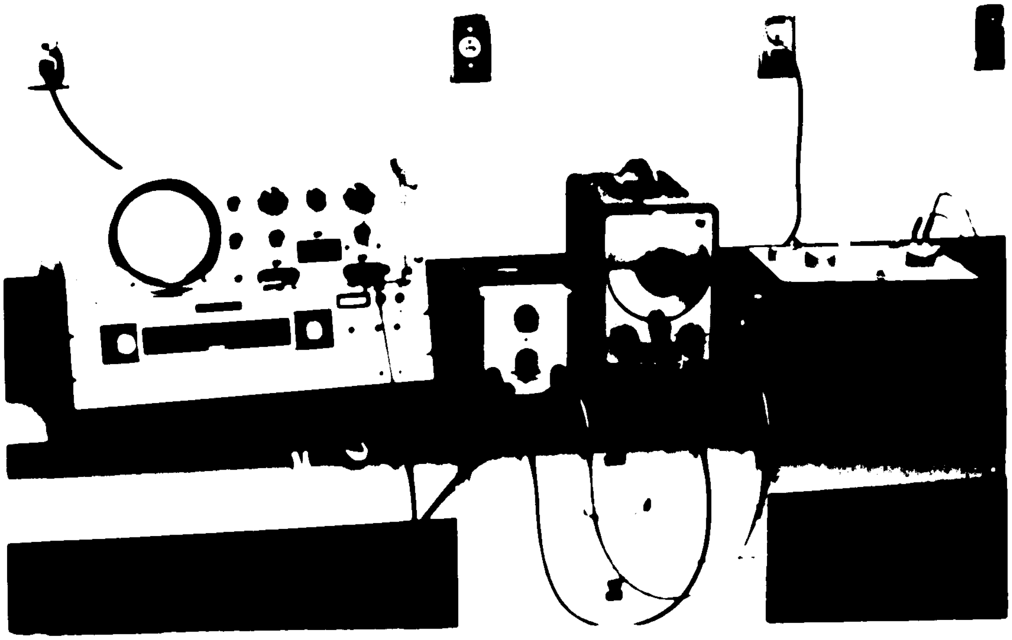


Fig. 23 Grip-strength dynamometer



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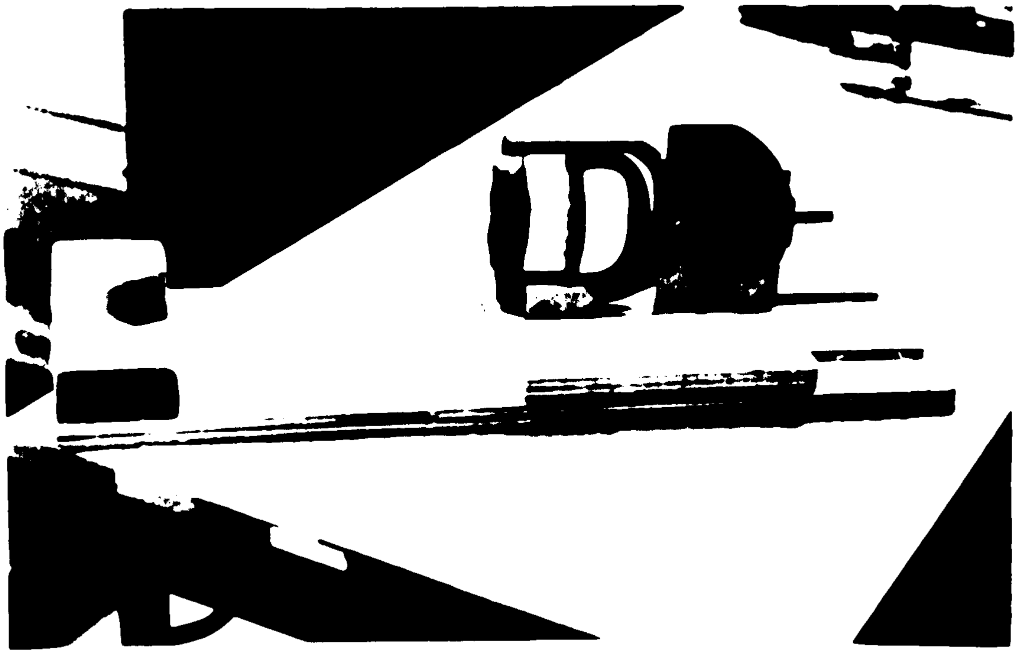


Fig. 24 Experimental situation and equipment; left-right impedance measuring equipment; monitoring oscilloscope; tape recorder; Honeywell console; task chair and equipment; laboratory clock.

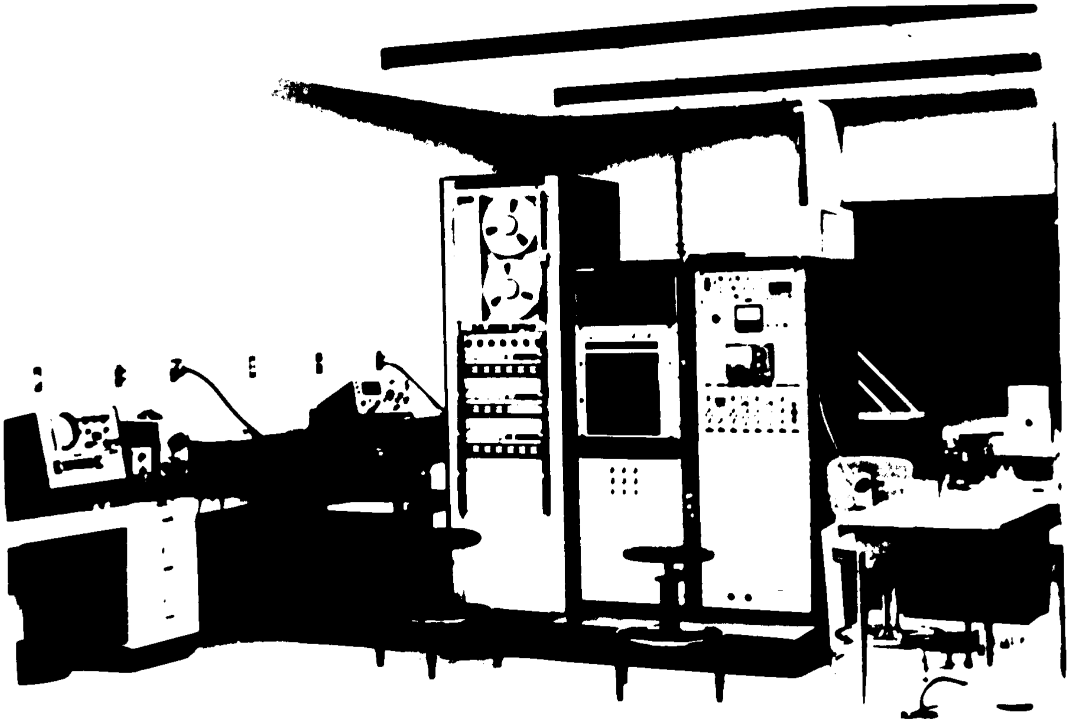


Fig. [illegible]: Experimental situation and equipment:
Left-right: [illegible] measurement equip-
ment; [illegible] [illegible] tape
recorder; [illegible] [illegible] base;
chair and equipment; laboratory clock.

CHAPTER IV

ANALYSIS

4.1 Hypotheses

The objective of the study was to examine the timing of components of the motor potential recorded on the scalp which were associated with different phases of muscular activity.

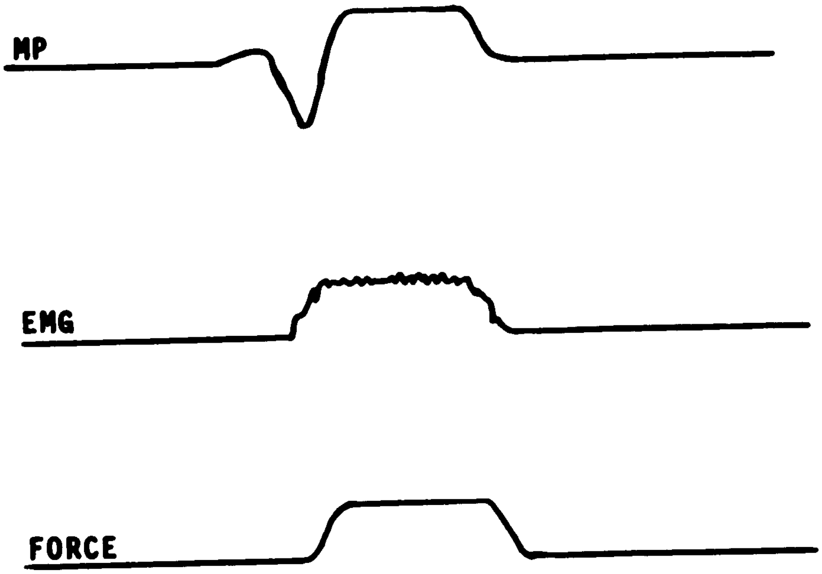
On the basis of the literature reviewed in Chapter II, and the objective of the study, the following hypotheses were set up.

4.1.1 Single Movement (Tasks 1 and 2)

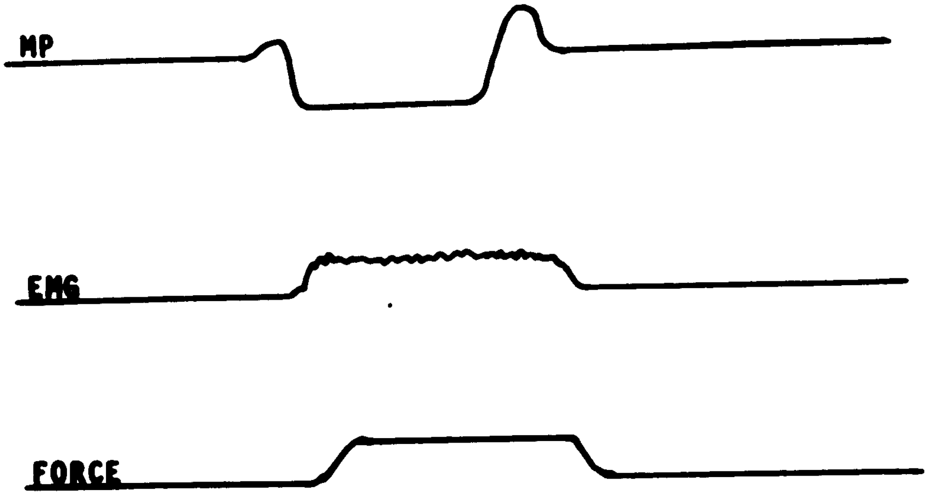
H1: A dominant component on the motor potential will be consistently and closely associated in time with the beginning of the steepest rise in the force trace.

H2: A dominant component on the motor potential will be consistently and closely associated in time with the beginning of the steepest fall in the force trace.

On the bases of these hypotheses and the findings of Vaughan (1965), Gilden (1966), Vaughan (1968, 1970) and Karlin (1970), the following wave forms may be expected for isotonic movements.



