ELECTROMYOGRAPHIC STUDIES OF MUSCLE ACTION IN SKILLED MOVEMENTS WITH PARTICULAR REFERENCE TO MUSCLE ACTION IN MOTOR SKILL OF TYPEWRITING

THESIS

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I certify that the work presented in this thesis has been carried out solely by the candidate, Miss Evelyn Hughes, in the Department of Ergonomics and Cybernetics at Loughborough College of Technology.

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CONTENTS

CHAPTER 1.

1. Electromyography.

Historical Introduction.

Man exhibits some of his most distinctively human characteristics in his pattern of movement. For this reason, the study of muscle action and co-ordination has long excited interest, and some of the earliest recorded experiments and investigations dealt with muscle and its function.

Prior to the discovery of "animal electricity" by Galvani in 1786, studies on muscle carried out by such men as Leonardo da Vinci and Andreas Vesalius, were limited to theoretical postulates on muscle dynamics and function which could only be supposed from the appearance and geography of dead muscle.

Following the initial discovery of electricity associated with the activity of frog nerve/muscle preparations by Galvani, many early physiologists interested themselves in the electrical properties of nerve and muscle. Notable amongst these were Matteucci and Du Bois Reymond, who working independently in the 1840's found a flow of current to be associated with contraction of isolated striated muscle.

As early as the 1860's, electrostimulation techniques were being used to study muscle action, and in 1867 "the father of medical electrophysiology", G.B.Duchenne published his classical work "Physiologie des Mouvements". Duchenne stimulated muscles by means of electric shocks, and combining his observations with clinical studies of muscle abnormalities, made a major contribution to the understanding of dynamic muscle function. Duchnne admits freely that his technique of stimulation is "insufficient to throw light on the physiology of voluntary motion" because "isolated action of the muscle is not the nature of things". Unfortunately Duchenne lived and worked before further advances in electrophysiology gave birth to the study of free muscle action using the technique of electromyography.

Hermann, in 1877, was probably the first physiologist to employ a technique of surface electrode recording to successfully show action potentials associated with muscle contraction. Using two electrodes, made of rope soaked in zinc sulphate solution, which he tied about the forearm, he was able to pick up measurable diphasis currents from the contracting muscles when the supplying nerves were stimulated with electric shocks.

In 1883 came the first recorded use of a needle electrode technique for recording the potentials associated with muscle contraction in the human muscle. Wedenski inserted two needles into his own biceps brachii, and studied the rapidly fluctuating potentials associated with contraction by means of a telephone earpiece. Using this method, Wedenski was able to calculate the fundamental frequency of the potentials which he found to be 40 cycles per second. This quite remarkable experiment gives a value for the fundamental frequency which corresponds to that found almost two centuries later for the biceps when Hayes (1960) used apparatus and experimental techniques that Wedenski could hardly have dreamed of.

This brief account of the early stages of the evolution of electromyography does not include many who contributed to knowledge, but many full accounts of the early history are now available. (Rasch and Burke 1959.)

A more scientific approach to the study of the electric changes associated with muscle activity became possible, as physics contributed to physiology, and with the use of the Lippmann capillary electrometer (1878) and later of the Einthoven string galvanometer (1906), the rapid variations in potentials could be followed and analysis made of both the wave form and frequency of the action potentials.

Further improvem nts in instrumentation came with the development of the electronic amplifier of Forbes and Thanker, based on Flemings thermionic valve invented in 1914, the electromagnetic oscilloscope of Mathews, and the Cathode Ray Oscilloscope.

Recent investigators in the field of electrical activity in muscles have enjoyed the great advantage derived from the development of value amplifiers with which the fluctuating potentials can be magnified as much as a million times or more without appreciable distortion of the wave form. The amplified potentials have been measured in various ways; as a sound in a loud speaker, projected as visible waves on the screen of a cathode ray tube, permanently recorded on gramophone records or photographic film, or else, with some limitation of frequency response, on paper by means of ink writing electromagnetic pen recorders. More recently, interest has been shown in quantifying the Electromyogram, as well as giving a qualitative description, and in the non-clinical fields particularly the use of integrating devices is a recent advancement.

In general, investigators are limited in their choice of apparatus. Those interested in the finer details of motor unit activity, the shape of the potential, high freqency potentials and similar aspects of muscle activity, are limited to the use of the cathode ray oscilloscope and other instruments with high frequency response. Denny-Brown (1949) and Basmajian (1962) comment on the better suitability of the cathode ray oscilloscope for clinical investigations, and for study of the detailed form of the action potential.

Many anatomists and kinesiologists, however, with their interest in the relationships between periods of rest and activity in muscle groups, and the inter-relations between muscles tend to use the ink writing electro-encephalographic equipment with which they can conveniently record the activity of many muscles simultaneously, and comparatively cheaply. Floyd and Silver (1952) found that the ink writing electro-encephalograph gave them results almost exactly similar to the Cathode ray oscilloscope.

The most recent development in electromyography has been the attempt to quantify the electromyogram with the use of integrating devices.

Some of the simplest in theory, but most tedious in practise and undoubtedly the first methods of quantifying the EMG, are those involving the visual analysis of the resulting potentials by the experimenter. Basmajian (1962), for example recommends the classification of activity into various levels, e.g. nil, negligible, slight, moderate, marked and so on. This method is suitable no doubt for some gross differentiation, but is difficult to apply when small graduated changes in activity occur.

A spike counting method of integration has been used in this laboratory (1963) where the number of spikes was estimated over a given time period. Berström (1958) compared the electronically integrated area of the electromyogram with the number of action potential spikes, and found the relation to be linear up to a frequency of 500 c.p.s. However, he emphasizes that the linear relation can only be assumed to be true if no synchronisation of the action potentials occurs. Since synchronisation has been shown to occur with fatigue (Lippold et al (1960); Buchtal and Marsden (1950)) a spike counting method of analysis can only be employed for short term experiments.

Another method of mechanical integration of the EMG to give quantitative results is that used by Lippold (1952) where he measured the amount of muscle activity from the photographed electromyogram using a planimeter (as used by geographers). This method of quantifying the record, successfully showed the linear relation between the electromyographic activity and the muscle tension, but for success with this method the action potentials must be recorded on paper moving at high speeds. The method would prove useless for quantification of high frequency potentials recorded on slow paper speeds.

Davis (1959) has used photoelectric integrators in some of his work on muscle tension. This method of integration is suitable for analysing the records obtained with ink writing recorders and depends upon the simple principle of measuring the amount of light blocked by the action potential waves with the photo-electric cell.

These simple methods of integrating the EMG have been used with success, but in studies on muscle co-ordination, where it is desirable to record simultaneously from four or more muscles any type of mechanical integration is quite impracticable and one must progress to the use of electronic integrating devices.

The extended use of electronic integrators would seem to be a natural progression in the evolution of electromyography. Biggland and Lippold (1954) found the use of an electronic intergrator gave results as accurate as the planimeter, with much less effort. Psychologists have already established the Integrated EMG as being a reliable measure of stress and effort (Eason and White (1961)) and integrating circuits are often incorporated into the electro-encephalographic recording apparatus, but physiologists working in the field of electromyography still seem to be reluctant to express their results in the quantitative form available with the use of integrators.

The most notable results obtained with the use of integrators are those which show:

a. the relation between electric activity in a muscle to the tension of the muscle. (Malmo (1958); Lippold (1952))

b. the relation between the velocity of muscle contraction and the electrical activity. (Small and Gross (1958); Biggland and Lippold (1954))

c. the relation between the force of the contraction and the electric activity (Biggland and Lippold (1952))

d. and to show the changes in muscle activity with fatigue. (Eason (1960)).

In this introduction emphasis has been given to the use of integrators for quantifying the electromyogram. In the work to be described the electronic integrator has been used extensively to simplify the analysis of the results, and using this method of quantifying the results, small differences in muscle activity have been detected which would perhaps not have been appreciated with some less exacting recording device. The description of the integrator together with calibrations and the method of use will be described in the methods section in the following chapter.

<u>Summary</u>.

Electromyography arose in response to a need; classical methods of investigation with their serious limitations in the study of free muscle action left gaps in the knowledge as to how living muscle functions in the normal situation, and gave only information which could predict what a muscle might or should do. Electromyography reveals, in a unique way, what a muscle actually does do at any instant, and further, it reveals the fine interplay of activity and co-ordinations which exists between muscle groups, which it is impossible to reveal in any other fashion.

The study is concerned with the co-ordination of muscle action occurring with the development of a motor skill and with other aspects of finely co-ordinated muscle action. The skill which has been chosen for study is the typewriting skill, where complex co-ordinations of hand and eye occur, until in the highly skilled person the movements involved in the typing task occur with a high degree of automatism.

In this study it is desired that the subjects should work freely, being as unconscious as possible of the experimental arrangements. Many investigators using a needle electrode technique to record muscle action potentials from contracting muscles have commented on the pain experienced by the subjects both when the electrodes are inserted and when muscles are

vigorously contracted which would tend to make subjects reluctant to work normally and vigorously. This method of recording action potentials has therefore been completely rejected in this work, since the patterns of muscle activity in the normal typing action was required with no stresses placed on the subject and no limitation on the free movement of the individual.

For this reason the surface electrode technique of recording muscle action potentials has been used throughout, and using this method of recording, typists were able to work at their optimal speeds with no inconvenience. Also, with using the simple painless method of recording with surface electrodes several subjects could easily be persuaded to attend for experimental sessions repeatedly and frequently!

CHAPTER 2.

General description of apparatus and experimental procedure.

Though not all the apparatus and techniques to be described here were used in every series of experiments, it is more economical to describe them at this stage, and to indicate the relevant ones in the methods section of subsequent chapters.

1. Subjects.

All the subjects who participated in the experiments were female. They ranged from highly skilled typists to completely untrained persons. In general the subjects were drawn from three main groups, one group were young girls at differing stages in the acquisition of the motor skill, who were recruited from a local college, and who were paid for their services. The second group of subjects participating in some of the work were employees of the I.B.M. Company, highly skilled typists who were employed as secretaries or demonstrators of the I.B.M. electric typewriters. The third group of subjects were members of the staff of Loughborough College of Technology, who were employed as secretaries or typists in the typing pool.

The subjects used in each study will be described separately in context.

2. Experimental Design.

This will be described in the methods section of each study.

3. Apparatus and Procedure.

(i) Typewriters used.

Two typewriters were used during the course of the work. These were an Imperial 77 manual typewriter, and a standard I.B.M. electric typewriter. During the course of the studies, it was necessary to attach various measuring devices to both typewriters, and these will be described in the relevant sections.

(ii) Typewriting Table and Chair.

A previous study (1963) had shown that the height of the table on which the typewriter is placed can have a significant effect on both the total energy expenditure, and localised muscle activity of typists. This study pointed to an optimal height of 24 inches for the table. The chair top height of 17 inches as recommended by B.S.I. (1959) was used in the study.

Since much of the experimental work to be described involves comparisons between the muscle activity between different typists and also with the same typists at different times, it is essential that the table height and chair height should be kept constant. These heights were therefore used for each subject and in all experiments.

(iii) Experimental Room.

All experiments were carried out in a room devoted to studies on the typewriting skill. Only the subject and the experimenter were present. All sources of interference (mains hum etc.) were earthed, and shielded leads were used.

(iv) Electromyographic Recording Procedure.

Since in electromyographic studies differences in opinion which may occur in the literature might well be due to variations in technique, instrumentation and methods of analysis, it is very necessary that a full description of experimental technique be given, together with descriptions of the apparatus used, with any limitations these might have.

In this work where the free movements of muscles is required the technique of surface electromyography has been used.

Schwartz et al (1949), define five variables which significantly affect the input voltage derived from muscles and recorded on an amplifier as being:

1. The type of surface electrode.
2. The electrode area.
3. The distance between electrodes.
4. The strength of the muscle contraction.
5. The power of the muscle.

As it is desired that the recorded electromyogram will only reflect changes in factors 4 and 5, it is necessary that due precautions are taken to ensure that the first three factors remain constant. Considerable care was therefore taken to ensure that these factors did not vary from experiment to experiment.

4. Surface Electrode Technique.

(i) Surface Electrodes.

The electrodes used were polarised silver discs, of one centimeter in diameter, having a small dome in the centre of the disc. Snyder (1953) recommends a diameter of 1 cm. as being most suitable for surface electrodes of this type.

Bipolar leads were used, and an inter-electrode distance of two inches separated the electrodes, which were placed over the muscle to run in parallel with the muscle fibres. The inter-electrode distance of two inches is recommended by Davis (1959) as was found to be a convenient separation for all the muscle groups investigated.

(ii) Placement of electrodes.

It is very difficult in electromyographic studies to be able to compare electromyograms recorded from different subjects, and from the same subject at different times, and to be able to draw any conclusions from these comparisons, since the electromyograms vary with many factors, including the position of the electrodes. Some authors recommend the placement of electrodes with reference to the motor points in the muscle (Eason 1960), but this procedure was found to be too time consuming to be of practical value, and was rather unpopular with the subjects.

The method therefore adopted in the positioning of the electrodes was based on the lead placements described by Davis (1959). Thus with each subject and each muscle group the electrodes were positioned with reference to surface anatomy markings, with precise measurements giving an accurate reproductability of positioning. The electrode placements described by Davis were used for the Forearm flexor and extensors, the Biceps and Triceps, and the Trapezius; a similar method of standardisation was used for the Median Deltoid.

The dome of the electrodes was filled with a conducting jelly (Cambridge Electrode Jelly), and the electrodes were fixed to the skin using adhesive plasters, a first plaster of diameter 2.5 cms., covered by a second plaster 3 cms. in diameter. This method of fixing the electrodes gives a good secure continual pressure on the electrodes with the minimum of inconvenience. A common earthed electrode was always placed on the back of the wrist.

(iii) Skin Resistance.

In surface electromyography it is essential that a thorough preparation of the skin be made before attachment of the electrodes so as to reduce the electrical resistance to practical levels. This high resistance offered by the skin to potentials produced within the body is thought to be due to the presence of non-conducting substances in the upper layers of the skin, and the procedure of preparation is so as to remove these substances and improve the conductance of this superficial skin layer.

After the proposed electrode sites had been marked, the skin at these sites was rubbed with the electrode jelly which contains a powdered abrasive in its formula. The jelly was then left to soak into the skin at these sites whilst other measures were taken to position other electrodes, and jelly rubbed in at these sites. The surplus jelly was then removed with cotton wool, and then electrodes fixed into position. Using this method the interelectrode resistance was lowered to values close to 4 kilohms. It is necessary to ensure that at the start of the experiment the resistance is of the sort of value, since it will improve with time after application of the electrodes, if it starts initially higher than 10 kilohms, presumably as the jelly soaks into the skin. This improvement in the resistance could conceivably give a false impression of increase in the recorded potentials after a period of time, if the potentials were being recorded on amplifiers with low input impedence. Once the value of about 10 kilohms is reached no further improvement in the interelectrode resistance appears to occur.

5. Recording Apparatus.

The muscle action potentials (M.A.P.) were recorded on either an Offner eight-channel ink-writing electroencephalograph, an Ediswan four-channel ink-writing electroencephalograph, or with a Nagard two-channel cathode ray oscilloscope. Also intergrated values of the M.A.P.'s were obtained from four electronic integrators which derived their input via the four amplifiers of the Ediswan electroencephalograph.

Each of these methods of recording, their uses, and any limitations will be described in detail below, and reference to the particular apparatus used will be given in context.

(1) Eight-channel Offner Ink-writing Eletroencephalograph.

Schwartz et al (1949) have fully described the electroencephalographic apparatus made by Offner Electronics, and discussed their limitations in electromyographic work. The more recent Type T model was used in this work, and as a general rule was used to substantiate and clarify observations made with the Integrator, and to observe the interplay of muscle activity between different groups of muscles, and to observe the times of activation and rest in the muscles under investigation. Little, if any, quantitative analysis of the E.M.G. records obtained from the Offner was attempted.

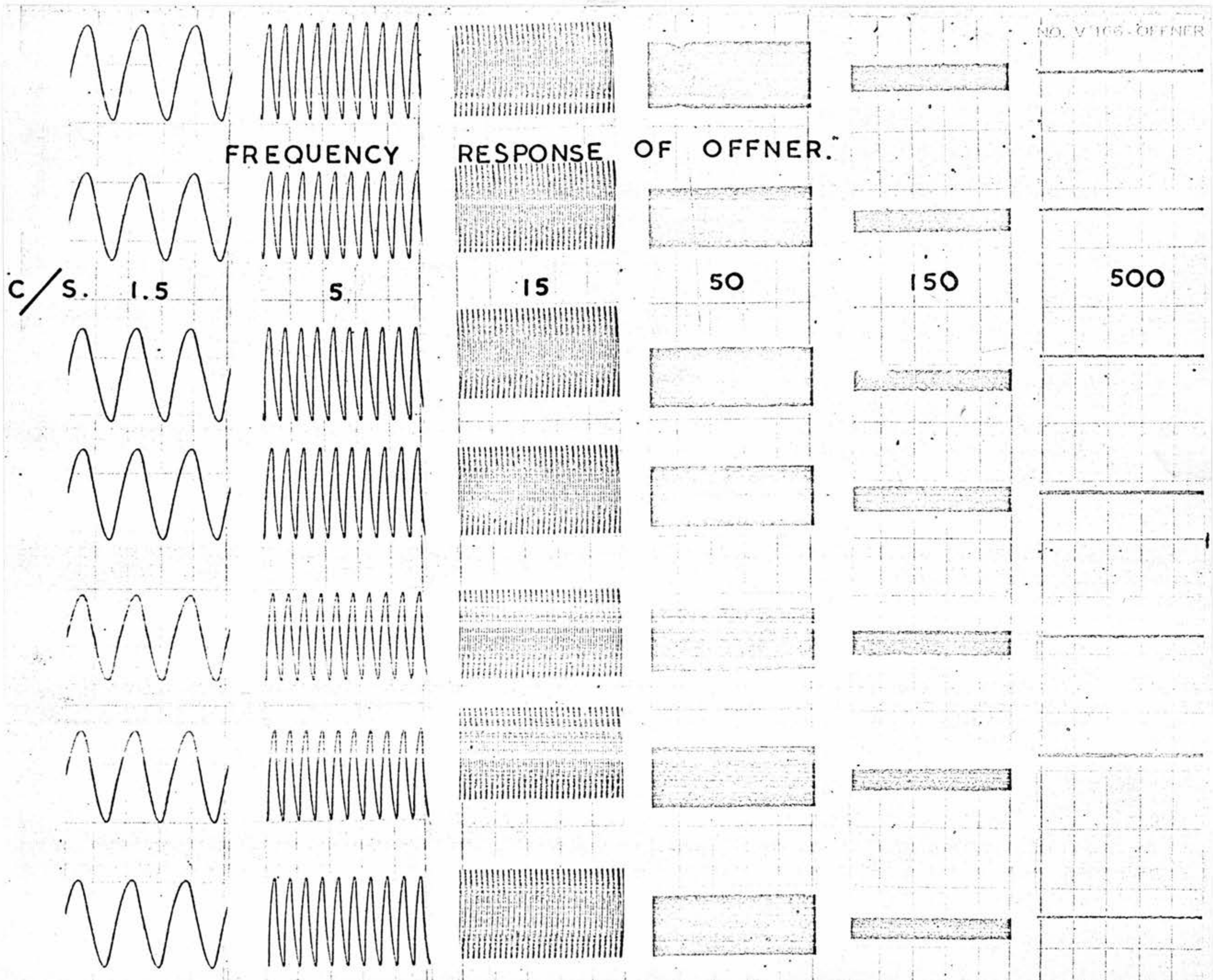
Input Impedence. The Offner has a very low input resistance of 0.6 megohms, which is reduced still further to 0.2 megohms when using the time constant of 0.03, which means that for any really accurate quantitative estimations of activity to be made of the amplitude of the M.A.P. the interelectrode resistance must be very low, consistantly low in every muscle, and equally low on every occasion.

Since the values of the interelectrode resistance vary between muscle sites and between individuals, and in the same individual at different times, misleading results could result from examination of the Offner records alone when trying to make quantitative analysis of records.

Frequency Response. Figure 1 shows the response of the Offner pen to a constant input voltage at frequencies from 5 cycles per second to 150 cycles per second. The Offner pens respond in a linear fashion to frequency of 50 cycles per second but a reduction in response to the constant voltage input is observed with frequencies of above 50 cycles per second. Hayes (1960) believes that the use of amplifiers with a limited frequency response is practical for the recording of motor unit potentials derived from surface electrodes, due to the sharply peaked spectra of the potentials occurring between 20 to 200 cycles per second. The Offner range is rather limited perhaps.

Paper Speed. Paper, 8½ inches wide, with 1-inch pen spacing was fed through the Offner either at speed 1.5, 3, or 6 cms. per seoand.

<u>FIGURE 1</u>. Shows the frequency response of the Offner pens to a constant input voltage with frequencies from 5 to 150 cycles per second. It can be seen from the figures that the pens pick up all frequencies to 50 cycles per second but a reduction in response is seen above this frequency.


NO. V106-OFFNER
FREQUENCY RESPONSE OF OFFNER.
C/S. 1.5
5
15
50
150
500

Calibration of Gain Settings. The master gain control for all eight channels, and the individual channel gain settings were calibrated frequently throughout the experimental work.

Summary.

The Offner was used for the study of the times of activation of muscle groups relative to each other, and relative to other measures, though the fastest paper speed of the Offner (of 6 cms/sec.) made the chief limitation here. This paper speed was not fast enough for really fine measurements of timing, and for more detailed and precise information the Nagard oscilloscope was used.

(ii) The Ediswan Four-channel Electroencephalograph and the Electronic Integrator.

The four electronic integrators used were designed and built by Mr. R.Harding of the Department of Ergonomics and Cybernetics, Loughborough College of Technology. The integrator receives the amplified potentials originally derived from the muscle via the amplifiers of the four-channel Ediswan electroencephalograph. After suitable amplification the muscle action potentials are passed through a full wave rectifier which provides a unidirectional output. This signal is used to control the anode run down of a transitional saw-tooth generator. The generator output, after shaping, is fed into an electronic pulse counter,which is in turn controlled by an electronic timer (Labgear timer), which can give a preset integration time period, or could be controlled by the experimenter switching an on/off switch on the timer.

Since the pulse rate at any instant is directly proportional to the amplitude of the incoming signal, the total pulse count in any timed period gives an index of the total voltage from the muscle in this period, i.e. an index of $\int /v/dt$, the area under the curve.

Calibrations of the integrators were carried out by feeding in known D.C. potentials at the integrator input, and the integrator pulse count was linear for input potentials over the range 0 to 100 volts. Calibration curves for the four integrators, showing the increase in pulse count with D.C. voltage inputs up to 9 volts are shown in Figure 2.

From the Figure it can be seen that the integrator pulse count is linearly related to input voltage. The individual integrators do give slightly differing digital readings for the same input voltage, though the slope of the line is much the same. As a general rule the potentials form the same muscle were always fed into the same integrator. The integrators were calibrated frequently during use, and four calibration curves taken over eight months use show no variation in digital curve with time.

Figure 3 shows the complete integration set up with the

FIGURE 2. Calibration curves for the four electronic integrators, showing the linear increase in pulse count with increase in input voltage. The calibration was carried out over a ten second integration period.

Ordinate Integrator pulse count.

Abscissa Input voltage.

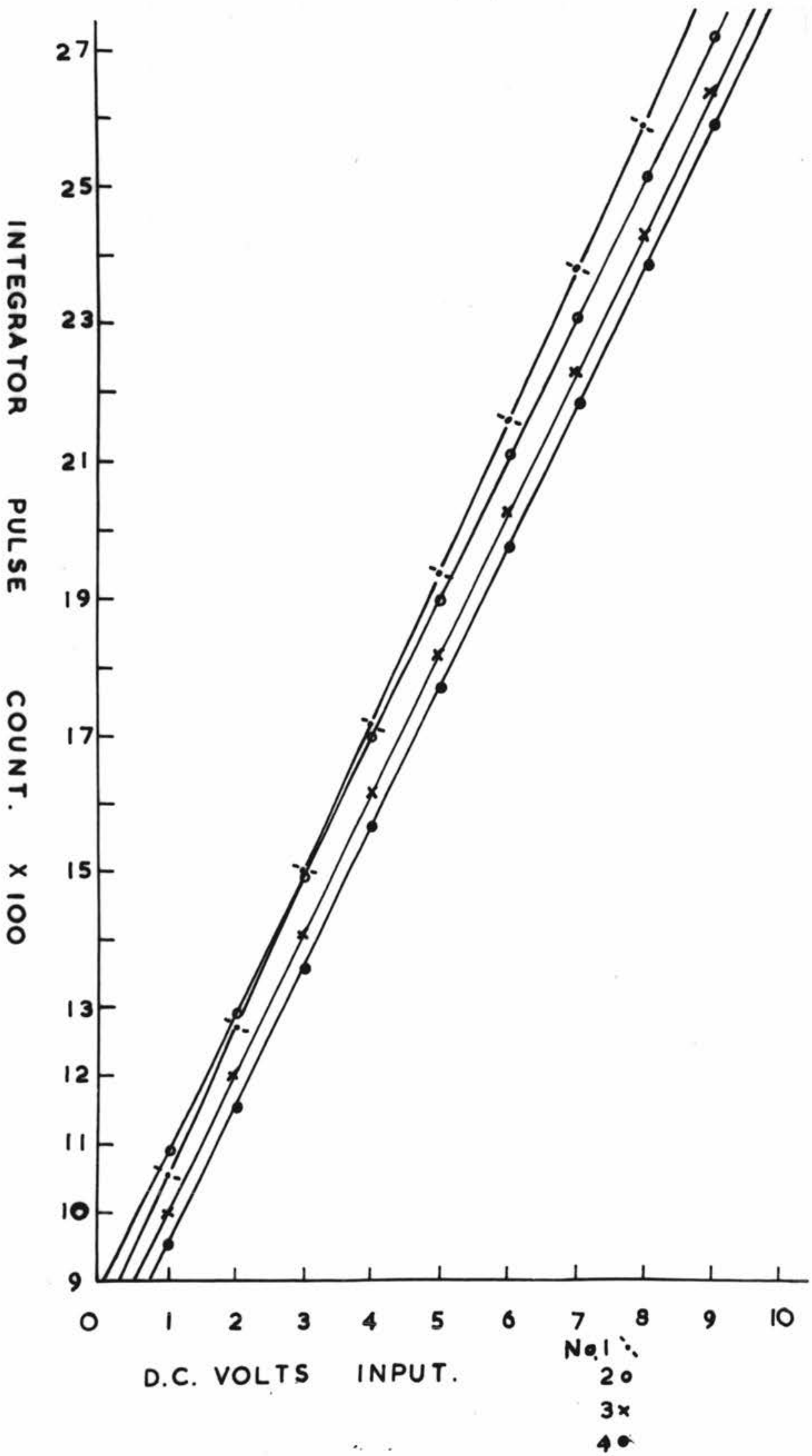
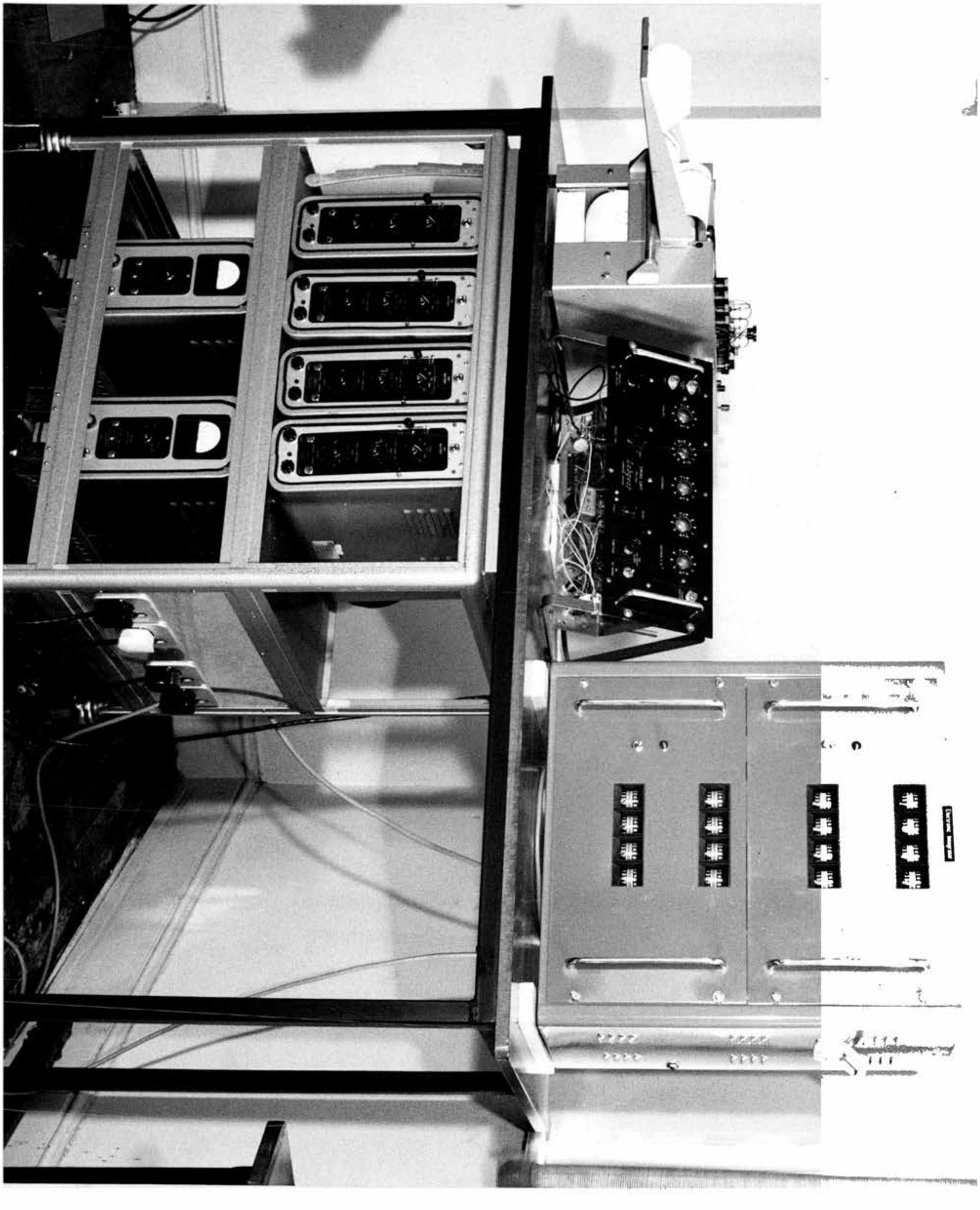