Alternate to this motor potential, if the EEG wave form is the same for isotonic as for isometric performance, the motor potential may be similar to that produced in Vaughan *et al*.'s work (1970).



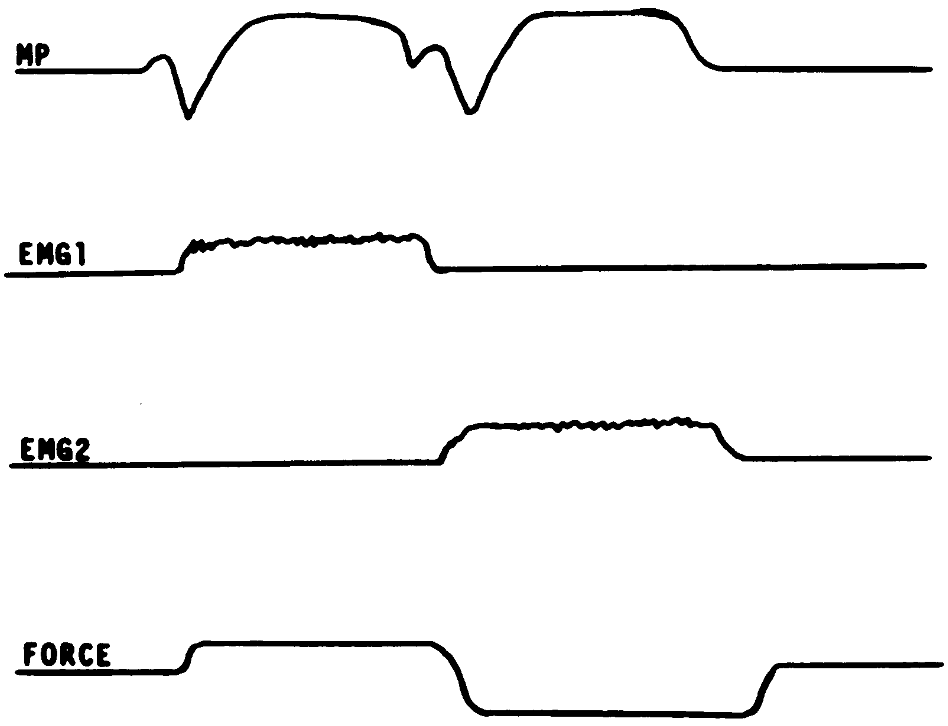
H3: A dominant component on the motor potential will be consistently and closely related to the steepest rise of the EMG.

H4: A dominant component on the motor potential will be consistently and closely related to the steepest fall of the EMG.

4.1.2 Return Movement (Tasks 3 and 4)

H5: For each of the two movements in the return trip, dominant components in the motor potential will show the same relationships with force and EMG as in H1, H2, H3, and H4.

On the basis of this hypothesis the following wave forms may be expected for the return trip.



4.1.3 Continuous Task

H6: For all movements of the continuous task dominant components of the motor potential will show a consistent and close time-relationship to the steepest rise and fall of EMG and force traces, as in the return movement task.

4.2 Results

4.2.1 Pilot Studies

Pilot studies were conducted at different stages in the development of the measurement system and in the experiment.

Electrodes for EEG recording were constructed as indicated in Appendix L. These were tested in association with the Grass encephalographs at the EEG Department of the University of Alberta Hospital. The records obtained were verified as being typical EEG's of high quality.

The linear response of force and displacement apparatus was tested using a variety of resistance and angles. Calibration graphs for these are shown in Appendices D and E.

To ensure that the sight and sound of the moving apparatus did not influence the EEG records a pilot study was conducted in which the subject was coupled to the recording system but merely sat and visually tracked the hand of the clock while the task was performed by the experimenter. In the processing of the data the averager was triggered from the voltage generated by the force equipment. The resultant wave forms are shown in Appendix K.

4.2.2 Treatment of Data

Examination of the analog data was carried out by means of a PDP8I laboratory computer with packaged programme for averaging of transient signals. This gave averages of the prescribed number of sweeps according to the following formula: Average of jth data point for

$$\text{N sweeps} = \sum_{i=1}^{N} Aij/N$$

In the averaging process all random signals (such as electrical noise and non-relevant neural potentials) are extensively reduced leaving the time-locked signal in greater relief from the noise in which it was originally embedded.

In order to relate the motor potential to the muscular activity the EMG was used to trigger the average. The EMGs were rectified before being fed into the trigger connection of the PDP8 computer so that the first major muscle spike on the EMG would start the sweep whether it was a negative or a positive going spike. In order to avoid low level muscular noise the trigger was set at approximately 150 microvolts for the muscular movements (this is equal to 0.3 volts amplified voltage as recorded on the tape). The sweep time was set to cover most of the inter-movement interval. Although this reduced the number of data points allocated to the actual motor potential it avoided extraneous muscular spikes triggering the averager at the wrong time.

Vaughan (1965) indicated that some of the relevant components of the motor potential occurred during the period of time shortly before the onset of the muscular response. Consequently the information which came into the computer during this pre-response period was also processed and included on the traces written out on the X-Y plotter. The period of time between the beginning of the wave form and the sharpest rise of the first EMG can be deduced from the time-base on each figure.

For Tasks 1 and 2 the sweep time was set at 5 seconds, the movements beginning at 6 second intervals. EMG2 was used as the trigger for the flexion movement and EMG1 as the trigger for the extension movement. For Task 3 EMG1 was used as the trigger and for Task 4 EMG2. The sweep time in these cases being 2.5 seconds. In order to examine both motor potentials in Task 3, sweeps were first averaged using EMG1 as the trigger and then EMG2. In this way it was possible to examine the second of two sequential motor potentials.

Averages were obtained for each 45 sweeps from the selected tasks for each subject. This number was selected after examination of the average of various numbers of sweeps (see Section 4.2.3). Sets of averages showing good relationships are included in the dissertation, along with a few showing poor relationships for comparison.

The average of each 45 sweeps completed by the PDP8 was written out using an X-Y plotter. All parameters for a given task were written out as wave forms on a common time base, so that the coincident occurrence of events on the different traces could be clearly seen and the latency between events measured. These measurements were taken using Dixon vernier calipers which made possible, measurements down to one-tenth of a millimetre.

Tables of the coincidence of dominant components on the motor potential and on EMG and force traces were depicted (see Tables 1, 2, 3). The occurrence of these events was based upon visual examination.

The average latencies between relevant events were computed where distinct wave forms were seen. These are recorded under results for Task 1 and results for Task 3. To give an idea of the extremes of these latencies the ranges are also recorded.

4.2.3 Selection of Number of Sweeps for Processing

As indicated in Chapter III sets of different numbers of sweeps, from 15 up to 90 were examined. It was found that sets of 90 sweeps were not superior to 45 (or even 30 or 15 in some cases) for purposes of this study (see Appendices G, I, J). As the growth of motor potentials was watched on the oscilloscope screen a clear potential was manifest after 10 or 15 sweeps in many cases. As further sweeps were fed in, the motor potential often deteriorated. This may well have been due to variability in the performance of the task, as the subject changed his mental set or became fatigued. It is therefore reasonable to suggest that in future research using this kind of task, the subject should be highly trained so that each component of the response is less variable and is closely time-locked to the trigger. If this is done a consistent response will be obtained for all sweeps and large numbers of sweeps would remove the random noise, leaving the motor potential more clearly visible. In this experiment the use of 45 sweeps in each sub-set appeared as demonstrative as any other number and had the advantage of providing a larger number of samples from which to obtain an idea of variability.

4.2.4 Selection of Task Data for Processing

In designing the experiment it was decided to examine the left-to-right movement (Task 1) as well as the right-to-left movement (Task 2) to check whether the motor potential for one was similar to that for the other. In examining the traces for Task 2 it was seen that the motor potentials were similar to those for Task 1. In Appendix L the general form of the motor potential for Task 2 appears the same as for Task 1. The major negative going spike is similar in form and amplitude and is similarly related to EMG and force traces. On the basis of this and the evidence from the work of Vaughan et al. (1965, 1966, 1968, 1970), it was decided not to process data from Task 2 any further and to work on the assumption that the single movement elbow extension of Task 1 is typical of elbow flexion or extension movements for purposes of examining related motor potentials.

Task 3 and Task 4 (return trip) were also similar except that one started moving to the right and the other to the left. These were compared as for Task 1 and Task 2. Several sub-sets of sweeps from Task 4 were averaged and compared with those from Task 3. On the same basis as the previous comparison they were found to be similar for purposes of this study. An example of an average from Task 4 is shown in Appendix H.

4.3 Data from Averaged Wave Forms

4.3.1 Single Movement (Task 1)

4.3.1.1 Motor Potential and Rise in Force

For Subject 1 and 3, in all sub-sets of sweeps, a large clearly defined negative potential is associated with the beginning of the steepest portion of the force trace (see Table 1). In these two subjects the mean and the range shown below in Table 2, of the negative potential around the rise in force is very small when compared with the total duration of the movement, which was greater than one second (see Figs. 1, 2, 7, 8).

In Subject 2 the negative potential is clear in only three out of eight sub-sets, and is more variable around the occurrence of the steepest rise in force (see Figs. 4, 5, 6). This may be due to the subject having increased force gradually instead of rapidly as with the other subjects.

TABLE I

COINCIDENCE OF NEGATIVE POTENTIAL WITH FORCE AND EMG (TASK 1)

	Rise in Force	Fall in Force	End of Force	Rise in EMG
Subject 1	8 out of 8*	5 out of 8	6 out of 8	7 out of 8
Subject 2	3 out of 8	6 out of 8	6 out of 8	5 out of 8
Subject 3	8 out of 8	7 out of 8	2 out of 2	8 out of 8

* The scores in the columns indicate the number of occurrences of the potential in the given number of samples.

TABLE II

MEAN LATENCIES AND RANGES - MOTOR POTENTIALS TO RISE IN FORCE (TASK 1)

Mean Latency: Steepest rise in force to lowest point on MP	
Subject 1	-15.6* m.secs (8 averages)
Subject 3	8.0 m.secs (8 averages)
Subject 1 & Subject 3	-3.8 m.secs (16 averages)
Range of Latencies:	
Subject 1	36* m.secs to -24 m.secs
Subject 3	48 m.secs to -40 m.secs

* A positive score means MP occurred first, a negative score means MP occurred second.

4.3.1.2 Motor Potential and Fall in Force

In Subject 1 a negative spike on the motor potential occurred in 5 out of 8 samples at the steepest fall in force. When it occurred the wave form was not well defined and was hard to allocate a time point (see Figs. 1, 2).

In Subject 2 a negative going wave clearly occurred in 6 out of 8 samples at the steepest fall in force. This was often a multiple spike and again was difficult to allocate a time point (see Figs. 4, 5).

In Subject 3, one, or a series of negative spikes on the motor potential occurred at the steepest fall in force in 7 out of 8 samples (see Figs. 7, 8).

Because of the complexity of the wave forms, actual time points could not be allocated and statistical analysis of variability did not appear likely to clarify the relationships.

4.3.1.3 Motor Potential and Termination of Force

In 17 out of 21 samples a negative component of the motor potential occurred at the time when the force ended. In 3 other sub-sets the epoch sampled was not long enough to show the termination of force.

Where the force tailed off very gradually a series of negative going spikes on the motor potential were associated with this gradual decline (see Figs. 1, 2, 4, 5, 7, 8).

4.3.1.4 Motor Potential and Rise in EMG

For Subject 1, in 7 out of 8 samples, a negative potential was associated with the steepest rise of the EMG trace (see Table I and Figs. 1, 2, 3). In most cases the EMG rise preceded the motor potential spike.

In Subject 2, 5 out of 8 samples showed a coincident potential on the EEG. The time relationship was variable and the potential not always dominant enough to be an exclusive relationship with the rise of muscle action (see Figs. 4, 5, 6).

Subject 3 showed a very dominant negative potential associated with the steepest rise of EMG in all 8 samples (see Table I and Figs. 7, 8, 9), which varied little around the time of the muscular activity. In this subject the association between the motor potential, rise in force and beginning of EMG was pronounced. The mean latency and range of latencies are shown below (Table III).

4.3.1.5 Motor Potential and Fall in EMG

The fall of the EMG was gradual in all cases even after applying a steady force for the performance of the task. It was therefore not possible to choose a criterion point on the EMG to represent the major fall off in muscular activity.

4.3.1.6 Motor Potential and General Form of EMG

In subject 2, 7 out of 8 samples showed a distinct positive potential on the EEG which was similar to the

TABLE III

MEAN LATENCIES AND RANGES - MOTOR POTENTIAL TO RISE IN EMG (TASK 1)

Mean Latency: Steepest rise in EMG1 to lowest point on MP	
Subject 1	-80* m.secs (8 averages)
Subject 3	-64.8 m.secs (8 averages)
Subject 1 & Subject 3	-72.4 m.secs (16 averages)
Range of Latencies:	
Subject 1	-60* m.secs to -88 m.secs
Subject 3	0.0 m.secs to -92 m.secs

* A positive score means MP occurred first, a negative score means MP occurred second.

general form of the EMG. This relationship is also suggested by the EEG and EMG wave forms of Subject 3 (see Figs. 1, 2, 4, 5, 7, 8).

4.3.2 Return Movement (Task 3)

4.3.2.1 Motor Potential and Rise in Force

Subjects 1 and 3 demonstrated a clear negative potential associated with the steepest rise in the force trace of the initial movement in 8 out of 8 samples (see Table IV and Figs. 10 to 13).

In Subject 2 the negative potential was manifest in

TABLE IV

COINCIDENCE OF NEGATIVE POTENTIAL WITH FORCE AND EMG (TASK 3)

	Rise in Force	Fall in Force	End of Force	Rise in EMG
Subject 1	8 out of 8	0 out of 8	3 out of 8	8 out of 8
Subject 2	2 out of 8	4 out of 8	5 out of 8	2 out of 8
Subject 3	7 out of 7	1 out of 7	0 out of 7	7 out of 7

TABLE V

MEAN LATENCIES AND RANGES - MOTOR POTENTIAL TO RISE IN FORCE (TASK 3)

Mean Latency: Steepest rise in force to lowest point on MP	
Subject 1	-9.6* m.secs (8 averages)
Subject 3	-34.6 m.secs (7 averages)
Subject 1 & Subject 3	-22.1 m.secs (15 averages)
Range of Latencies:	
Subject 1	9.6* m.secs to -28.8 m.secs
Subject 3	9.6 m.secs to -52.8 m.secs

* A positive score means MP occurred first, a negative score means MP occurred second.

only 2 out of 8 samples. But it seems that the task was not normally performed by him. EMG1 and force traces indicate that the subject was applying force to the lever, even though no displacement occurred. If such was the case, the relationship between the motor potential and EMG would not be related to the task.

4.3.2.2 Motor Potential and Fall in Force

In only 5 out of 23 samples (see Table IV) was a dominant component of the motor potential associated with the steepest fall in force. This occurred with a coincident rise in the second EMG and cannot therefore be looked upon as a consistent relationship purely with the steepest fall in force.

4.3.2.3 Motor Potential and End of Force

In 8 out of 23 samples a negative component of the EEG was associated with the end of force. As can be seen from Table IV, most of these are from Subject 2, where the negative potential was also coincidental with the beginning of EMG2 (see Fig. 14). These negative components were often complex in form and not very distinct.

4.3.2.4 Motor Potential and Rise in EMG

In Subjects 1 and 3 (where the beginning of force and EMG was clearly indicated at the beginning of the movement of the lever) all samples showed a distinct negative potential in the EEG as the first muscle activity appeared (see Figs. 10 and 12). In these two subjects this was as clear as for the beginning of the EMG in Task 1.

From the latencies reported below it can be seen that for the return movement the negative component of the motor potential occurred after the steep rise in muscle action, as in the single movement (see Table VI).

TABLE VI

MEAN LATENCIES AND RANGES - MOTOR POTENTIAL TO RISE IN EMG (TASK 3)

Mean Latency: Steepest rise in EMG1 to lowest point on MP	
Subject 1	-42.0* m.secs (8 averages)
Subject 3	-71.3 m.secs (7 averages)
Subject 1 & Subject 3	-55.68 m.secs (15 averages)
Range of Latencies:	
Subject 1	9.6* m.secs to -67.2 m.secs
Subject 3	0.0 m.secs to -110.4 m.secs

* A positive score means MP occurred first, a negative score means MP occurred second.

Subject 2 seems not to have removed the force from the lever in the rest period and as a result his EMG1 and force records show activity when no movement of the lever was manifest. In this case no clear motor potential can be expected at the commencement of the movement.

If there is a relationship between the motor potential and EMG1 then one would also expect a similar association between a component of the motor potential and EMG2. This was found to occur in 14 out of 23 sub-sets considering all three subjects.

Triggering the computer from EMG2 produced poorer averages with less distinct motor potentials. This could be due to overlap of EMG1 and EMG2. One of the better examples is shown in Appendix K.

Subject 2 although not performing the first movement of the task as required showed a large positive wave form associated with the activity of EMG2 in 6 out of 7 samples as shown in Fig. 14.

4.3.3 Continuous Movement (Task 5)

In the averages produced with a relatively short sweep time negative going components in the EEG were associated with the rise in force and rise in EMG in the majority of cases (see Table VII). This relationship is further clarified by the averages produced with a sample twice as long, taken from alternate sweeps (Figs. 17 and 18).

In these a clear relationship can be seen between the negative going components of the EEG wave form and the force trace produced by the activity.

As in Task 3 there was extensive overlap of the action

TABLE VII

COINCIDENCE OF NEGATIVE POTENTIAL WITH FORCE AND EMG (TASK 5)

	Rise in Force	Fall in Force	End of Force	Rise in EMG
Subject 1	2 out of 5	0 out of 5	0 out of 5	2 out of 5
Subject 2	7 out of 8	3 out of 8	0 out of 8	6 out of 8
Subject 3	5 out of 5	4 out of 5	0 out of 5	5 out of 5

of the two muscles. Since it was shown in Task 1 that EEG potentials were related to the beginning and fall of force generated by the muscles, one may expect motor potentials related to one muscle to overlap those related to the other. The negative going components which were manifest in the motor potential in Task 5, although clearly related to rise and fall of force, were not clear in form and could not be allocated a distinct time point.

In Subject 2 large positive EEG waves were associated with the rise and fall of the EMG. The negative phases of these were not distinct in form and for this subject could be allocated a time point in only one sample (Fig. 15).

4.3.4. Displacement Relationships

Displacement was used mainly as a control measure to check the adequacy of the performance. Its value in this can be seen in Fig. 14. There, EMG1 is generating force before much displacement occurs. As mentioned previously it may have been that the subject was pressing on the lever in preparation to act. The confounding of force with displacement is further discussed in Section 4.4.6.D.

Displacement was dependent upon force and the muscular activity generating it. It was therefore to be expected that displacement would be related to these two parameters and to the motor potential which is related to them. The displacement was less well related to the motor potential since different latencies were involved. These were; the delay for the muscle to "take up the slack" before force could be manifest in the force trace, the time taken to generate enough force to overcome the initial frictional resistance and the transmission time between cortex and muscle. It is only after these delays that the displacement trace can provide any information. (See Figs. 1-14).

4.4 Discussion

4.4.1 Limitations Within the Experiment

4.4.1.1 The Performance

This was somewhat different for each of the three subjects. Had they been trained to an automated level this could have been overcome, but the training procedure was avoided in order to observe any progressive automation effect reflected in the motor potential. Since this result did not come out, training might have improved the results obtained by reducing intra-subject variability and the difference between the subjects.

Although the performance of the task was closely prescribed and examples of desirable wave forms presented to each subject (Appendix C), it may have been possible to initiate the movement by the use of unmonitored muscles, because the body was not strapped in position.

4.4.1.2 The Task Apparatus

The task apparatus in this study is capable of providing information from both the natural performance (gradual increase and decrease of force) and from that when the subject has been trained to produce a square-wave type of force response. The voltage output of the strain gauge bridge and the displacement potentiometer were checked for linearity. Calibration graphs are shown in Appendices D and E.

Strapping the arm in the starting position might have isolated the movement more than with the arm freely resting on the lever platform. But the strapping could also have caused a general muscle tonus which would have been recorded in the EMG as extraneous noise. Training of the subjects to a stereotype level is probably a better answer than strapping the subject in the basic position.

4.4.1.3 Bio-Electronic Equipment

The electrodes used for EEG transduction were as recommended by Skov and Simons (1965). These were satisfactory from an electronic point of view in that under still and moving conditions they provided good EEG signals. However it was found necessary to re-chloride the silver discs before each application in order to obtain acceptable noise free signals. These electrodes were also very slow to apply, having several parts to be glued to the subject. This contributed to a subject preparation time of approximately 45 minutes, adding considerably to each subject's experimental time of approximately 5 hours. In total the subject had a very difficult and tedious experience.

The open type recessed silver electrodes used for EMG gave a very good record of muscle activity when coupled with the Honeywell 135 a.c. amplifiers. If the activity of specific muscles is required these surface electrodes are inadequate, and needle electrodes should be used, so that extraneous muscle activity is not picked up in the EMG recording.

The Honeywell accessory pre-amplifier for the EEG channel failed after one application. It was therefore decided to couple up a Beckman pre-amplifier (through the power amplifier in the Beckman unit) to the input of the Honeywell system which was being used for all other channels. This Beckman pre-amplifier worked quite well but by interfacing the two systems, noise from both was being amplified and fed into the recordings. Fortunately the initial noise level was very low and so satisfactory results were obtained.

Two main types of amplifier were used. For EEG and the two EMG channels Honeywell a.c. 135 amplifiers performed very well giving low noise signals with little or no base-line drift. The d.c. 113 amplifiers used for force and displacement channels were not as reliable, were sporadically noisy and were susceptible to small voltage surges when part of the equipment was switched off or on. As a result the force trace in some of the write-outs had to be corrected by hand (see dotted lines on some of the traces). Twice during the experiment the output of the displacement amplifier drifted to an extend beyond the capacity of the tape recorder and had to be switched off.