INTEGRATOR PULSE COUNT. X 100
9
10
11
12
13
15
17
19
21
23
25
27
0
1
2
3
4
5
6
7
8
9
10
D.C. VOLTS INPUT.
No.1
2
3
4

FIGURE 3. Shows the apparatus used for the integration of the electromyogram, with the four-channel Ediswan electroencephalograph, the electronic timer and the four-channel integrator.



Ediswan four-channel electroencephalograph, the timing unit, and the four integrator channels incorporated into the one unit. The output from the muscles, using this recording unit is obtained in two forms:

1. The original E.M.G. tracings, written on paper by the four pens of the Ediswan electroencephalograph, and

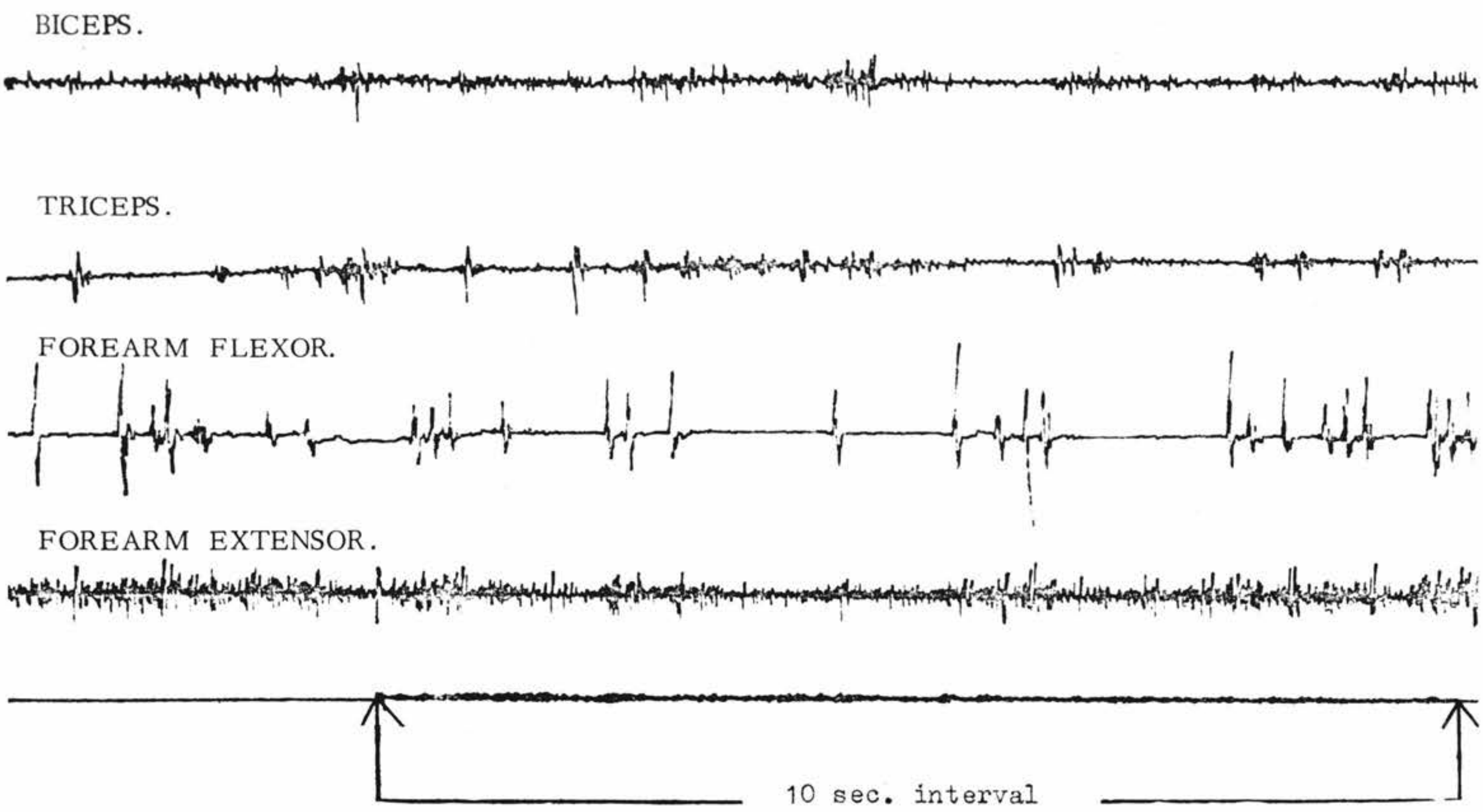
2. The secondary reading, obtained from the four integrators as pulse counts, with integrator 1 deriving its current from amplifier 1, and with the primary record being obtained with pen no. 1, and so on.

The integrated potentials are presented as a digital pulse count and most of the information relating to the degree of muscle activity is obtained from these counts. Little analysis has been carried out on the primary Ediswan record though a study of these was carried out as a check on the integrals to ensure that artifacts of recording do not invalidate the integrator reading.

A time marker was actuated on the primary trace whilst an integration was being carried out (Figure 4), and thus a check for artifacts in all four channels could be carried out at the time of integration and the reading rejected if such an artifact did occur.

<u>Characteristics of the Edswan Amplifiers which might affect the Integrator Input.</u> The electrical characteristics of the Ediswan amplifier make it much more suitable than would be

FIGURE 4. Shows the actuation of the time marker on the Ediswan electromyographic trace during the ten second integration period.
Artifacts which will invalidate the integrated values can be picked out from continuous monitoring of this primary trace.


BICEPS.
TRICEPS.
FOREARM FLEXOR.
FOREARM EXTENSOR.
10 sec. interval

the Offner for amplification of the potentials fed to the integrator inputs.

Input Resistance. The Ediswan amplifier with the high input resistance of 10 megohms grid to grid, makes it highly unlikely for the magnitude of the muscle voltage to be affected by the interelectrode resistance. Even with the comparatively low interelectrode resistance of 10 kilohms the reduction in the input voltage is negligible. Therefore, using the Ediswan amplifiers, one can be sure that variation in the voltage amplitude is not due to any variation in the skin resistance.

Frequency Response. The Ediswan amplifier is capable of picking up frequencies up to 5000 cycles per second. Through the experiments, the high frequency switch was kept at 500 cycles per second, above this value some reduction in higher frequencies would be expected. The integrators therefore sample through a very wide range of possible action potential frequencies throughout the range of 2 - 200 cycles per second quoted by Hayes.

Summary.

Since a careful check was made of the primary Ediswan record for recording artifacts, and since a regular calibration and check of the apparatus was carried out, the integrator readings can be taken as giving a true estimation of the degree of muscle activity in a given time period.

All frequency potentials within a very wide range could be picked up by the amplifier and integrator, and no artifact in the results can be introduced by variation in the electrode resistance.

(iii) Ediswan Electroencephalograph Ink Writer.

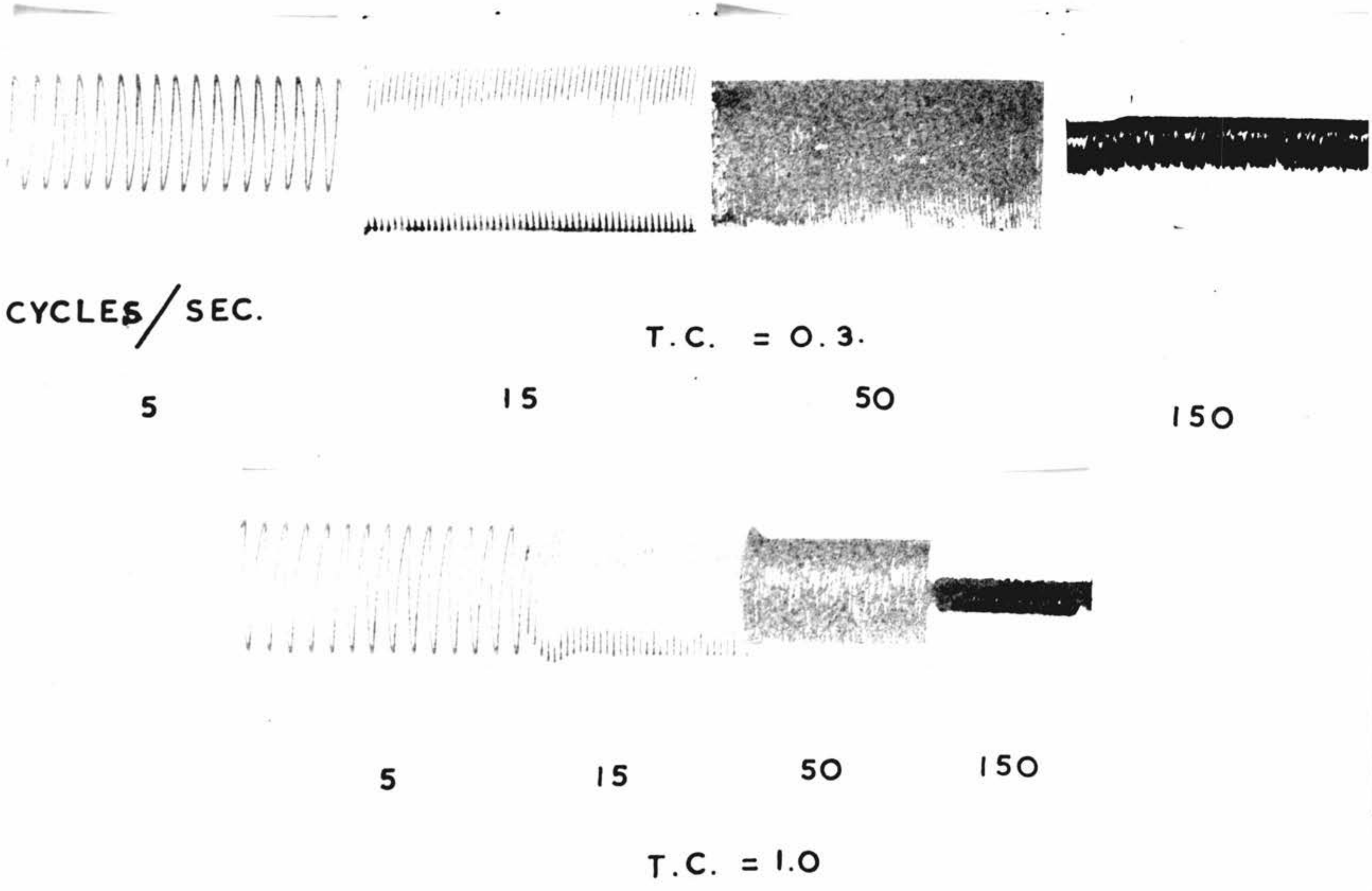
Figure 5 shows the response of the Ediswan pens to a constant voltage input of frequencies to 150 cycles per second. The pens show a reduction in response to frequencies above 150 cycles per second. The Ediswan ink writer was only used in the experimental work as an essential check on the integrator readings.

(iv) Nagard Two-channel Oscilloscope.

The Nagard oscilloscope type 311 was used in experiments when more accurate timing of events was required. Using the Nagard and moving film camera a maximum speed of 15 inches per second could be used. Calibration of the Nagard is shown in context.

FIGURE 5. Shows the frequency response of the Ediswan pens to a constant input voltage fed in at frequencies from 5 to 150 cycles per second.

FREQUENCY RESPONSE OF EDISWAN.



CHAPTER 3.

Neuromuscular Changes Occurring with the Development of the Motor Skill of Typing.

1. General Introduction.

This study is concerned with the functional structure of automatic movements in man, particularly with the development of automatism which occurs with training. These electromyographic investigations have been carried out to seek to further knowledge on the muscular co-ordinations which occur as skill develops, with training in a complex motor skill.