The Honeywell ultra-violet strip chart recorder produced a good paper record of all raw data.

A high fidelity record was made on a Hewlett Packard 3911 FM tape recorder. Having output voltage control it was easy to adjust voltage levels of each channel for the input requirement of the PDP8 analog computer, which averaged three channels at once over 240 data points.

4.4.2 Discussion of Wave Forms from Single Movement (Task 1)

In all averages from the three subjects in this experiment a negative component of the motor potential is distinctly related to the beginning of muscle action and the related rise in force (see Figs. 1 to 9).

This is in accord with Vaughan (1965, 1968), Gilden (1966) and Karlin (1970) who found, from scalp recordings, that the beginning of muscular activity occurred in time with the occurrence of a small positive wave, followed by a large negative component. They found that whereas the small positive wave was not a reliable occurrence, the negative component was always present, was dominant in form and its latency from the rise of EMG was not great.

Vaughan *et al*. (1970) recording directly from the cortex of monkeys found the same components as from the human scalp. But from the wave forms published in the article it seems that the negative going component reaches its peak before the rise of the muscular activity. This seems to be a difference between the motor potential from the cortex of monkeys and that from the scalp of humans. The impedance of the tissues through which the signal passes to the scalp could be involved with this difference. Vaughan (1968) states, these positive and negative waves "...occurring shortly before the onset of movements, seem to reflect some processes closely associated with their initiation." If later research supports this idea, the dominant negative potential which occurs after the rise of the EMG could be involved with these processes and its transmission through to the scalp electrode be delayed by this impedance. This would comply with the reports of Hubbard (1969), Creutzfeldt (1966) and Jasper and Stephanis (1965), who all indicate that a negative field at the surface of the cortex is associated with the firing of pyramidal tract neurons. It can be seen in the wave forms shown by Vaughan *et al*. (1965, 1966, 1968, 1970) that the negative going phase although clearly present does not have a well defined form in all cases. This was also found in the research reported in this dissertation, especially in Subject 2 where the motor potential was ill-defined and could not be allocated a reliable time of occurrence. As a result it seemed unwise to include the samples from Subject 2 in mean and range results. It could be, that in this subject, the scalp electrode was not directly over the appropriate area of cortex, and hence a motor potential may well have been generated by that subject but not picked up by the electrodes. This points out one of the weaknesses of using external scalp electrodes, where actual location of the specific area on the motor cortex cannot accurately be determined.

In some of the samples from Subject 3 a near square wave force trace was produced. In these cases a negative potential occurred at the time of fall in force and fall in EMG (Figs. 7 and 8). In Subject 1 (Figs. 1 and 2) the negative going potentials occurring at the steepest fall in force may also be interpreted this way.

From these results it seems that a negative component of the motor potential is associated, after a given latency, both with the rise and the fall of the force generated by muscular action. This can be seen in the results only when these events occur abruptly, as in wave forms from Subject 3.

Following the first sharp negative going phase of the motor potential (N_2) a large positive component develops in association with rising or sustained muscular force. A crude relationship was seen in 16 or 17 samples out of 24, (Figs. 7 and 8) between the shape of the positive component of the motor potential and the EMG and force traces, as hypothesized in Chapter IV, page 74. Vaughan et al. (1965, 1968) and Gilden et al. (1966) show similar positive waves occurring immediately after the dominant negative component in most subjects for hand and foot movements, but these seem not to be reliably related to the characteristics of the EMG wave form, although their tasks did not generate an EMG with a unique form.

In referring to the dominant positive component (P2) Gilden (1966) states "This component might be attributed, at least in part to afferent feedback generated by the movement. Since the positive deflection developed more than 50 milliseconds after onset of contraction, sufficient time elapsed to permit somatosensory and proprioceptive impulses to reach the cortex." To examine this problem Vaughan (1970) conducted research which used deafferentation techniques on monkeys (in this, surgery on the spinal cord separates peripheral nerves conducting feedback impulses from the joints and muscles). Contrary to their expectations the basic form of the motor potential did not change even though some parts of it were delayed. From this, the conclusion was drawn that during activity feedback from the moving part is probably blocked at the motor cortex.

Vaughan's findings are supported by the work of Evarts (1969, reported in Chapter I) on single cells of the motor cortex from which he concluded that "...the output of cells of the precentral motor cortex is related to the muscular activity causing the action rather than the joint displacement or steady joint position resulting from the muscular activity."

Although the above studies do not totally eliminate the possibility of feedback influencing the motor potential, it seems feasible to hypothesize that the late components of this are related to the outgoing signals rather than the feedback from the movement. Further research on motor potentials may help to clarify the position.

The results obtained from the single movement indicate that Hypotheses 1 and 3 related to the beginning of EMG and force, are clearly supported, and that Hypotheses 2 and 4 related to the fall of EMG and force, are supported only where the fall off in these two traces is steep. In a few samples some similarity can be seen between the hypothesized wave form on page 74 and the results as in Figs. 7 and 8.

4.4.3 Differences Among Subjects

(A) Each subject seemed to have unique characteristics in the motor potential produced. This was to be expected when the performance (indicated by EMG and force traces) were so different. These general differences in form could also be due to difference in location of the scalp electrode relative to the appropriate area of cortex. It is also well demonstrated (Cooper, 1969) that in normal subjects the general form of the basal EEG is unique to the individual. These factors will no doubt influence in a general way the wave forms obtained, but nevertheless should not mask the different components of the motor potential if these truly represent the cortical function related to the motor performance.

(B) On the basis of the data collected it is possible to say that not all components of the motor potential as suggested by Vaughan _et_ _al_. (1968) occur in all subjects, at all times. However from close examination of the force and EMG wave forms it can be seen that where clear and abrupt changes occur in the performance, this is more often than not reflected in the motor potential. It therefore appears likely that lack of demonstration of the appropriate wave form is a function of the variability of performance, the inadequacy of the task and perhaps the noise and distortion of the electronic system.

(C) In Subjects 1 and 3 who showed a clear relationship between the negative components of the motor potential and the rise and fall of muscular activity and force, the latencies are somewhat different (see page 82, Chapter IV). However when compared with the duration of the total movement (up to 1.5 secs.) the latency and the range of latencies is very small and indicates little difference between the two subjects.

4.4.4 Discussion of Results from Return Movement (Task 3)

From the results of Task 3 (see Table IV and Figs. 10, 11, 12, 13, 14) it can be seen that, a distinct negative potential occurs at approximately the same time as the rise in force and the rise in EMG, as in the single movement. This is a consistent result for Subjects 1 and 3, but not for Subject 2. The faulty data of Subject 2 could be due to leaning on the apparatus, or using unmonitored muscles to initiate the movement.

Comparison of mean latencies (p. 82 and p. 86) for the single movement and the return movement indicate no clear difference between the tasks. Considering the MP-to-force latency, Subject 1 shows a decrease in mean latency whereas Subject 3 shows an increase for the more complex task.

In both Subject 1 and Subject 3 the range of the latencies decreased in the return movement. These being derived from only eight samples for each subject may or may not indicate a difference between the latency of MP for the single movement and that for the return movement.

Between MP and EMG1, the mean latencies on pages 85 and 88, do not show a common direction for both subjects; Subject 1 shows a decreased latency from single to return movement, whereas Subject 3 shows an increase. The range of latencies for the two subjects does not show a distinct pattern, hence one cannot assume a latency difference between tasks.

Since a negative-going component in the MP was associated with the rise of EMG1 it was reasonable to expect a similar potential with the rise of EMG2. Such a potential was a clear event in 14 out of 23 samples, but was not distinct enough in form to allocate an accurate time of occurrence, or to measure its latency from the EMG. EMG1 overlapped EMG2 and the motor potentials associated with these also seemed to overlap, in that, the second negative potential occurred where a positive wave form was recorded in the single task. In Figs. 10 and 14 these phenomena can be seen associated with the cessation of EMG2, in the same way that one was recorded in the single movement. It is therefore reasonable to conclude that in the return task the complex EEG wave form may well represent superimposed motor potentials related to EMG1 and EMG2.

Hypothesis 5 relating to the return trip movement is supported in Subjects 1 and 3 where rise and fall of force and EMG are steep as in the beginning of the first phase. Some similarity to the hypothesized wave form on page 75 can be seen in Figs. 10 and 14, where the shape of the EEG wave form reflects to a certain extent the activity of the two muscles.

4.4.5 Discussion of Results from Continuous Movement (Task 5)

The wave forms of averages derived from the continuous movement were not distinct enough to allocate times of occurrence to the different components. Nevertheless examination of the averaged wave forms clearly indicated a negative potential on the EEG trace related to the beginning of muscular activity in 13 out of 18 samples. Examples of these are shown in Figs. 15 and 16. Both of these figures also illustrate a second negative-going component in the EEG associated with the beginning of EMG2.

When the length of the epoch was doubled and alternate sweeps averaged, the time relationship between EEG potentials and increase in muscular force was made more obvious as indicated in Figs. 17 and 18. Although in these, the EEG wave form is very noisy, the major negative components are obviously related to the occurrence of the rise of force in both the flexion and extension phases of the task.

In referring back to Hypothesis 6, it may be stated that for the continuous task, negative components of the motor potentials were related to the rise in EMG and force for both directions of movement and that the wave forms obtained were not clear enough to determine whether similar signals existed for the fall of force and fall of EMG.

4.4.6 Comparison of Single, Return and Continuous Movements

From the comparison of the different tasks used in this study the following observations may be made.

(A) In single, return and continuous movements, in 2 out of the 3 subjects in the experiment, a negative-going potential in the EEG was associated with the onset of muscular activity. In the more complex tasks this was less well demonstrated because these potentials were less definite in form, perhaps caused by the loss of reliability in the performance of the tasks.

(B) In the return and continuous movements, where the activity of the two muscles overlapped, the motor potentials related to them also seemed to overlap. In that, a negative potential associated with the onset of the second muscle occurred before the end of the activity of the first.

(C) A negative potential coincident with the fall of muscular activity occurred in both the single movement and the second phase of the return movement of several samples.

(D) Although it may appear from some of the wave forms of Task 3 that negative-going EEG potentials are related to the beginning and end of movement, as indicated in the displacement trace, on examination of Task 1 samples it can be seen that the negative potential is more nearly related in time to the beginning of the EMG and the steepest rise in force. From this it seems unlikely that differences between isotonic and isometric performance is reflected in the motor potential.

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

The purpose of this study was to determine whether dominant components of the motor potential recorded from the scalp, were coincident with the rise and fall of muscular activity in single movements, return movements and continuous movements, in serial flexion and extension of the elbow.

Electroencephalographic recordings obtained from three right handed subjects through scalp electrodes were averaged by computer and related to EMG, force and displacement of the limb.

In the single movement, coincident events in the motor potential indicated the rise and fall of EMG and force.

Events in the motor potential of the return movement coincided with the rise of EMG and of force in the first phase, and the rise of EMG in the second phase. Other time relationships were not clear.

Dominant negative potentials were still evident, associated in time with change in direction, despite relatively high noise level in the motor potentials for continuous movement.

Relationships between events were clearer in some subjects than in others. This could have been caused by different characteristics in the performance of the task or by problems related to the location of scalp electrodes.

The general wave form of the motor potentials and the EMG traces seemed to be related in a few samples of the single movement task, suggesting that other factors than time may be related between the motor potential and the EMG.

5.2 Conclusions

Results of this study indicate the feasibility of further research using subjects trained to the stereotyped stage, for more discriminating results in the tasks as used.

It seems from the results of return and continuous movements that overlap of the activity of the two muscles was reflected in the motor potential records, making time relationships less distinct. In order to examine whether this overlap does exist clearer records of the EEG will be necessary with more distinct rise and fall of the EMG. These may be obtained from extensive training of the subjects and a modification of the task to include irregular rhythms.

Some further research seems to be required on the motor potential derived from the pre-central motor areas before examination of whether potentials reflecting components of motor performance are also manifest on other areas of the cortex.

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APPENDICES

APPENDIX A

TESTS OF HANDEDNESS

A.1 Questions

(1) With which hand do you normally write?

(2) With which hand do you normally throw a ball?

(3) Which hand do you use to cut with scissors?

Response of all subjects to all questions was 'right hand'.

A.2 Grip-Strength Test (in kilos)

Subject 1:	left hand	47, 47, 46
	right hand	58, 57, 54
Subject 2:	left hand	45, 46, 46
	right hand	54, 51, 49
Subject 3:	left hand	46, 46, 47.5
	right hand	47, 49, 49

APPENDIX B

IMPEDANCE OF EEG ELECTRODES

Subject 1

motor to frontal	1.2 - 1.4 kohms
motor to ear	1.8 - 2.0 kohms
frontal to ear	1.6 - 2.0 kohms

Subject 2

motor to frontal	1.1 - 1.6 kohms
motor to ear	1.8 - 2.4 kohms
frontal to ear	0.8 - 1.2 kohms

Subject 3

motor to frontal	1.2 - 1.6 kohms
motor to ear	1.8 - 2.5 kohms
frontal to ear	1.8 - 2.5 kohms

APPENDIX C

DIRECTIONS TO THE SUBJECT

A full explanation was given to each subject regarding the requirements of the task and the different variables which could cause artifacts on the recordings. These included the general state of arousal of the subject and his ability to establish a basal state.

Recordings of the EEG obtained during pilot studies were used to illustrate the influence of swallowing, speech, clenching the teeth, vertical and horizontal eye movements and blinking. A recording was also shown to illustrate a normal wave form with a low noise level and maximal amplitude of 50 microvolts (see Fig.).

C.1 Instructions to Subjects

C.1.1 Introduction

The task is not intellectually or physically demanding, but it is taxing to maintain attention to the task for the period of time required without performing extraneous movements. If these movements occur the data obtained will be very noisy and hard to process or interpret.

C.1.2 The Basic Position

This is a relaxed sitting posture with eyes fixed on the sweep finger of the laboratory clock. The tongue is to be resting on the floor of the mouth, the jaw relaxed and lips together; the non-performing arm resting easily on the lap and the right arm (when not in motion) resting on the elbow platform and lever handle in a totally relaxed state. The task is to be performed while maintaining the above position for each series of trials.

C.1.3 Artifacts

On the accompanying sheet are examples of artifacts in the recordings. These are caused by muscular activity of different kinds including swallowing, speech, clenching the jaw, and various eye movements. These artifacts will totally mask the signal and should be avoided at all cost.

C.1.4 Performance of the Task

A recording of the force signal, with ideal form is shown on pages and of the traces. You should try to replicate this wave form in each movement.

The flexion or extension movement is to be performed, beginning sharply from the basal starting position, such that, the movement of the lever is not delayed while force is being built up to the necessary level. When the lever has started to move, maintain the force so as to keep the movement at an even speed up to the end of the excursion. Each excursion should cover a sweep of approximately 18 inches. At the end of each movement, stop, and totally relax the arm. Commence each movement of the task as the sweep finger of the clock passes each mark on the clock face. These are at three second intervals. When you wish to move your position in any way, or swallow or blink the eyes, stop the lever and totally relax the performing arm. Try to do as many repetitions as possible before stopping and without losing the basal condition. In the few practice trials try to reproduce on the oscilloscope the sample wave form which is on the paper.

C.1.5 Tasks 1 and 2

This involves single separated movements. When you are told to begin, track the sweep finger of the clock one full turn and when it reaches the vertical begin the task as previously instructed. Perform each movement as the sweep finger passes each mark on the clock face.

Try to perform the task to give the wave form as practiced.

In this first task, arm movements are performed alternately with a rest after each one.

For this task 400 movements in each direction are required. You do not need to count, but perform the task with full attention until asked to stop.

C.1.6 Task 3

This involves return trip movements, R - L - R. Task 2 is to be performed as for task 1, but performing double movements instead of single ones.

At the end of the first movement perform the return trip immediately without rest.

Try not to tense the arm excessively as the change of direction is made.

When each return trip is completed, totally relax the arm before the next movement.

It is important that you try to make the movement in each direction the same length.

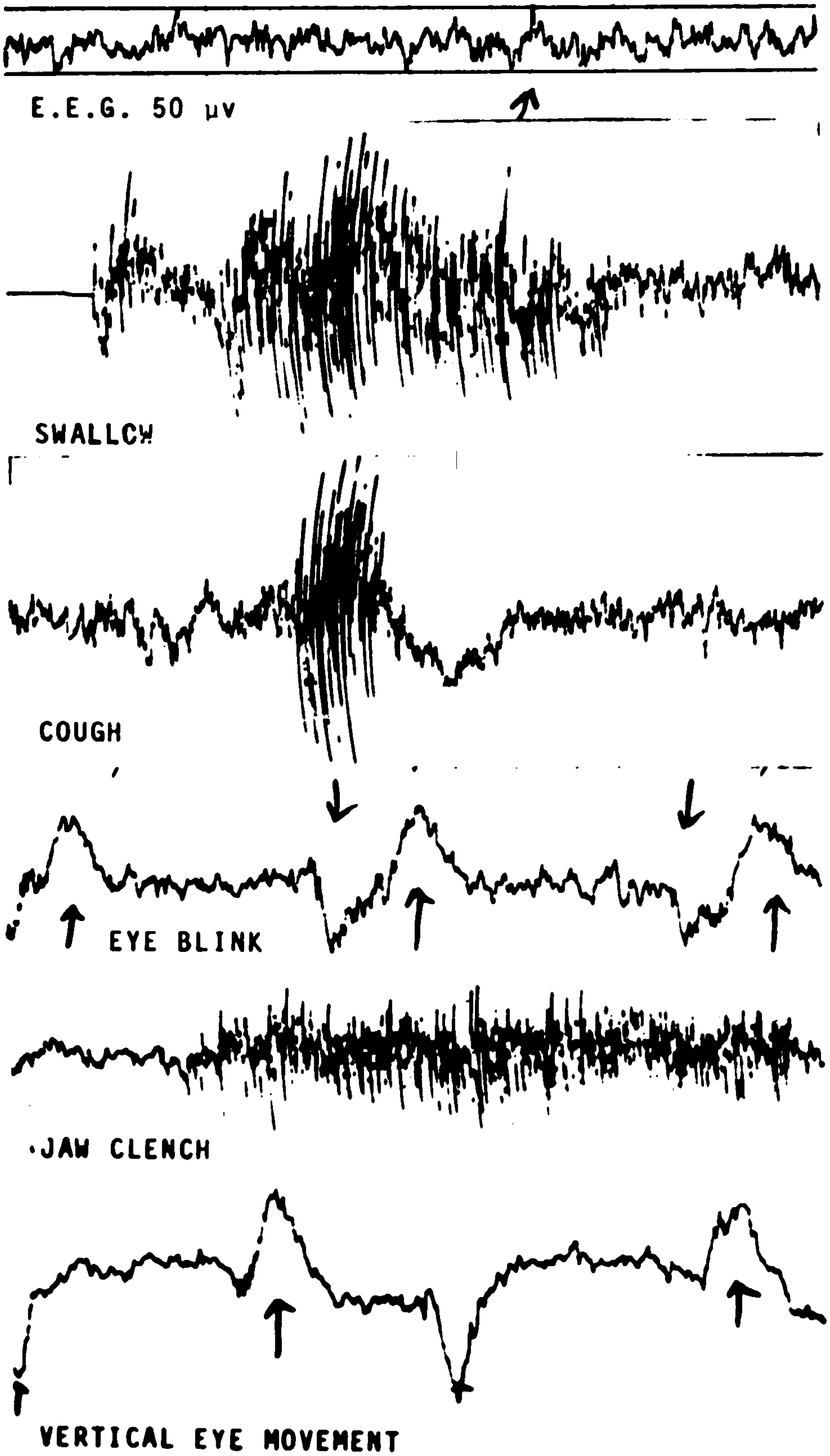
C.1.7 Task 4

This is a return trip as for task 2 but in the opposite direction. Try to give a mirror image of your performance in task 2.