The skill which has been chosen for the study is the typing skill; a motor skill involving a complex co-ordination between the hand and eye, and where the movements carried out by the highly skilled person have attained a high degree of automatism.

A definition of the degree of skill acquired by an individual may be given in terms of end results, with these being speed, precision or strength, or some combination of these three. With persons attaining the same end results it might be said that the one doing so at the lower energy cost is more skilful. With the typing task, the level of attainment of the skill is easily assessed in terms of end results.

The fine motor co-ordinations which occur are largely limited to the action of the muscles in the upper limb where the size of movements is small, and where the factor of strength is secondary to those of accuracy and speed. The strength factor can therefore be ignored in assessing the 'skilfulness' of typists, and her degree of attainment of the typing skill at any time can be assessed by the number of words typed per minute, with due correction being made if errors occur in the copy.

2. Psychology of Motor Skills.

There is an abundance of literature on the psychological aspects of the acquisition of motor skills including much work on the typing skill and other allied skills such as telegraphy. The classic reference in this field is the work by Bryan and Harter (1899) who plotted the learning curves of trainee telegraphers. W.F.Book (1908) showed similar learning curves for typists with the characteristic plateau in the learning curve. The observed plateaus were explained in terms of the building up of 'hieracys of habits'. As persons become more skilled in typing or morse receiving, they appear to pass from dealing with letters as units, to words as units and eventually to whole phrases as units. The observed plateaus presumably occur as the lower order habits are being built up and being made sufficiently automatic, before progression and improvement occur in the more complex task of dealing with connected discourse.

Vince (1949) showed further how this is probably the case, when he found that in tasks such as responding to signals in rapid sequency, or making a rapid series of movements the number of discrete perceptual motor 'units' which can be dealt with is only about two to three per second, but that performance can be greatly speeded up by grouping signals so that several can be dealt with as a single unit. Skilled typists, morse operators and pianists execute individual movements of printing letters, making dots and dashes or pressing notes much more rapidly than the two to three per second, therefore it seems clear that they can only do so by dealing with whole words or phrases as single perceptual motor 'units'.

Hellix and Coburn (1961) in their studies on keyboard design reached this same conclusion that the skill of the typist is the ability to work with units of letters of undetermined size, these units being sometimes several letters. When these units are destroyed so that the typist must work with individual letters her typing speed decreases, and the number of errors she makes increases. The measures of speed and accuracy are those by which a typist assesses her skill and thus it appears that an essential feature in the development of the typing skill is the recognition by the central nervous system of these learned units.

The work carried out by psychologists on motor skills is largely limited to the perceptual processes which occur on the sensory side of the arc which makes up the skilled action.

3. Physiological Studies of Muscle Co-ordination occurring with Training.

Physiologists using the electromyographic technique have shown interest in the effector processes which shape and carry out the skilled act.

Work which has been carried out on the muscular co-ordinations that occur as skill develops with training, comes mainly from the Russian schools of physiology. Much of the work is concerned with the grosser skills of athletics, and though distinction must be made between these sort of skills and the fine skill of typing some consideration of this work is necessary.

Piper (1912) using some form of surface electrode recording and the string galvanometer described changes in the patterns of the excitation of the muscles as movements become learned and automatic, but perhaps the most useful early work was that carried out by Kiselev and Marshak (1935), who showed changes in the electrical activity of muscles, with training, in persons learning weight lifting over a two-month period.

At the beginning of training the electromyograms showed continuous electrical activity in the muscles during the whole movement of lowering the weight, but after two months of training, action potentials were only observed during the beginning and at the end of the lifting action.

Stephanov (1957) also made periodic observations on 15 weight lifters during their training programme. With surface electrodes on the deltoid and triceps, he compared the recorded electromyograms with the athletic form of the weight lifters, and found a marked reduction in the amplitude of the recorded potentials and a smaller, but distinct, reduction in the frequency, as training progressed and athletic form improved. Table 1 quoted from Stephanov shows the results obtained.

Figure 6 redrawn from this same paper shows the changes in frequency and amplitude of the potentials in the anterior deltoid with training. Stephanov also comments on the amazing synchronisation of motor unit activity which occurred in some weight lifters who attained supreme form. He shows action potentials recorded during the press lift reminiscent of sinusoidal curves. This synchronisation of activity is so marked and unusually apparent that Stephanov finds it necessary to comment that the frequency of the action potentials (117 cycles per second, and 68 cycles per second

Table 1. Quoted from Stepanov (1957).

Frequency and Amplitude (mV) of the muscle potentials in relation to athletic form.

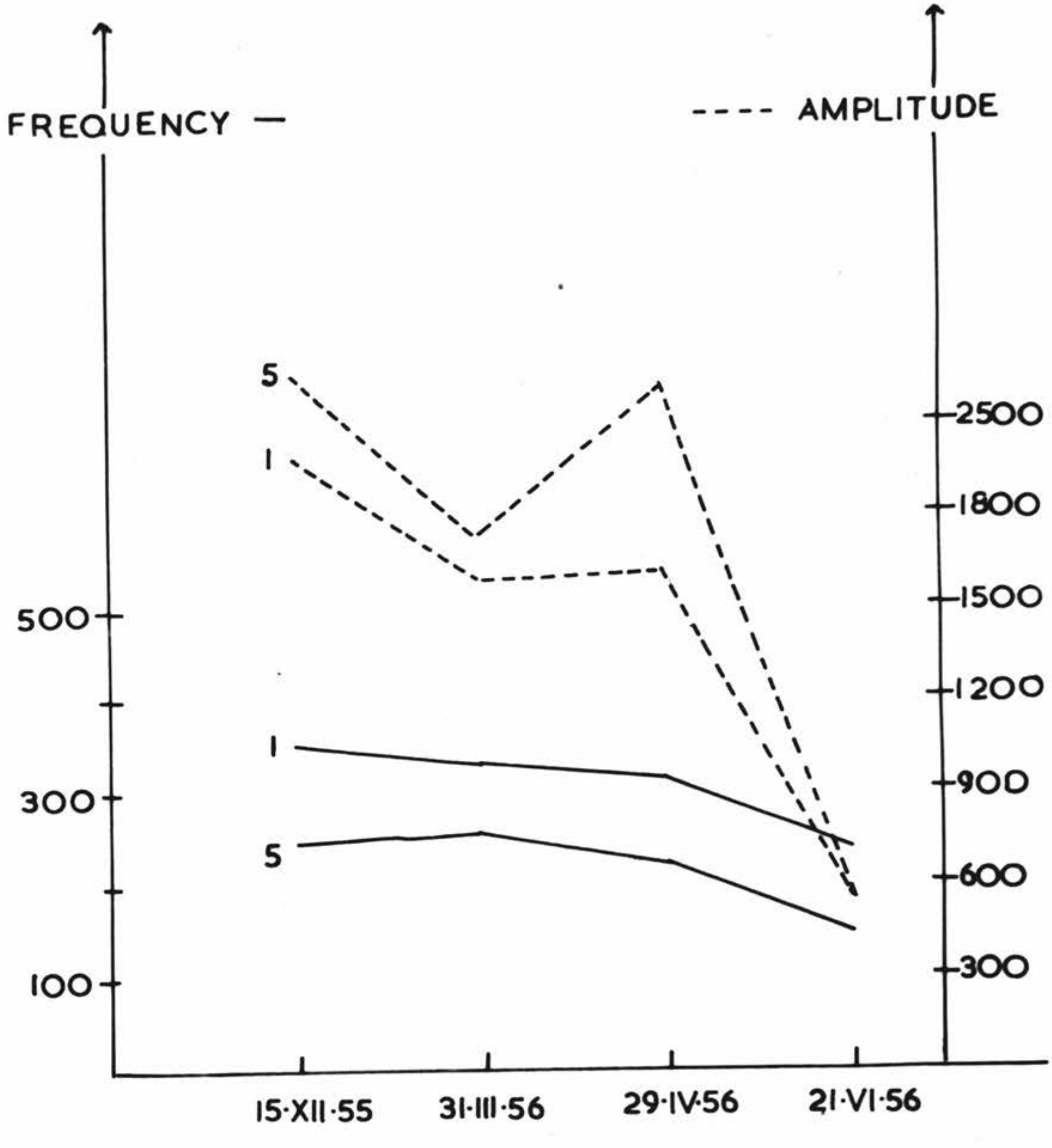
Date of experiment	Athletic Form	Weight of Bar raised (kgm)	Weight of Bar as % maximum	Triceps		Deltoid	
				Freq.	Ampl.	Freq.	Ampl.
15.12.55	Bad	85	81	254	1427	358	2000
31. 3.56	Better	85	77.2	255	1125	345	1625
29. 4.56	Still Better	92.5	80.4	236	1250	325	1642
*21. 6.56	Out-standing	85.0	81	230	333	250	583

(Subject M v)

*A correction has been made here. In the table given in the paper the date of the fourth experiment is given as 21.6.55. This must be a misprint in the text and makes nonsense when reading the paper.

FIGURE 6. This is redrawn from Stephanov (1957), and shows the changes in the frequency and amplitude of the action potentials recorded from the anterior deltoid with training in weight lifting with subject M v.

Ordinate	Date of experiment	
Abscissa	Left hand side	Amplitude in M.volts
	Right hand side	Frequency in cycles per second.


FREQUENCY —
- - - - AMPLITUDE
500
300
100
2500
1800
1500
1200
900
600
300
5
1
1
5
15·XII·55
31·III·56
29·IV·56
21·VI·56

in separate subjects) differs from that of the mains electricity supply of 50 cycles per second.

Staphanov also compares the electromyograms obtained from athletes of differing capability and shows that the novice lifting a weight of 72.5 kgms shows considerably greater muscle activity than does the grade 1 athlete lifting a bar of 105 kgms.

Zakariants (1954) also found differences in the electrical activity of muscles of the arm and shoulder in athletes of different grades. Top grade athletes, presumably due to their rich motor experience were able to concentrate muscular effort at the right moment and to relax their muscles during individual phases of the execution of the movement. This concentration of the electrical activity into bursts giving alternate periods of activity and rest in the skilled person was beautifully illustrated in experiments carried out by Person (1956).

Person studied the electromyograms obtained from normal persons and from forearm amputees wearing working prosthetics during their training in filing tasks. Before training he found the forces were applied irregularly and muscle action potentials could be recorded from the triceps and biceps during the whole of the filing operation, but after a training period the action potentials became concentrated into salvos and periods of activity were followed by periods of electrical silence. In a less precise chiselling task however he found that even before training alternate periods of rest and activity were obtained in some of his subjects.

Hering (1897) had already come to the conclusion that a principle of reciprocal innervation existed in the co-ordination of movements in man which develops with practise and training. Person showed in his paper that this is certainly true in the filing task. In normal subjects, after two weeks training, a clearly reciprocal relationship develops between antagonistic muscles which were only revealed as the motor habit developed. The disabled person,however, does not develop this reciprocal relationship with training, though showing the concentration of activity into bursts. This was thought by Person to be due to the fact that with the loss of the radio-carpal joint in these persons, precision of movement must be taken over largely by the elbow joint, and co-contraction appears to be necessary in this case to correct the movement and make it more precise. Person suggests that the form of co-ordination that occurs must depend upon the precision character of the task. In a more precise movement co-contraction might be the necessary form, though wasteful of effort; but in less precise tasks which can become largely automatised a reciprocal activation of antagonists may occur giving the more efficient form of movement co-ordination. Nasledov and Filippova (1956) investigated the disturbed motor centre co-ordination resulting from the immobilisation of a limb, to test the hypothesis that reciprocal innervation and antagonistic relationships are established with practise, and that immobilisation of a limb will cause disturbance of the normally close antagonistic relationships, between the flexor and extensor centres. Recording muscle action potentials as a convenient method for assessment of the activity of the motor centres, and making tests of the functional state of the muscles, they found that disturbances did occur in the motor centres, and when one muscle was voluntarily flexed, then all the other muscles examined underwent involuntary contraction. They found no material changes in the strength duration curves for the muscles and therefore concluded that the changes must be ascribed to processes occurring in the motor centres; namely some disturbance of the reciprocal innervation mechanism, which allows excitation to spread widely through the nerve centres rendering accurate co-ordination of motor acts difficult. Practise and training therefore appear to set up reciprocal relationship between antagonistic muscles in some conditions.

However, as shown by the amputees in the filing task of Person, co-contraction does occur in movements that have become skilful and automatic. Gurfenkel (1953) has shown that simultaneous excitation of antagonistic muscles of the leg is a feature of certain phases in the act of walking. In the typing task, one might expect the skilled operators to show reciprocal relationship existing in the muscle antagonists, the biceps and triceps, but the literature seems to suggest that movements of the fingers can only occur with simultaneous contraction of the forearm flexors and extensors. Duchenne found with his electrostimulation techniques that active extension of the finger is always accompanied by synergistic and involuntary contraction of the flexors, and he also observed from clinical examination that when deprived of the forearm extensors the flexors are unable to flex with much force.

Nakamura et al (1957) carried out an electromyographic study to determine the muscles which control finger movements in man, and found that the simplest flexion and extension movements are brought about by an intimate co-operation of the long extensors and flexors of the forearm, often acting together to effect these movements.

Person and Roshchina (1958) recording the action potentials, from the flexor digitorum sublimis and the extensor digitorum communics, with surface electrodes, studied the relationships between the antagonistic muscles of the forearm in finger movements. They found that during flexion or extension of one finger, the antagonistic muscles contract simultaneously; though if all the fngers are contracted or extended together then a reciprocal relationship exists between the antagonists. Thus, action of individual fingers on a co-ordinated fashion appears to require simultaneous contraction of the anagonists in the forearm. Kvasov (1951) also carried out an electromyographic study on the development of automatism in movements of the fingers. He was particularly concerned with the development of rhythm in repetitive movements, and believes that with practise, individuals become skilled as they arbitrarily develop a strictly rhythmic pattern of movement. He found his subjects to work when skilled according to a definite rhythm, and that their rhythms were approximately equal in value.