C.1.8 Task 5

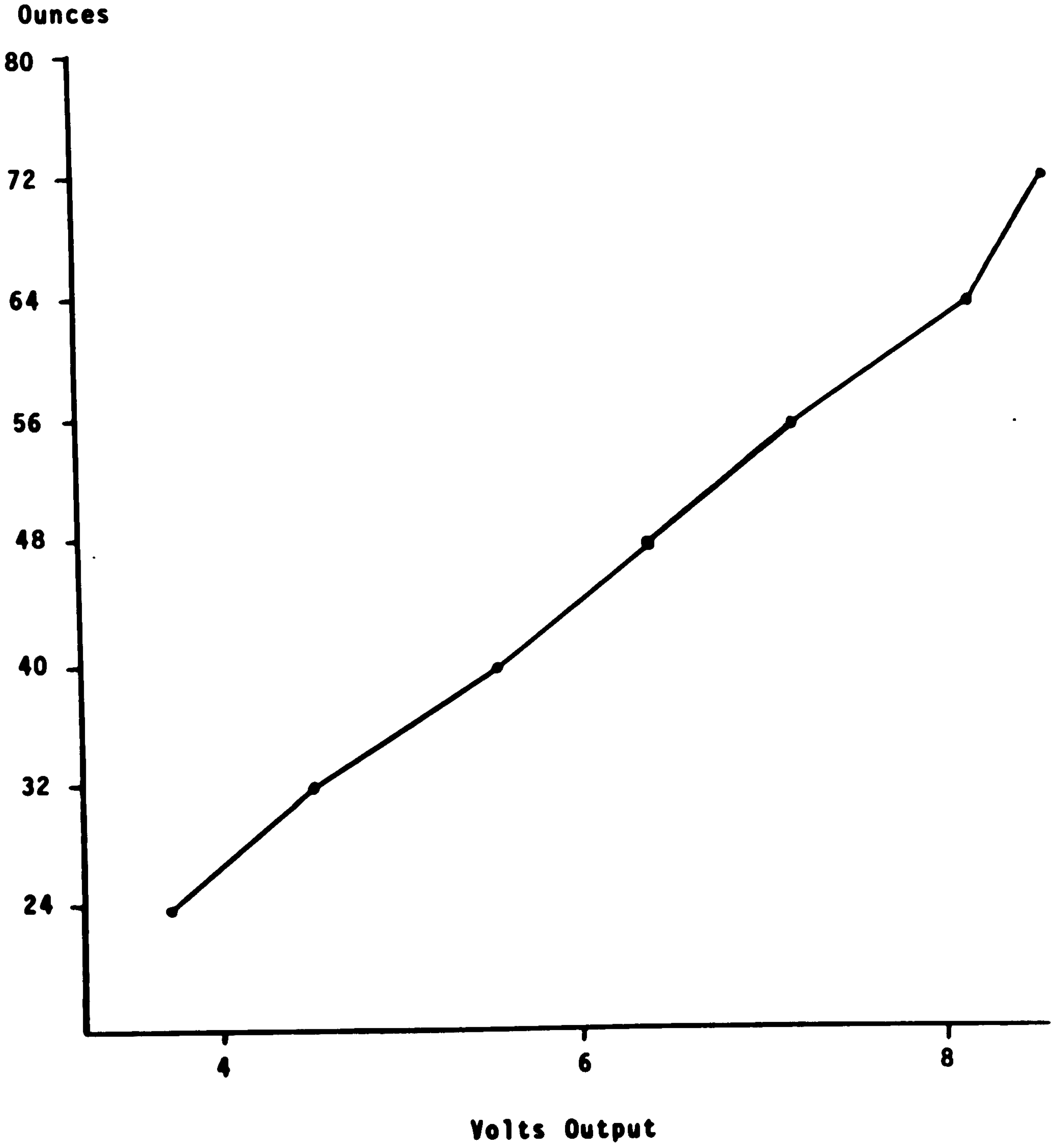
This is a continuous task with alternating movements. In this, continue alternate movements until asked to stop.

The marks on the clock face have been covered, but to control for the effects of eye movements it is important that you track the sweep finger of the clock accurately until the task is completed.


E.E.G. 50 µv
SWALLOW
COUGH
EYE BLINK
JAW CLENCH
VERTICAL EYE MOVEMENT

APPENDIX D

FORCE CALIBRATION

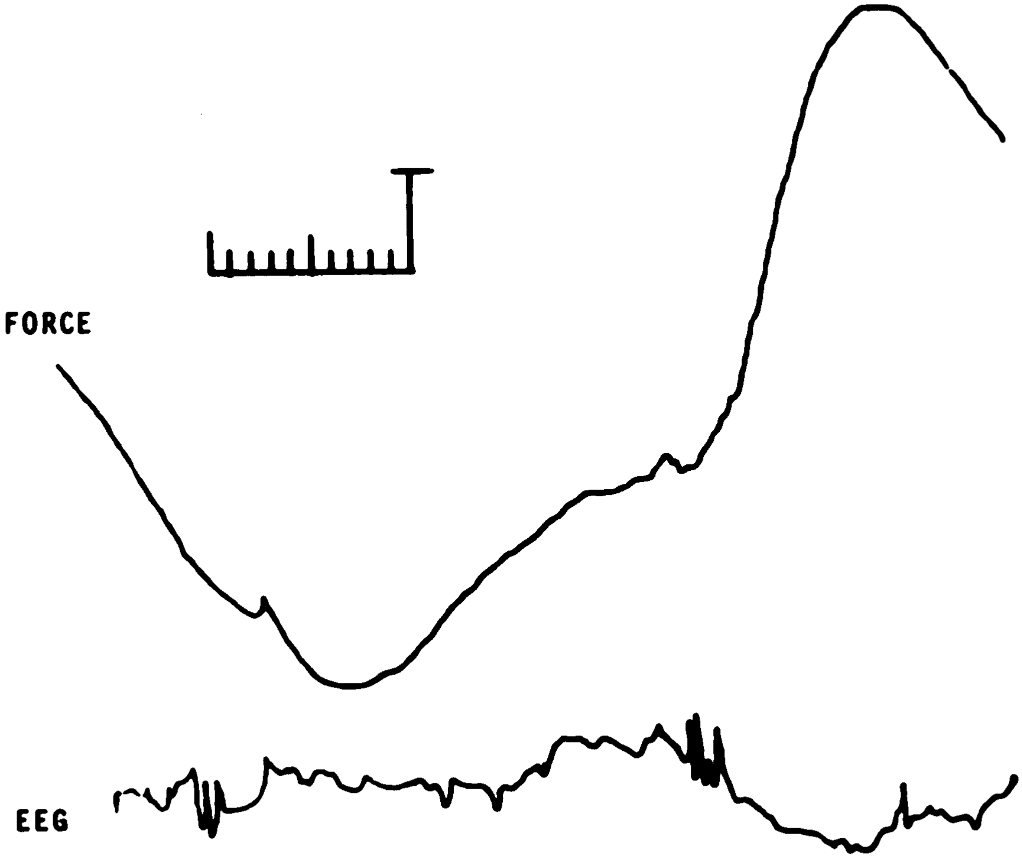


APPENDIX E

DISPLACEMENT CALIBRATION

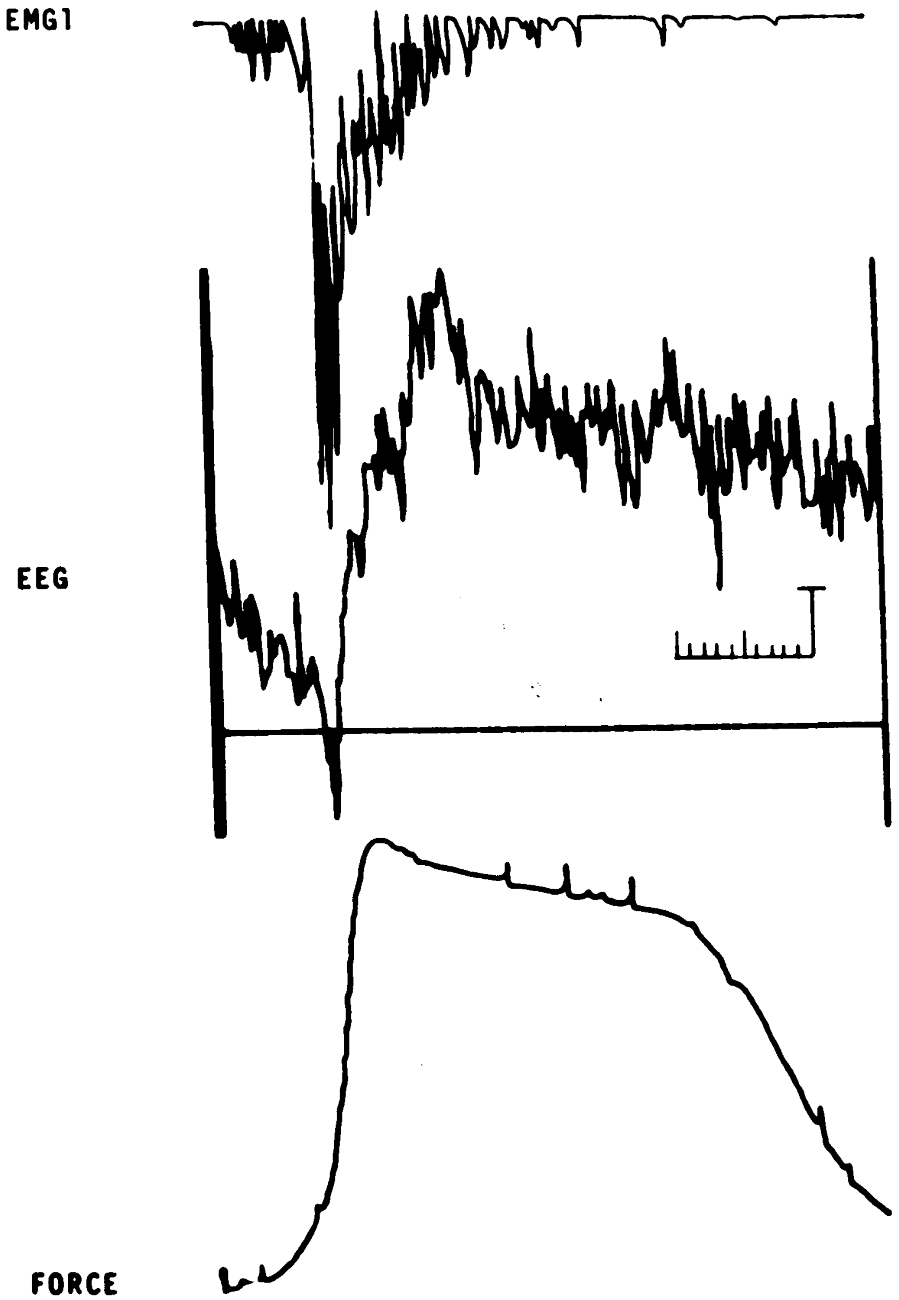
APPENDIX F

Pilot study, EEG from Subject 2, force from experimenter. EEG calibration, hor. scale, 10 divisions = 320 millisecs. vert. scale, 1 division = 10 microvolts.



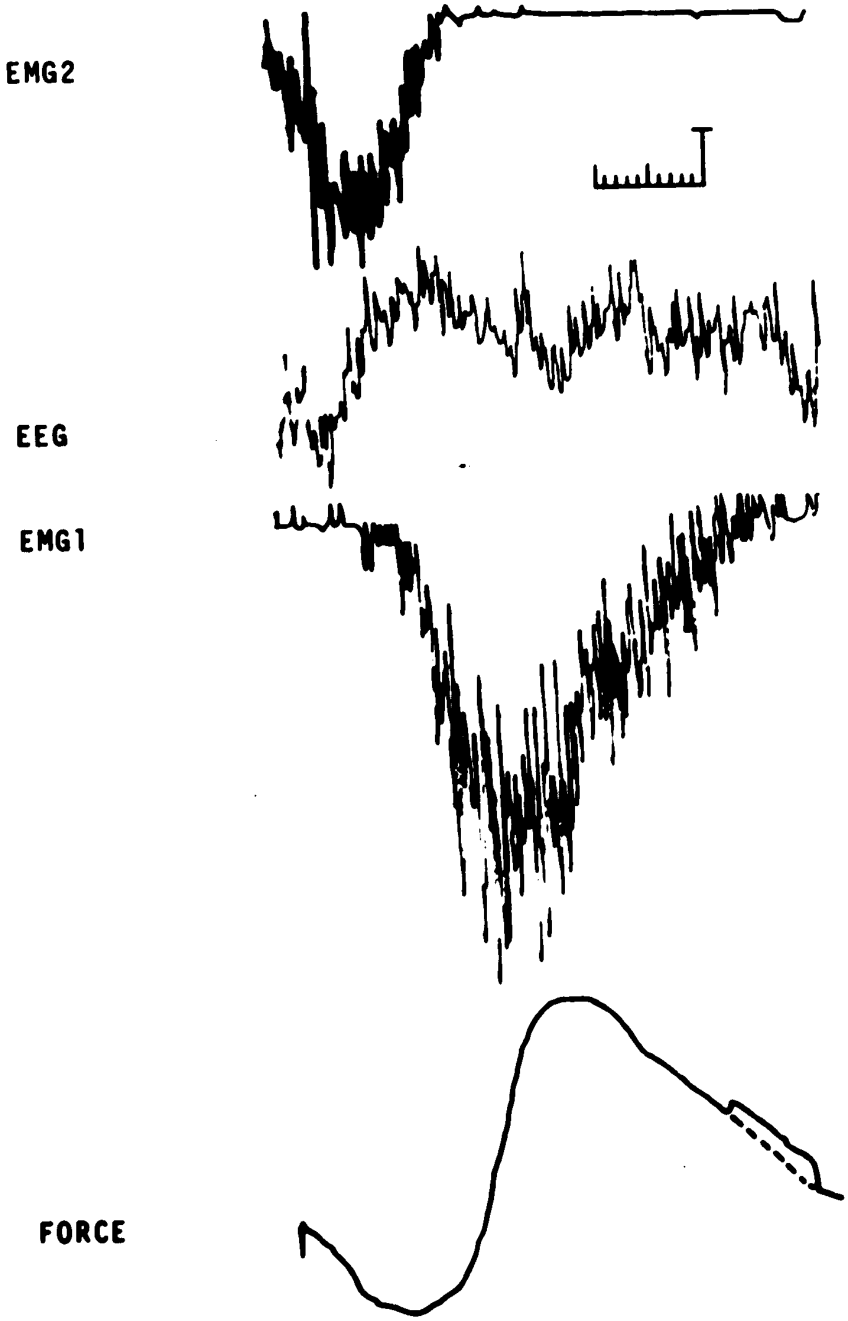
APPENDIX G

Subject 3, Task 1, single movement, 90 sweeps. EEG calibration, hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.



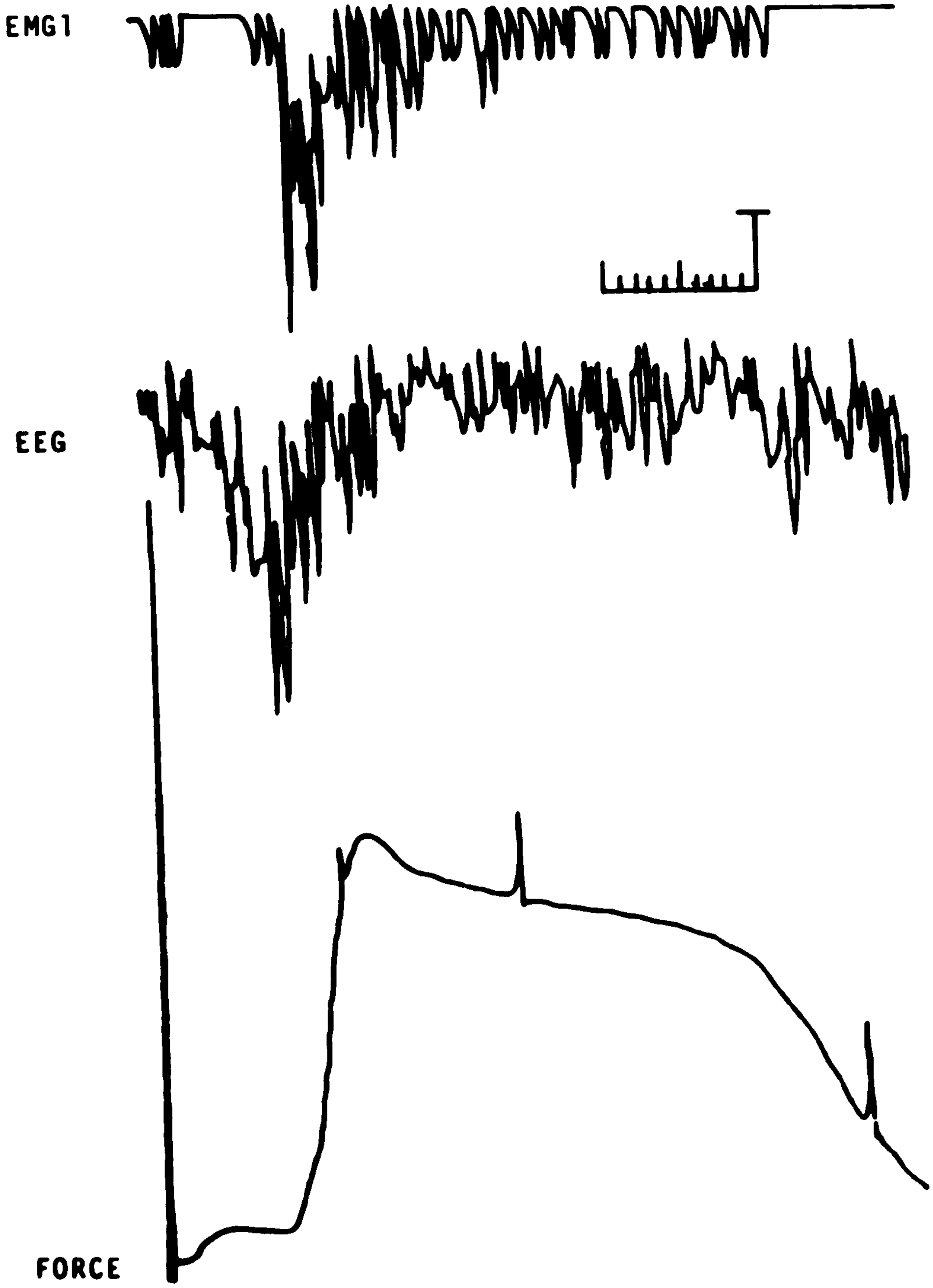
APPENDIX H

Subject 3, Task 4, computer triggered from EMG2. EEG calibration, hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.



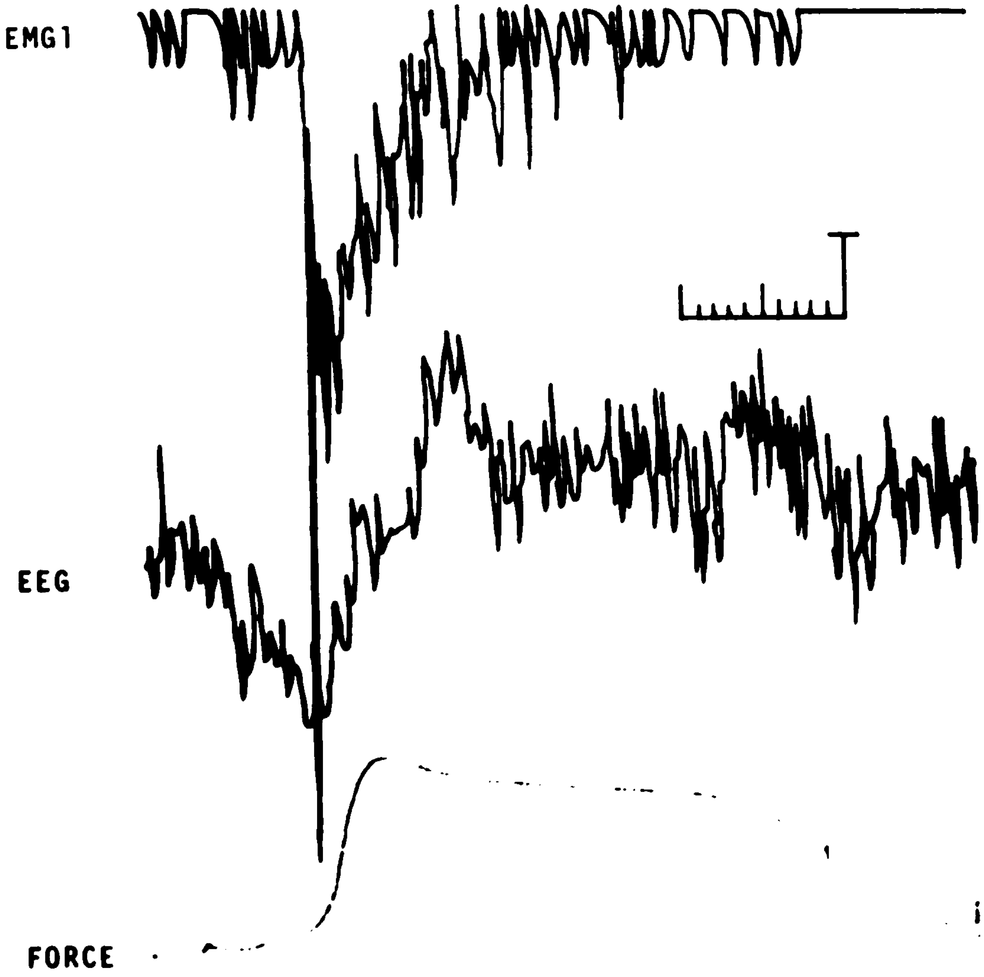
APPENDIX I

Subject 3, Task 1, single movement, 15 sweeps. EEG calibration hor. scale, 10 divisions = 400 millsecs. vert. scale, 1 division = 5 microvolts.