With practise, as the rhythmic pattern of movement becomes established, he found that the action potentials recorded from the forearm flexors became concentrated in time, and the ratio of the duration of activity to rest in the muscle changes from about 2:1 or even 4:1 to values of 1:1. The only person who has studied the electromyogram obtained from a typist in any detail is Lundervold who in 1951 reported the results of a detailed study on the electromyography of typing in 47 healthy men and women.

In this study, Lundervold is primarily concerned with the more clinical aspects of various myalagias and muscle disorders, though he also shows the effects of posture and fatigue on the recorded electromyogram.

Lundervold has obtained electromyograms from both unskilled and skilled persons, and he does briefly compare the results obtained from the two groups when carrying out simple typing exercises. He found the electromyograms to much of the same form, with muscles apparently following the same activation patterns, but he records a 'distinct impression' that both the amplitude and duration of the action potential bursts were greater in the unskilled person.

It is of interest to note the persistance of the typing skill. Swift (1906) reported retention of about 67% of his typing speed over a two year period, and Hill, Rejall and Thordike (1913) also report little loss in typing speed after four and a half years break.

Two series of experiments have been carried out in an attempt to study the changes which occur with training in the skill of typing.

The first series of experiments involve a comparison of typists of differing capability, whilst the second study follows the changes in the electromyograms during the first six months of training in the skill with eight subjects. Both experiments will be described separately, but a generalised conclusion will be made when both studies have been completely described.

CHAPTER 4.

A Comparison of the Electromyograms obtained from Typists of Differing Capability and Experience.

Experiment 1.

Introduction.

The first series of experiments were carried out to compare the electromyograms obtained from highly skilled typists, with those obtained from typists who were still in the process of learning the skill.

Measures of typing speed, the total energy expenditure of the typists and electromyograms were recorded from both these categories of typist, when working with a manual typewriter, and also when working with the lighter pressure operated electric typewriter.

Subjects.

The first group of subjects, G1. were ladies regularly having to type for long periods, being employed as secretaries or typists; who had originally been trained on manual typewriters, but now using electric typewriters.

The second group of subjects, G2. were teenagers just beginning their second years instruction at a local college. Though typewriting was included as part of their commerce course, they had no more than an hour's daily instruction in the subject. These subjects were able to touch type at speeds of about 30 words per minute, but could by no means be called highly skilled. These subjects had been trained on manual machines but had some introductory experience with electric typewriters.

Each group G1 and G2 consisted of eight subjects.

<u>General experimental work</u>.

Each of the typists attended for an experimental session which lasted for approximately two and a half hours. Each subject was asked to copy type a given passage, using both the manual and electric typewriters. The order in which the typewriters were used was randomised. During the typing of the passage, on each machine, measures were taken of the typing speed, the energy expenditure to type the task, and the action potentials were recorded from ten muscle groups. The whole passage could be typed on one foolscap sheet of paper, so that the typists worked continuously for a period of about a quarter of an hour. The rest of the experimental session was taken up with the placement of the electrodes, ten minutes practise period with each machine for each of the subjects, and a short time, usually 15 minutes, for the subject to become accustomed to the wearing of the face mask worn for the measurement of the energy expenditure, and with a short period in the middle of the experimental session as a rest period when the typist was given some form of refreshment.

Measurement of Energy Expenditure.

Introduction. Several studies of energy expenditure during typewriting have been carried out. Turner (1955) measured an average rate of 2.1 k.cals/min, for typists using manual machines. Marro, Miliani and Vigiliani (1954) compared the energy expenditure rates of typists using electric and manual machines and also the rates with the typists working at different speeds and gave the following rates:

Manual typewriter	1.39 (30 words/min)
	1.48 (40 words/min)
Electric typewriter	1.16 (30 words/min)
	1.31 (40 words/min)

showing:

A. An increase in energy expenditure with increase in typing speed

B. An economy in energy expenditure when using the electric typewriter with its lighter pressure.

Though values of energy expenditure measured for the typing task are within the B.M.A. category limits for sedentary work, measurements of the energy expenditure were included in the study, to see if the measure would add further to the electromyographic measures.

Method. The energy expenditure of the subjects was measured for the time they took to type the complete passage. The passage was of such a length that it could all be typed on one sheet of foolscap paper, using single line spacing, so that the energy expenditure was that for continuous typing for 20 minutes or so dependent upon the typing speed of the individual.

The subjects breathed into an I.M.P. face mask, and the volume of the expired air was measured with a Kofranyi Michaelis respirometer. One of the subjects wearing the mask and the surface electrodes is shown in Figure 7. Expired air samples were analysed using the Lloyd gas analysis apparatus, and the energy expenditure per minute was calculated using the De Wier nomogram.

Since each subject worked at her own speed, the energy expenditure values were also calculated for the typing of 1,000 words, so that values of the energy expenditure per minute were found as well as the energy expenditure to type a given task.

Electromyographic Measurements.

Earlier studies have indicated the best location of surface electrodes in order to detect substantial muscle activity when typing. In this study electromyograms were recorded from the

FIGURE 7. Shows one of the subjects taking part in the first series of experiments wearing the I.M.P. face mask, and surface electrodes.

following ten muscles of the arm and shoulder region:

R. Trapezius

R. Deltoid

R. Triceps

R. Biceps

R. Forearm Extensor

R. Forearm Flexor

L. Triceps

L. Biceps

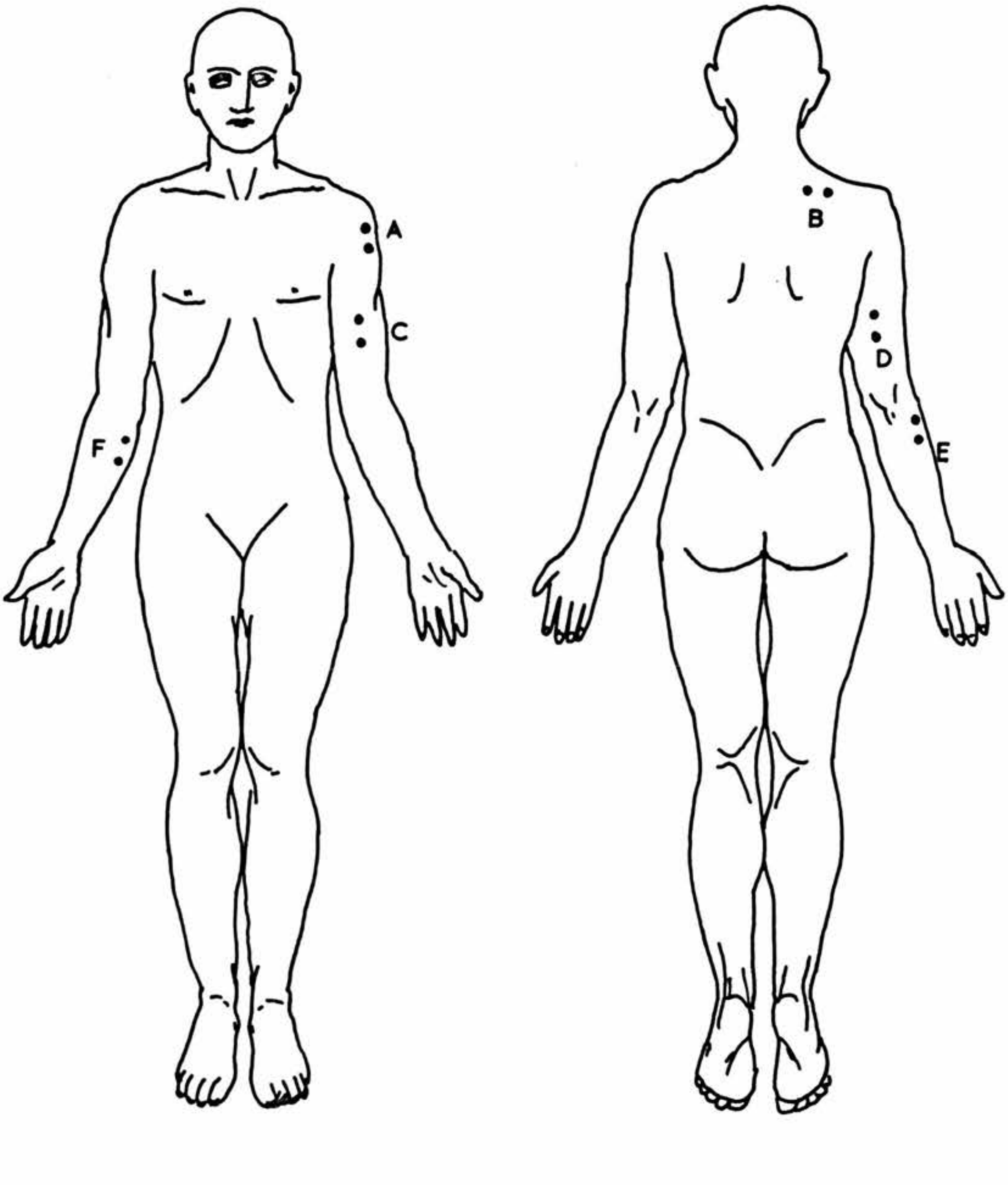
L. Forearm Extensor

L. Forearm Flexor.

In order that a more reasonable comparison can be made between the electromyograms of the two groups of subjects, the electrodes were positioned with reference to surface anatomy markings, using the measures described earlier, from Davis (1959), and a constant interelectrode distance of 2 inches was used. The general plan of the electrode placement is shown in Figure 8.

The muscle action potentials recorded from the muscle groups were lead to the four-channel Ediswan oscillograph, where two records of the potentials were obtained; the primary record written on the paper, giving the visual picture of the original E.M.G., and the secondary recordings of the integrated E.M.G. derived from the four-channel integrator which receives the voltage input via the four amplifiers of

FIGURE 8. Shows the approximate placing of the electrodes which was used in most studies. A is Deltoid, B is Trapezius, C is Biceps, D is Triceps, E is Forearm extensor, and F is Forearm flexor.


A
C
F
B
D
E

the Ediswan oscillograph. The primary record was continuously monitored by the experimenter.

Since only four channels were available at one time the E.M.G. from only four muscles could be integrated simultaneously. Hence a timing system was adopted so that each of the ten muscles was investigated at four times during the typing of the passage and each separate integration was carried out (over ten seconds) at the same time from the beginning of the typing of the passage with each of the machines. Thus the R. Forearm Flexor, Extensor, Biceps and Triceps activity were integrated simultaneously at the beginning of the passage, after 4 minutes typing, after 8 minutes and after 12 minutes typing, and so on for the other muscles, and with both typewriters.

The muscle activity recorded on the integrators (as a pulse count which is directly proportional to the input voltage) was thus found for each of the ten muscles at the four times during each experiment. The results from the four determinations were meaned, and the mean activity for each muscle for the two groups G1 and G2 were determined.

Results.

Table 2. Difference in mean integrated E.M.G. results obtained from Group 1 and Group 2 subjects when typing on the manual and electric machines.

Muscle	Group	Mean E.M.G. count over ten second integration period			
		Electric Typewriter		Manual Typewriter	
		Count	Difference	Count	Difference
R.Triceps	G.2 G.1	1007 1004	4	1049 1112	-63
R.Biceps	G.2 G.1	1178 841	337	1184 865	319
R.F.Ext.	G.2 G.1	1167 1205	-40	1285 1220	65
R.F.Fl.	G.2 G.1	1087 960	127	1185 1021	164
R.Deltoid	G.2 G.1	1090 1015	75	1084 1052	32
R. Trap.	G.2 G.1	1143 990	153	1150 980	170
L.Triceps	G.2 G.1	1054 981	73	1108 1016	92
L.Biceps	G.2 G.1	1143 922	221	1241 1032	209
L.F.Ext.	G.2 G.1	1143 1074	69	1209 1178	91
L.F.Fl.	G.2 G.1	1115 981	134	1144 1065	79

Table 3. Shows the muscle groups which show a significant reduction in the integrated E.M.G. when the lighter pressure electric typewriter is used. A significant reduction in the muscle activity at the 0.01 level is shown by a cross.

Muscle group	Group 1	Group 2
R. Trapezius		
R. Deltoid	x	
R. Biceps	x	
R. Triceps		x
R.F.Extensor	x	x
R.F.Flexor	x	x
L. Biceps	x	x
L. Triceps	x	
L. Extensor	x	
L.F.Flexor	x	

Table 4. Mean typing speed for Group 1 and Group 2 typists.

Group	Electric	Manual
2	39 words/minute	40 words/minute
1	55 words/minute	58 words/minute

Table 4. Energy expenditure in k.cals per minute for each of the eight subjects in Group 1.

Subject	Electric	Manual	d	Rank
A	1.26	1.31	0.05	3
B	1.36	1.58	0.22	4
C	1.84	2.27	0.43	6
D	1.73	2.62	0.89	8
E	1.07	1.71	0.64	7
F	1.53	1.43	-0.10	2
G	1.43	1.69	0.26	5
H	2.26	1.99	-0.27	1

Using Wilcoxon signed rank test the energy expenditure is less in the case of the electric typewriter (p 0.055).

Table 7. Energy expenditure calculated to type 1,000 words with Group 1 subjects in k.cals/1,000 words.

Subject	Electric	Manual	d	Rank
A	26.6	32.8	6.2	5
B	25.2	30.9	5.7	4
C	35.7	47.0	11.3	7
D	21.3	29.3	8.0	6
E	21.2	37.0	15.8	8
F	41.5	44.0	2.5	2
G	30.6	33.8	3.2	3
H	36.4	33.5	2.9	1

The results show an economy in energy expenditure to type 1,000 words using the electric typewriter (p 0.055).

Table 8. The energy expenditure in k.cals/minute with six of the Group 2 subjects using the manual and electric typewriters. Two of the Group 2 subjects were unable to wear the I.M.P. face mask due to respiratory difficulties.

Subject	Electric	Manual	d	Rank
A	1.03	0.92	.11	5
B	2.23	1.84	.39	6
C	1.14	1.07	.07	3
D	1.12	1.81	-.06	1
E	1.58	1.49	.09	4
F	1.61	1.70	-.09	2

From Table 7 and using the Walsh statistical test, the difference in energy expendituee rates per minute using the two machines were not found to be significant with the Group 2 subjects.

Table 9. Energy expenditure calculated to type 1,000 words with the Group 2 subjects.