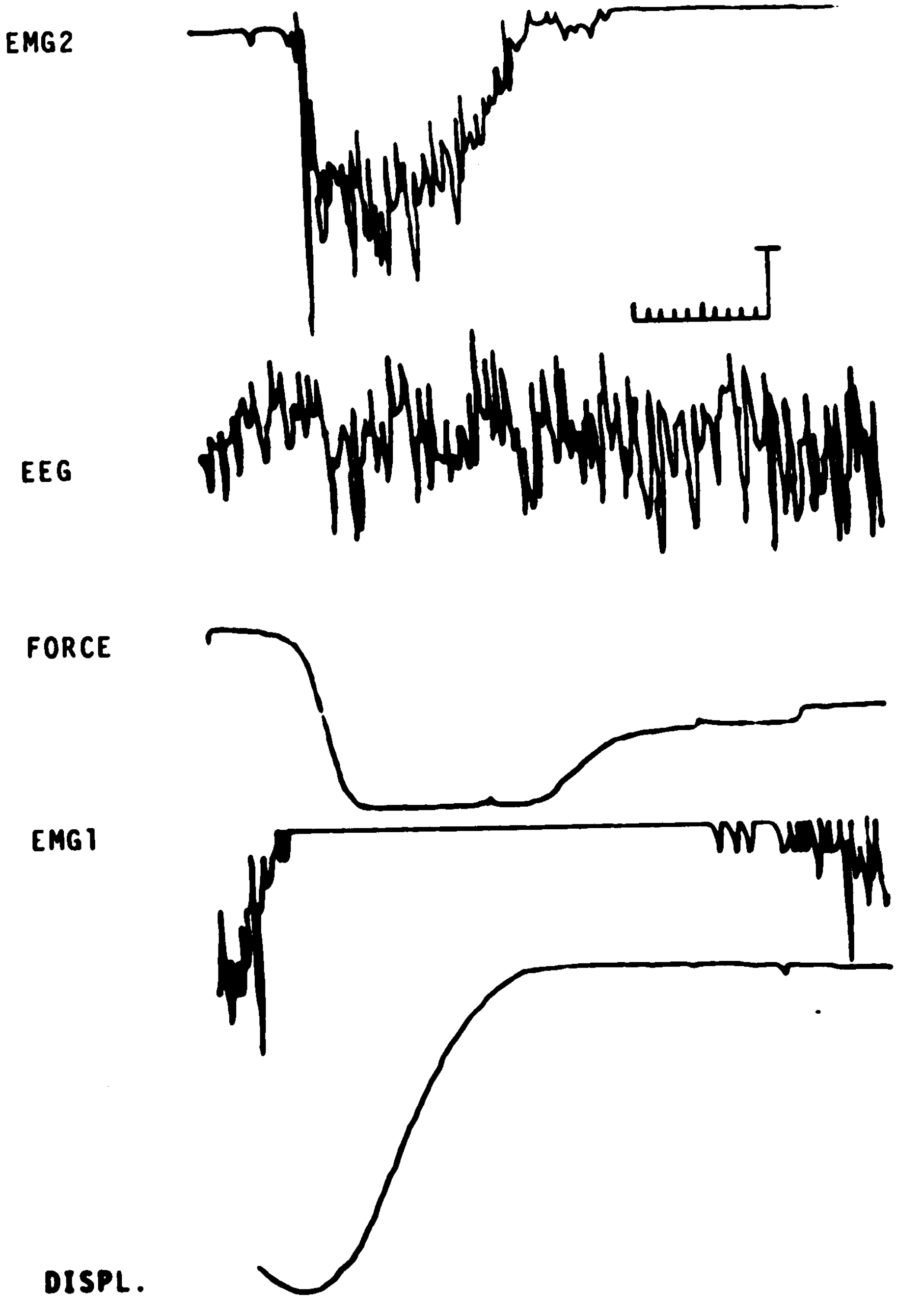
APPENDIX J

Subject 3, Task 1, single movement, 30 sweeps. EEG calibration, hor. scale, 10 divisions = 400 millisecs. vert. scale, 1 division = 5 microvolts.



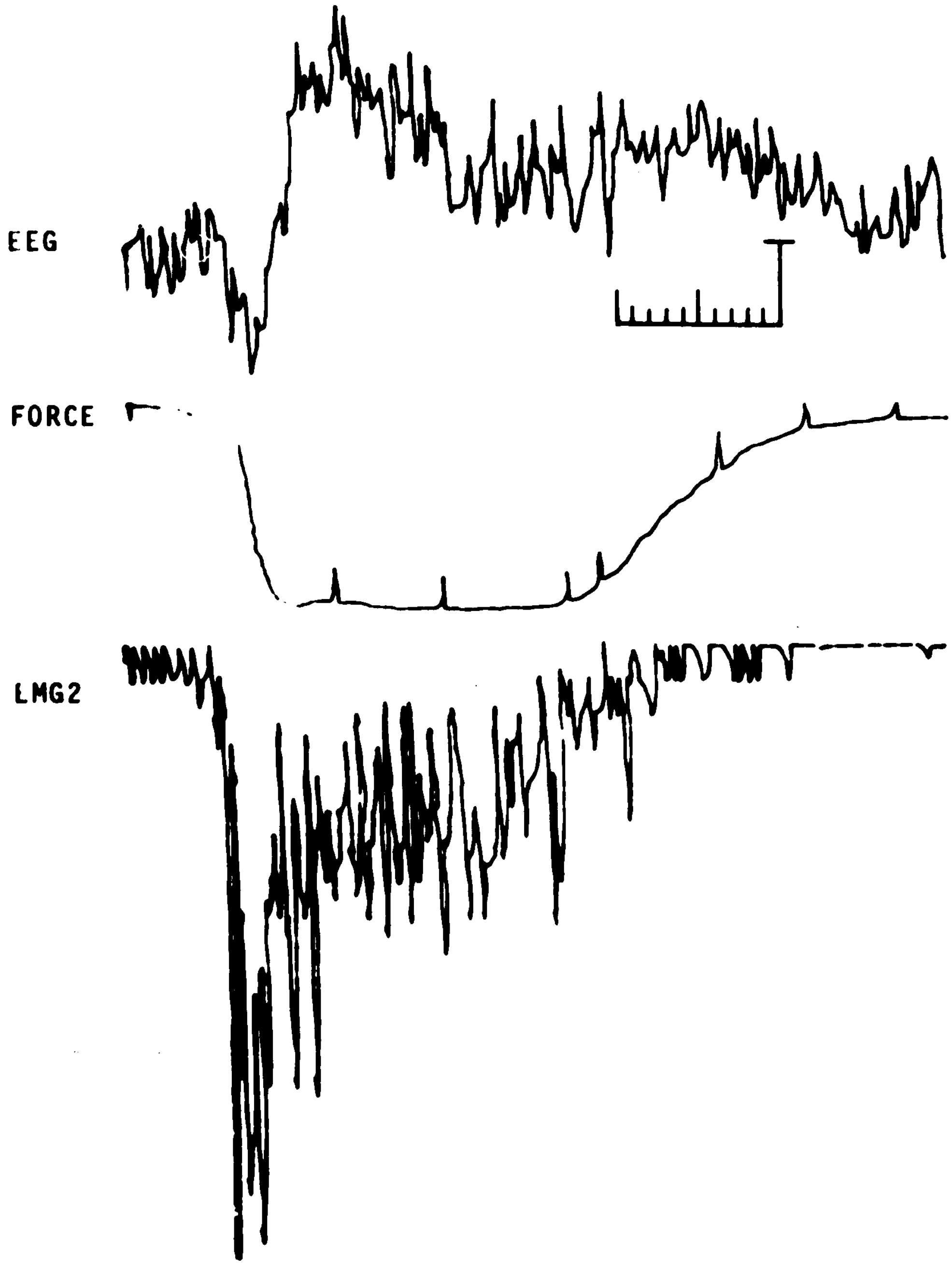
APPENDIX K

Subject 3, Task 3, return movement, computer triggered from EMG2. EEG calibration, hor. scale, 10 divisions = 480 millisecs. vert. scale, 1 division = 2.5 microvolts.



APPENDIX L

Subject 3, Task 2, single movement. EEG calibration, hor. scale, 10 divisions = 480 millisecs. vert. scale, 1 division = 2.5 microvolts.



APPENDIX M

PREPARATION AND CHARACTERISTICS OF EEG ELECTRODES

For the recording of the EEG it was necessary that the electrodes were small for easy application and adjustment, and could be applied to the scalp so that any future application of this work could be conducted either in clinical or field situations.

The following characteristics were therefore required of the electrodes:

(1) That they give stable signals with low level noise and no significant phase shift. These characteristics are found in the non-polarizing Ag/AgCl electrode.

(2) That the conducting electrode surface be small so that little hair would need to be removed from the scalp, and yet large enough so that the amount of current passed by the electrode per unit area, would not be too high.

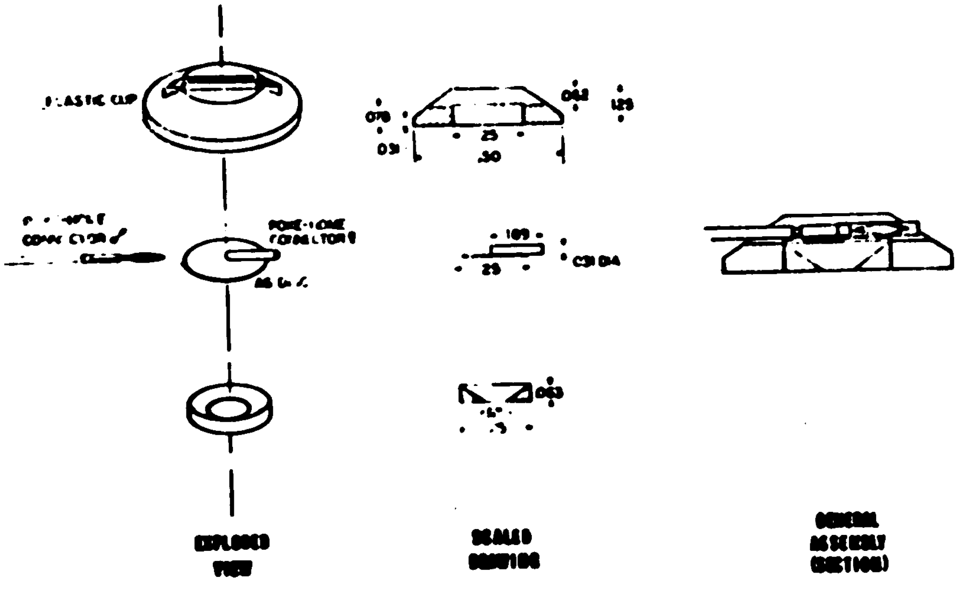
(3) That the electrodes be surface recording, so that they can be used without medical attendance, in general clinical and field applications.

(4) That the conducting surface of the electrode be isolated from the skin so that movement artifact does not contaminate the signals.

(5) That easy access be available to the scalp underneath the electrode for adjustment of the skin condition to bring the skin-to-electrode impedance within limits prescribed in Chapter III.

(6) That the electrode surface be renewable, so that if damaged, the surface can be re-anodized.

Of the electrodes available, the ones providing most of the above characteristics were those used by Skov and Simons (1965). As can be seen from the specifications diagrammed below, the small insert used, requires only a small amount of hair to be cut. The removable caps allow improvement of the skin-to-electrode impedance and if the silver discs are not cemented in, allow for easy re-chloriding.



Specifications for Electrodes

(Skov and Simons, 1965)

The micro-connectors attached to the electrodes allow for replacement of broken leads without re-making any of the electrode parts.

In preparation for this experiment, the small connectors were silver-soldered to the silver discs; the discs were cleaned by immersing in a 1% saline bath and making them the negative pole in an electric circuit with 60 m.a. applied at 10 volts for 10 minutes. The cleanliness of the discs was verified by close examination through a microscope at an amplification of 50 times. It was observed that even in the troughs of the irregular silver surface the reverse polarity had cleaned off all impurities.

In anodizing the discs, the current density recommended by Geddes (1969) was obtained from a 12 volt source and was varied using a potentiometer. The current was checked using a volt-ohm meter. After anodizing, each disc was examined under the microscope for irregularities and bare spots in the chloride surface.

After some experimentation, current density was varied using 2 minutes at 1 ma/cm^2, 3 minutes at 2 ma/cm^2 and a further 2 minutes at 1 ma/cm^2. By using this method of chloriding very few bare spots could be detected under the microscope and a very even layer of chloride was deposited. The electrodes were agitated in the bath from time to time and between the three different levels of current application the electrode was washed thoroughly.