Subject	Electric	Manual	d	Rank
A	28.7	22.3	6.4	4
B	30.8	42.7	-11.9	1
C	51.4	32.3	19.1	6
D	49.4	49.4	0.0	2
E	37.7	35.7	3.0	3
F	50.0	37.0	13.0	5

Again no statistical difference in the energy rates could be found with the Group 2 subjects.

Discussion of Results.

It is apparent from the results displayed in Table 2 that the amount of muscle activity recorded from the Group 2 typists as reflected by the integrated electromyogram, is considerably greater in almost all the muscle groups, than that used by the highly skilled people.

In considering these results, it must be remembered that the resting integrator count with no voltage input taken over a period of ten seconds is between 750 and 800 digits. Bearing this in mind, it can be seen that in some cases, notably the biceps, forearm flexors, and the trapezius, that the muscle activity for the relatively unskilled people is almost twice as much as that required for the more skilled people.

The type of machine used appears not to affect this general pattern at all, and the performance of the Group 1 subjects is more economical which ever typewriter is used.

If the results of the mean typing speeds of both Groups are considered (see Table 3), the differences in the integrated E.M.G. are made even more apparent. It has been shown by Lippold and Biggland, and others, that the integrated E.M.G. increases with the increase in velocity of the movements carried out, and it will be shown in a later chapter that this relationship holds with an increase in the integrated

E.M.G. with increase in typing speed.

The Group 1 subjects are typing at rates of 10 words a minute or more above the rates of the Group 2 typists, doing approximately 8 strokes more per ten second integration period. Thus though the Group 1 typists are doing more movements and work in the ten second integration period they are still using less muscle energy. This must be a reflection of the economy in the muscle activity which develops as the skill is improved with practise.

The Group 2 subjects could by no means be called unskilled, since they had learned the hand/eye co-ordinations involved in learning the touch typing method, and all of them were able to type the whole passage using standard touch typing techniques. However they were still relatively unpractised when compared with the girls who were employed as typists.

The more unskilled typist appears to waste most muscle effort in the flexor muscles, i.e. the forearm flexors and the biceps, and in the trapezius, a muscle not so directly involved in the typing task. Lundervold found that a characteristic of his unskilled group of subjects was a great wastage of effort in muscles which are not directly concerned with the task, and he mentions the trapezius as being one of these muscles.

The relatively greater activity in the flexor group of muscles in the unskilled persons leads to the conclusion that they must waste energy here in hitting the typewriter keys harder than they actually require to be hit, or perhaps they direct the greatest forces on the keys at the wrong times. Since the more practised persons show economy in muscle effort particularly with the flexor muscles, it appears to suggest that with practise one learns to hit the key with only sufficient force to depress it, and applies the force in such a manner and at such a time that once sufficient force has been imparted to the key the finger then leaves it and can travel on rapidly to the next key.

If one compares the results obtained with the two groups of subjects with the lighter pressure electric machine and the heavier manual machine, it can be seen from Table 3 that the Group 1 subjects show significant economy in muscle effort when they use the electric machine in eight of the muscle groups investigated. The less skilled Group 2 people on the other hand show economy only significantly in four muscle groups. The energy expenditure results also show that the highly skilled group can effect a significant reduction in the all-over energy rate when using a lighter operated machine, though the Group 2 subjects do not show this same reduction.

These results would appear to substantiate the hypothesis that with practise and training, highly skilled people develop some more refined kinesthetic sense, what Book (1924) calls 'an exceptionally high voluntary motor control', and practise in typewriting develops the ability to feel physically how much force is needed before and during each key descent, and to apply this force in just sufficient amounts to overcome the particular key resistance.

Thus when the highly skilled subject transfer to a machine with a different key pressure she is able to judge more accurately just what extra, or less muscle effort is required to operate the keys. Then with the lighter pressure machines she shows substantial economy in muscle effort, which can be even reflected in an economy in the total energy rates. The less skilled person has not had sufficient practise to be able to develop this regulating process to any marked degree. She is able to show economy of effort in some muscle groups, but nothing marked enough to show any reduction in all-over energy rates. The unskilled person when presented with the opportunity of economising on her effort does not appear to be able to do so, but continues to waste effort in the application of forces greater than those actually required.

The work carried out by Stephanov on his weight lifters also seems to point to this same conclusion, though he does not himself make these deductions. Figure 9 redrawn from his paper shows the frequency of the recorded potentials from the deltoid with a weight lifter performing lifts of 80% and 90% of his maximum lift over a training period of six months.

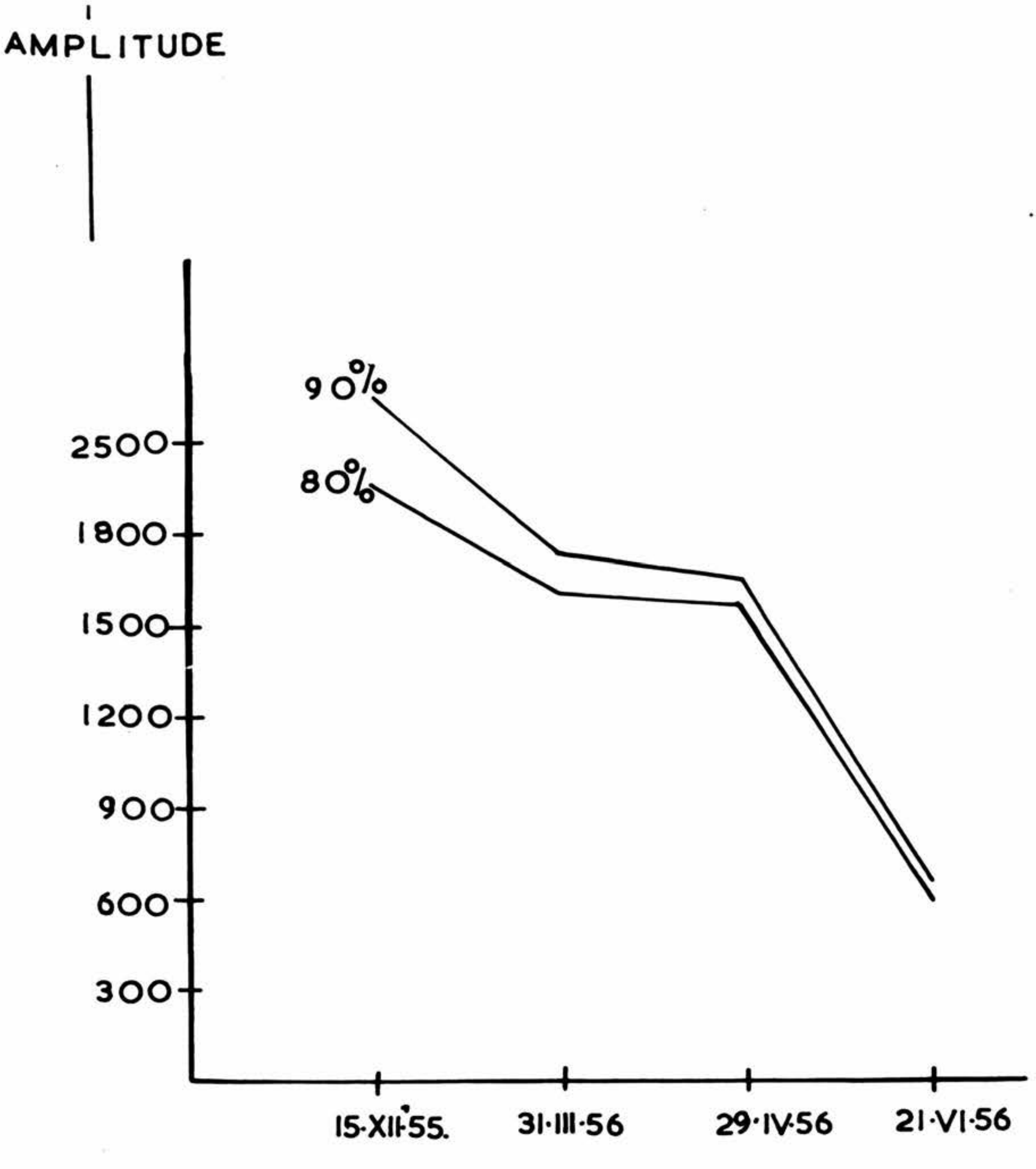
Initially, at the beginning of the training period, the frequency of the action potentials for the 90% maximum lift well exceeds those for the 80% maximum lift, but as the training period progresses, the frequency of the potentials for these two lifts become more similar, and the curve draws closer together.

These results could suggest that the weight lifter with practise becomes more sensitive as regards the amount of muscle activity which is actually required to perform weight lifts of varying degrees of magnitude. Initially, the wide separation of the frequency curves suggests that he is using more effort than is actually required to perform the 90% maximum lift. As the curves approximate with practise it would seem that the weight lifter is now able to judge more exactly just what extra muscle activity is required to perform the more heavy weight lift.

The improvement in kinesthetic sensation, giving the improved motor control enabling the skilled typists to judge more accurately just how much force is required to depress a key, both before and during each key descent, may be seen if

FIGURE 9. This is redrawn from the paper by Stephanov and shows the change in the frequency of the action potentials recorded from the anterior deltoid of a weight lifter (M v) when he is performing lifts of 80 and 90% of maximum, during the six months period.

Ordinate	Date of experiment
Abscissa	Frequency of the recorded action potentials.



AMPLITUDE
2500
1800
1500
1200
900
600
300
90%
80%
15·XII·55.
31·III·56
29·IV·56
21·VI·56

recordings are taken simultaneously of the force exerted on the keys, together with recordings of the E.M.G.

A further experiment was therefore carried out with the two classes of subjects to compare the forces exerted on the keys of the typewriter and to investigate the relationship between the time of contraction of the flexors of the fingers and the application of forces to the keys.-

Experiment 2.

Aim.

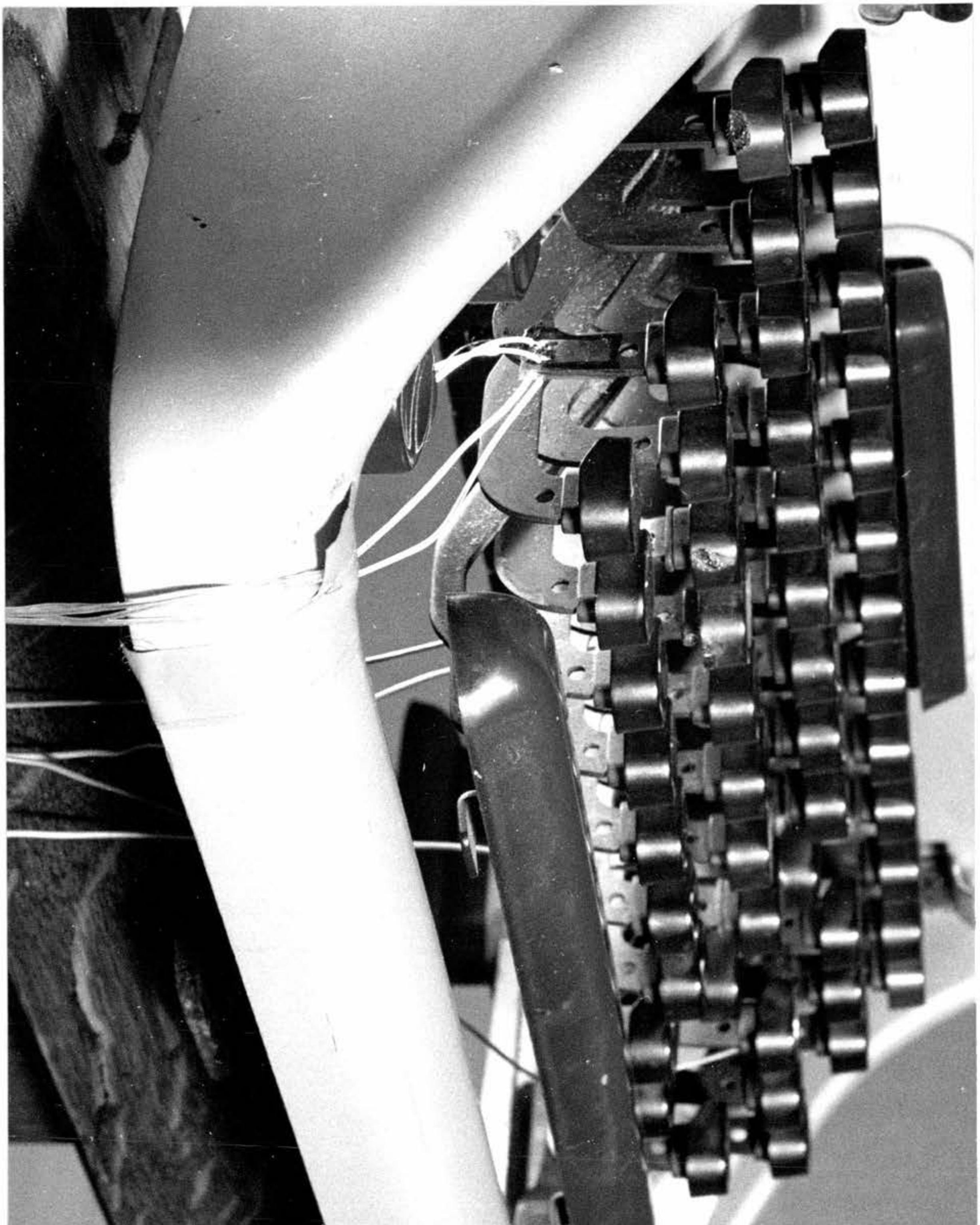
To show the differences between the forces applied on typewriter keys and the time of application of these forces relative to the forearm flexor activity in highly skilled typists and semi skilled typists.

Experimental Method.

Muscle activity was recorded from the forearm flexor muscle of the left arm using surface electrodes. The electromyograms were recorded with the Offner eight channel electro-encephalograph using a paper speed of 6 cms. per second, and with the gain settings kept constant throughout.

The force exerted on the typewriter keys was measured by means of strain gauges placed on the lever of Key A of the manual typewriter. The positioning of the strain gauges is shown in Figure 10. The two gauges were fixed in position using the adhesive Aroldite. The strain gauges were

FIGURE 10. Shows the positioning of the strain gauges on the level of key A. The wires leading from the two strain gauges placed on each side of the lever are also shown.



Saunders Row Foil Strain gauges, type $\frac{1}{4}$ linear, with a resistance of 65 ohms = 0.5%, and with a gauge factor of 2.19.

A constant voltage supplied from a 2 volt batterywas passed through the strain gauge. Force exerted on key A by the little finger of the left hand caused a distortion in the delicate strain gauge. This distortion of the gauge causes a variation in the gauge resistance which will in turn produce a change in the constant voltage passed through the gauge. The extent of distortion of the gauge is proportional to the applied force; the resistance changes are proportional to the distortion of the gauge and hence the change in the voltage will be directly proportional to the force applied on key A.

A strain gauge was placed in exactly similar positions on each side of the level from key A, so that any right or left movement of the key was counteracted, and only the vertical downwards force exerted on the key was measured.

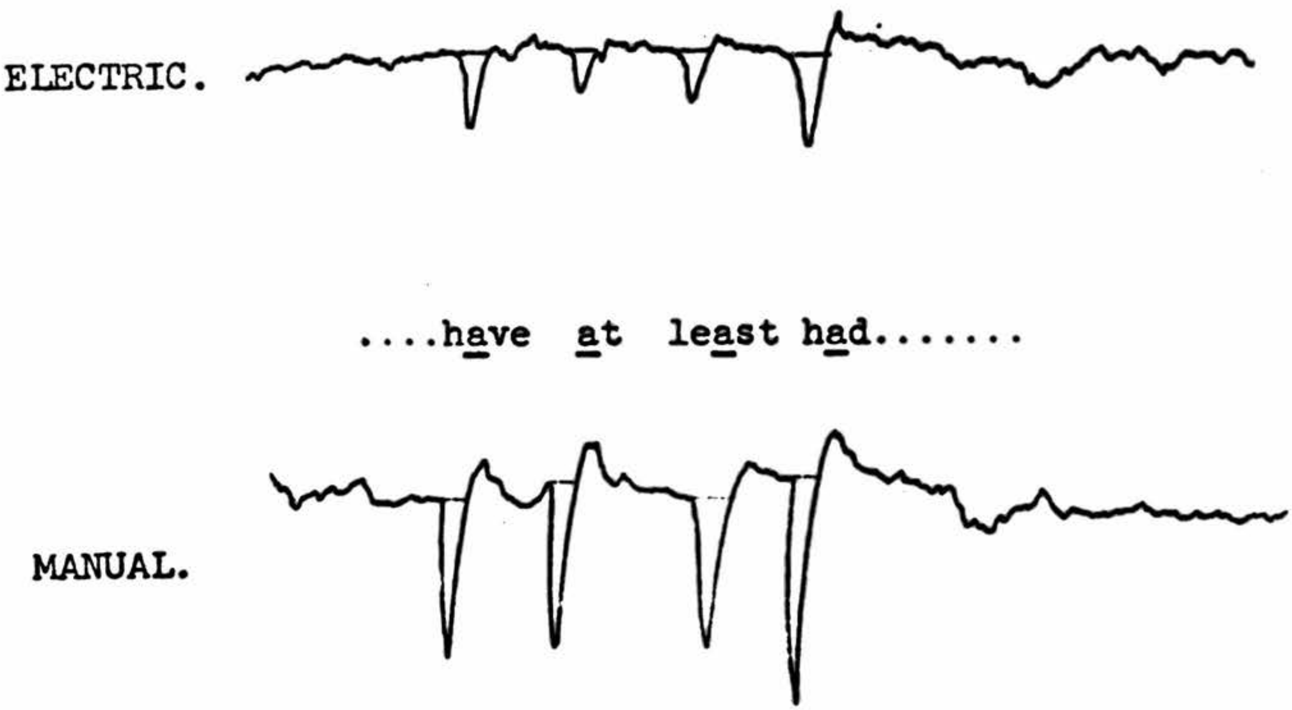
The change in the voltage input caused by forces applied to the key were recorded on one channel of the Offner recorder, together with the electromyograms.

Results.

Typical results obtained from the two groups are shown in Figure 11, which gives the force deflections occurring each

FIGURE 11. Shows the voltage deflections produced by distortion of the strain gauges which occours each time key A is hit.

Subject J.W.



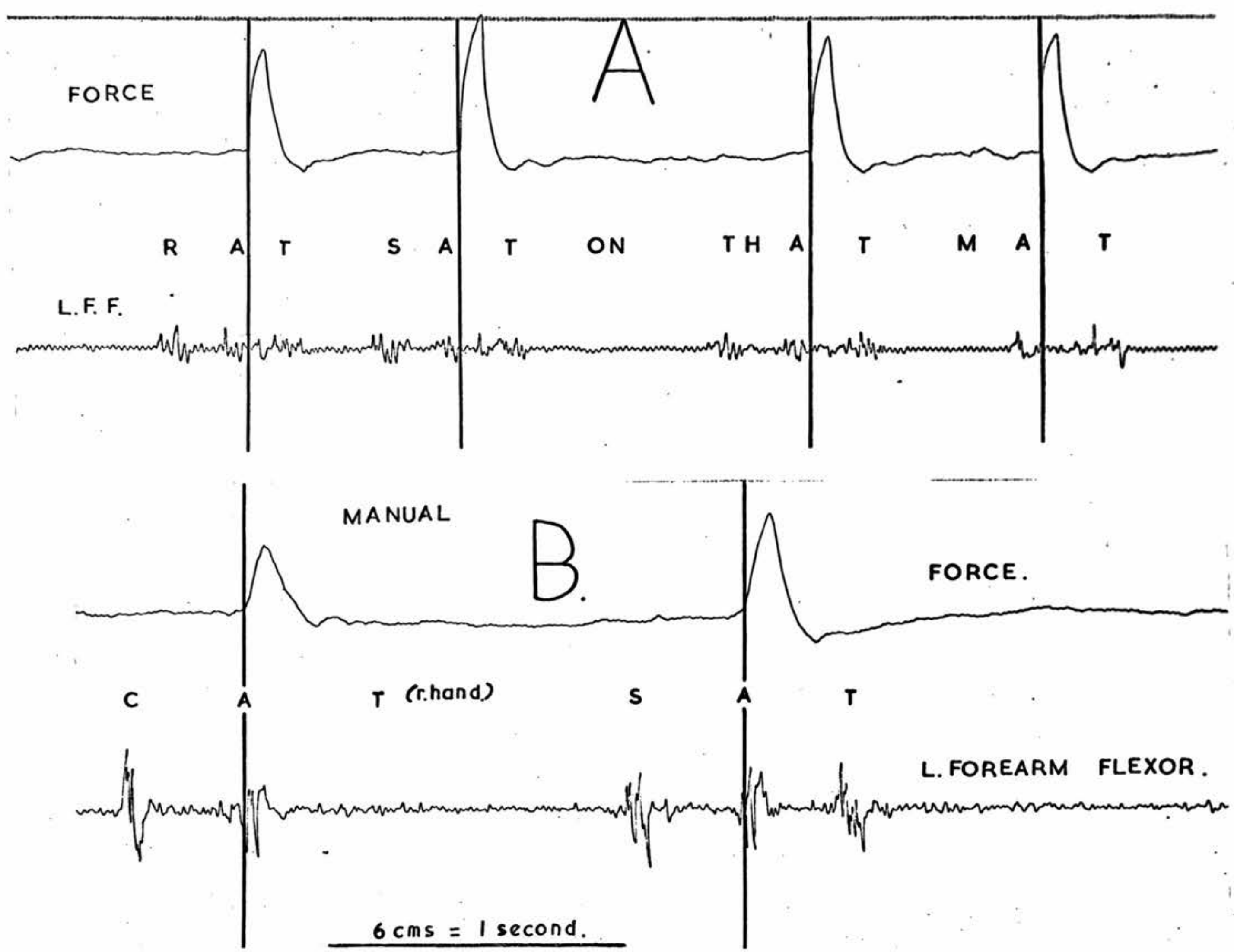
time key A is hit, In figure 12 electromyograms recorded from the left forearm flexor each time a key is hit with a finger of the left hand. The letters which were being typed in each case have been written above the flexor bursts to which they correspond.

The flexor activity was recorded with the Offner gain setting being kept constant, and it is apparent that the skilled and practised typist shows less activity per stroke of the keys than does the less skilled person. The electromyograms are markedly reduced in amplitude, and to some extent reduced in duration, though the force deflections are equally as great if not greater for the highly skilled person, as these shown with the less skilled. The practised typists are therfore hitting the keys of the manual typewriter with forces as great as the unskilled person uses but somehow are applying this force more efficiently with the use of considerably less muscle activity.

Figure 12 shows the difference in the timing of the muscle activity in relation to the application of the force.

Trace A. Shows the relationship between the time of exertion of the force on key A and the action potentials recorded from the forearm flexor of the highly skilled typist of Group 1.

<u>FIGURE 12</u>. Shows the electromyograms recorded from the forearm flexor muscles of a highly skilled and a relatively unskilled typist together with the records obtained from the strain gauge. The Figure shows the difference in the timing of the muscle activity in relation to the application of the force on the keys, between a highly skilled typist and an unskilled typist.



A
FORCE
R A T S A T ON TH A T M A T
L.F.F.
B.
MANUAL
FORCE.
C A T (r.hand) S A T
L. FOREARM FLEXOR.
6 cms = 1 second.

Trace B. Shows the same measures recorded from the less practised typists of Group 2. From trace A it can be seen that the action potentials associated with the fifth finger striking key A (in rat sat that and mat), precede the force deflection in time. Thus it appears that the highly skilled typists use their forearm flexor muscles to impart force to the key and the main contraction of the muscles to give this force occurs before the key is actually hit. Once the skilled person has imparted sufficient momentum to the key to cause it to print, she is then able to leave the key rapidly and progress to the next letter to be typed. The figure shows how the skilled girl is already contracting the flexor muscle in preparation for the striking of key T (in rat, sat and that) before the force curve produced by the striking of the preceding A has returned to normal.

From trace B it can be seen that the less practised typist does not have the same action as the Group 1 person. Here the action potentials occur with a different time relation to the force curve. The flexor muscle appears to contract at the time when the little finger actually touches key A, just as the force deflection begins. Action potentials are then recorded throughout the rise of the force curve to continue until the force deflection has raached its maximum. This would imply that the less skilled person continues to to exert force throughout the whole movement of the key until the letter is imprinted.

Thus the highly skilled person has learnt to apply sufficient momentum to the key by concentration of muscle activity and effort just prior to the touching of the key, whereas the less skilled person has not developed this skill, and she can only tell what force is required for the printing of a letter when her finger is actually in contact with the key, and her muscles remain in a state of contraction through the whole travel of the key when printing the letter.

This imparting of momentum to a key, and then leaving it to continue its travel under the imparted momentum appears to be the skill which must be acquired before the typist can progress to working at greater speeds. The less skilled person is limited in her speed if she leaves her fingers on the keys till imprint every time. Even in simple typing exercises requiring no typing skill as such the lesser skilled typist cannot perform at speeds comparable to the skilled person due presumably to the fact that the lesser skilled person cannot appreciate in advance just how much effort she must give to impart sufficient momentum to the keys, for them to complete the travel. This was seen in a simple experiment carried out with one subject from each of the Groups 1 and 2.

Experiment 3.

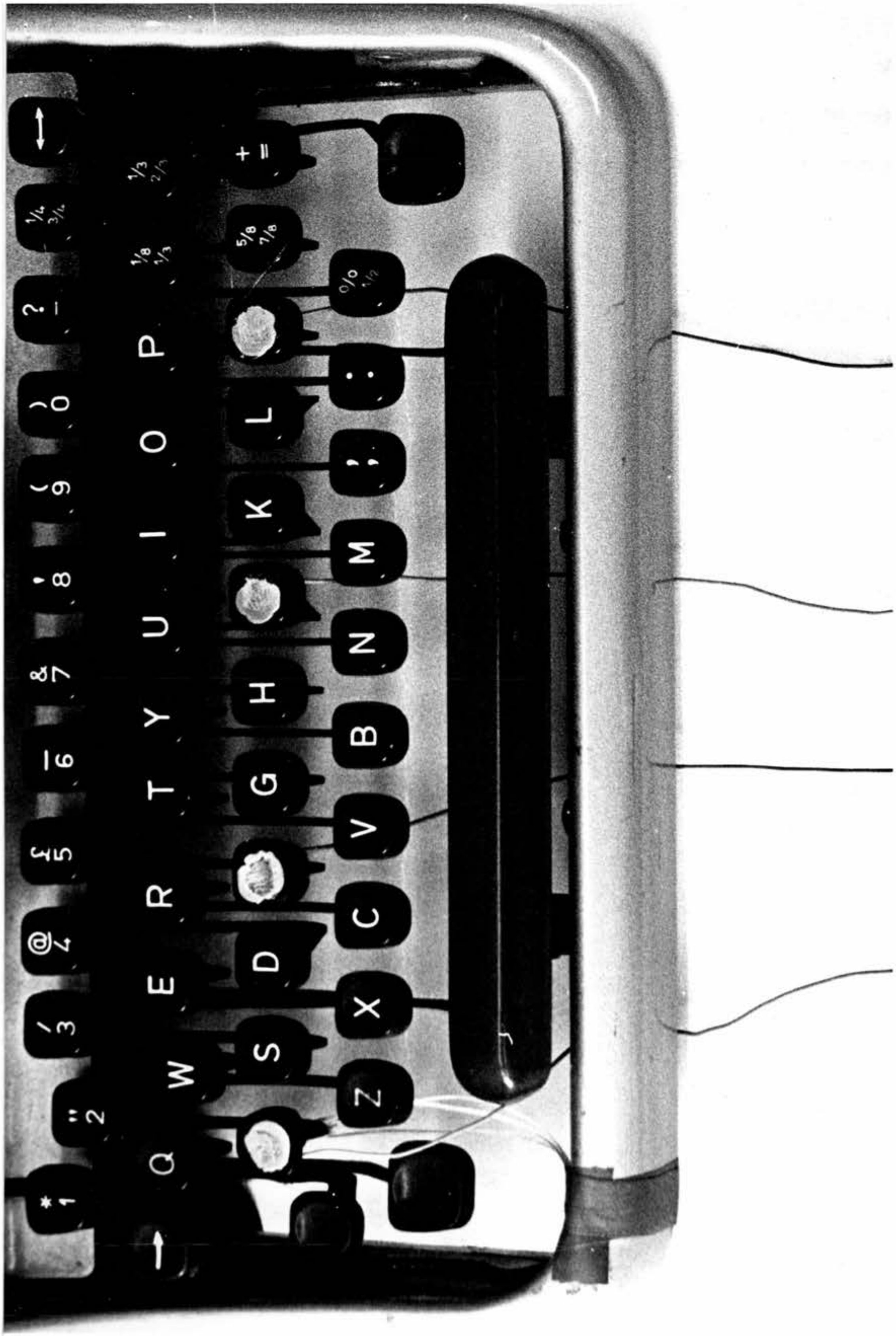
Method.

One subject from each of the two groups was asked to type the characters of the 'home keys' A S D F J K L :, using the conventional fingering. A timing device was incorporated so that the interval between touching the first and last of the four keys with either hand was measured to the nearest 10 millisecond.

The timing device was as follows: - metal contacts were placed on the surface of the keys A and F and J and : (see figure 13) and leads were fed into the Labgear timer. When the subject's finger touched key A, the timer was started, and the timer was stopped when key F was touched by the fifth finger. By reversal of the leads the time taken to type from F to A could also be measured. The timing was exactly similar for the other hand. Thus the time taken to type with the 2nd - 5th fingers in each direction (from right to left and vice versa) for each hand was found.

Each subject reapated the typing exercise forty times in each direction and the mean times were found.

FIGURE 13. Shows the metal contacts placed on the keys A,F and H,L of the manual typewriter. Similar contacts were placed on the corresponding keys of the electric typewriter. The labgear timer was started when the finger made contact with one of the keys and was stopped when the other finger of the same hand hit the other contact. The leads shown were fed into the labgear timer.



1 2 3 4 5 6 7 8 9 0
Q W E R T Y U I O P
S D G H K L
Z X C V B N M

Results.

Table 10. The mean times (in tens of milliseconds) taken to perform the experimental task under the various conditions.

	Electric Typewriter		Manual Typewriter	
Finger movement	Group 1	Group 2	Group 1	Group 2
R.H. Left to right	28	71	50	78
R.H. Right to left	38	76	54	91
L.H. Right to left	24	70	49	78
L.H. Left to right	37	73	51	81

Discussion of Results.

From this simple experiment it can be seen that the less skilled typist is limited in her typing speed even in the simplest of finger movements. Thus her slower typing speed in normal typing would seem to be some reflection of an inability to move her fingers rather than some reflection of the lack of knowledge of the keyboard. The Group 1 subject is able to almost double the speed at which her fingers move when performing an the electric typewriter, but the Group 2 subject, though showing some small increase in finger movement speed does not show any marked improvement.

These results again would appear to lead to the conclusion that the more skilled typist exerts forces on the keys in a ballistic fashion, having such motor experience so as to be able to judge how much force she must exert on the key for it to imprint before she strikes the key. The force is imparted to the key on striking and then she leaves the key and progresses to the next, whilst the key continues its motion under the imparted momentum. The lesser skilled person has apparently not developed this sense, and she adjusts the force whilst the key is in motion and continues to apply force until the typebar reaches the paper. Then when she has learned from the muscle proprioceptors that the letter has been struck she is ready to progress to the subsequent key. This gives the limitation in her speed even in the simplest movements and the wastage in muscular effort. It is of interest to note that the movements starting with the fifth finger coming towards the body (i.e. R.H. from right to left and L.H. from left to right) take longer with both subjects, and with both machines.

General Conclusions from Experiments 1, 2, and 3.

The results from the experiments carried out with a group of highly skilled and practised typists and a group of typists with the basic training but with little practise and experience indicate that with further practise in a motor skill an economy in muscle activity in the performance of work results from the efficient application of the forces required. The more efficient application of force appears to result from some further co-ordination between the sensory proprioceptors of the joint carrying out the work, and the muscles effecting the work. In the typing task this co-ordination must take place in the latter stages of the acquisition of the skill, and is not exhibited by subjects who have a years training in the skill.

It is hoped in the following chapter to show some of the co-ordinations that occur in the initial stages of the acquisition of the motor skill of typing.

CHAPTER 5.

Neuromuscular changes occurring during the first six months of training in the typing skill.

1. Introduction.

It is shown in the previous chapter that highly skilled typists perform more work, with less muscle energy than do typists with limited practise and experience. The typists of both categories show much the same patterns of muscle activity with muscles being activated in the same sequences.

Both these groups of subjects had learned the hand-eye co-ordinations involved in the initial training in typing and all could work using the touch typing technique. The further improvement in muscle co-ordination which comes with practise, and which brings about the economy in muscle effort in the more skilled typist, appears to be an improved co-ordination between the kinesthetic proprioceptors and the muscle effectors.

This previous study throws no light upon the changes in muscle activity which occur in the initial stages of the acquisition of the skill, and therefore a series of experiments was carried out with a group of girls beginning to learn the skill. Using the technique of electromyography the muscle activity was studied during the first six months of training in the typing skill.

2. General Experimental Work.

Eight girls, about 17 years of age, who were beginning a year's course in commerce at a local College, volunteered to act as subjects in this investigation.

During their year's studies at the college the girls are taught various commercial subjects including the motor skill of typing. In the six months or so that studies were made of these girls, they had an hours daily instruction in typing at the college plus any practise they undertook in their own time.

In the duration of six months the girls progressed from being totally unable to type, their first visit taking place before they had any instruction in typing method, to being able to type quite proficiently at speeds of about 30 to 35 words per minute.

Each girl visited the laboratory for an hours evening session nine times in all during this six month period, so that a total of 72 experiments should have been carried out. Unfortunately due to illnesses and other mishaps some of the girls were not able to attend for all the proposed sessions, and account is made of this in the presentation of the results.

The girls were paid for their services, showed interest throughout the work, and were most unaffected by the experimental arrangements.

The experiments were started in September 1962, with subject D.H. coming to the laboratory on the evening of her first day at the commerce college, the second subject J.L. came the second evening and so on, until all eight subjects had attended for one experimental session in the first fortnight of their attendance at the college. At this stage the subjects had no typing skill, but begun their typing instruction during this first fortnight.

Subject D.H. attended for a second experimental session on the evening after the last of the eight subjects had attended for her first session, and was followed on successive evenings by the remaining seven girls. None of the subjects attended for experimental sessions at the weekend, therefore almost a fortnight elapsed between one experimental session and the next.

Thus during their first term at the college the subjects attended for seven experimental sessions at almost fortnightly intervals, with subject No.1 (D.H.) following subject No.8 (E.S.), and with the other six coming in a regular and repeatable order.

After the seven visits the Christmas holiday intervened, and the subjects had no typing practise or experimental sessions for three weeks. Subjects then attended for the experimental sessions again in the first week of the Easter Term, i.e. for experimental session No.8, and then the last experimental session, No.9, for each was held in late March/ early April 1963 in the last fortnight of the Easter Term of the commerce college.

The subjects were asked to carry out three different typing exercises during the hour's experimental session, and during the performance of these tasks electromyograms were recorded from the muscles of both arms and shoulder regions of the right arm. The electromyograms were recorded using the Offner, and the Ediswan with the integrator unit. The gain, filter controls, paper speed and time constant were kept constant for each visit, and calibrations of the apparatus were carried out before the start of each session.

The three separate parts of the experiments will be described separately, together with the results and conclusions, and a final conclusion will be given when all three sections have been discussed.

The three tasks which were carried out by every subject were as follows:

1. Simple tapping tests.
2. Sentence typing.
3. Typing continuously for three minutes.

At the first experimental sessions the subjects were only able to carry out the first two tasks, but at the later sessions all three tasks were performed.

3. Section 1.

Simple tapping tests.

A. Method.

The subjects were asked to hit the typewriter keys following the beat of a metranome, at a rate of 160 beats per minute. Integrated electromyograms were recorded from the forearm extensors and flexors of both arms.

The subjects were first asked to relax completely and a resting integral was taken over ten seconds. She was then asked to tap the space bar with the first finger (the thumb), of the right hand, in time to the metranome and a ten second integral was taken of the activity when the right first finger worked.

The same procedure was repeated with each finger of the right hand hitting its corresponding key in the 'home row' of keys, (i.e. the 2nd finger tapping H, the 3rd J, the 4th K and the fifth L) in time to the metranome over a ten second period. The ten second integration period was started 10 seconds after the beginning of the typing work done with each finger.

The same procedure was repeated with the left hand, i.e. first the recording of a resting integral and then the recording of flexor and extensor activity when each finger hit its particular key of the 'home row' of keys (i.e. space bar,F,D,S,A).

The muscle activity required from the forearm extensors and flexors when each finger was hitting its particular key over the ten second period (i.e. 16 strokes) was found by subtracting the resting integral from the working integral.

The amount of flexor and extensor activity required to tap the different keys with the fingers of both hands was found for each individual on each visit. The amount of the activity as measured for all persons for each visit was meaned so that the general picture of the muscle activity for the group at each particular session was found.

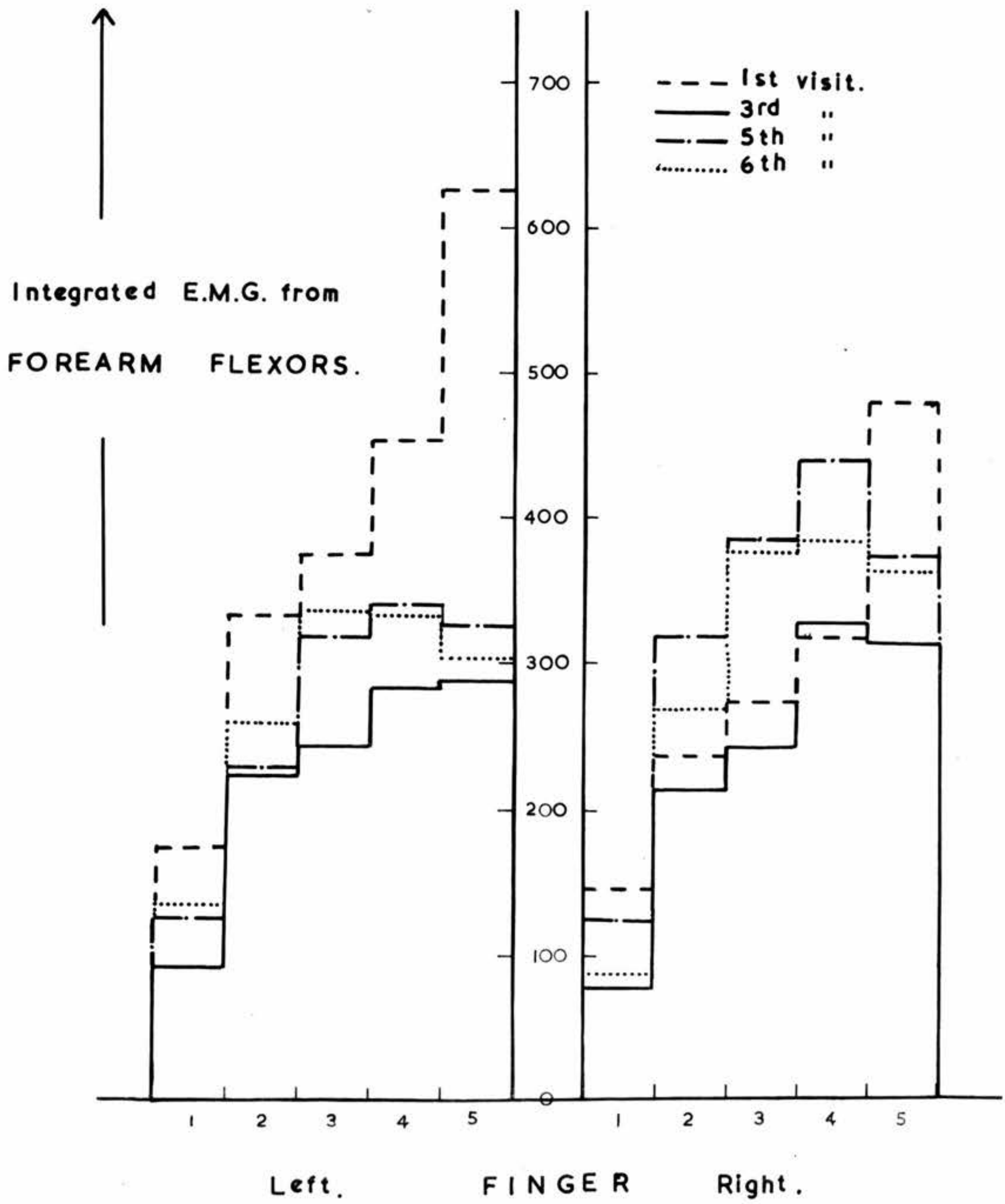
B. Results.

The integrated E.M.G. recorded from the flexor and extensor muscles of the forearm when the fingers work at the tapping tasks, is best represented graphically in the form of a histogram. Thus, the muscle activity required for each finger to perform the similar task, i.e. tapping its corresponding key, is represented as the height of the rectangle above the abscissa axis, where the number of the finger working is represented.

The integrated E.M.G. given on the ordinate axis is the count read directly from the integrator, minus the resting integral, with this count being directly proportional to the input voltage.

<u>Figure 14</u> shows the integrated E.M.G. recorded from the forearm

FIGURE 14. Shows the integrated E.M.G. recorded from the forearm flexors when the fingers carry out the tapping tasks. The integrator count, which is expressed as the digital count is the mean of the results recorded from the eight subjects, as is given on the abscissa axis. The numbers given on the ordinate axis are the fingers which are working.



Integrated E.M.G. from
FOREARM FLEXORS.
1st visit.
3rd "
5th "
6th "
700
600
500
400
300
200
100
0
1
2
3
4
5
1
2
3
4
5
Left.
FINGER
Right.

flexors of the right and left forearms when the fingers carry out the tapping tasks on visits 1, 3, 5, and 6. The integrator count is the mean of the results recorded from all eight subjects on these visits.

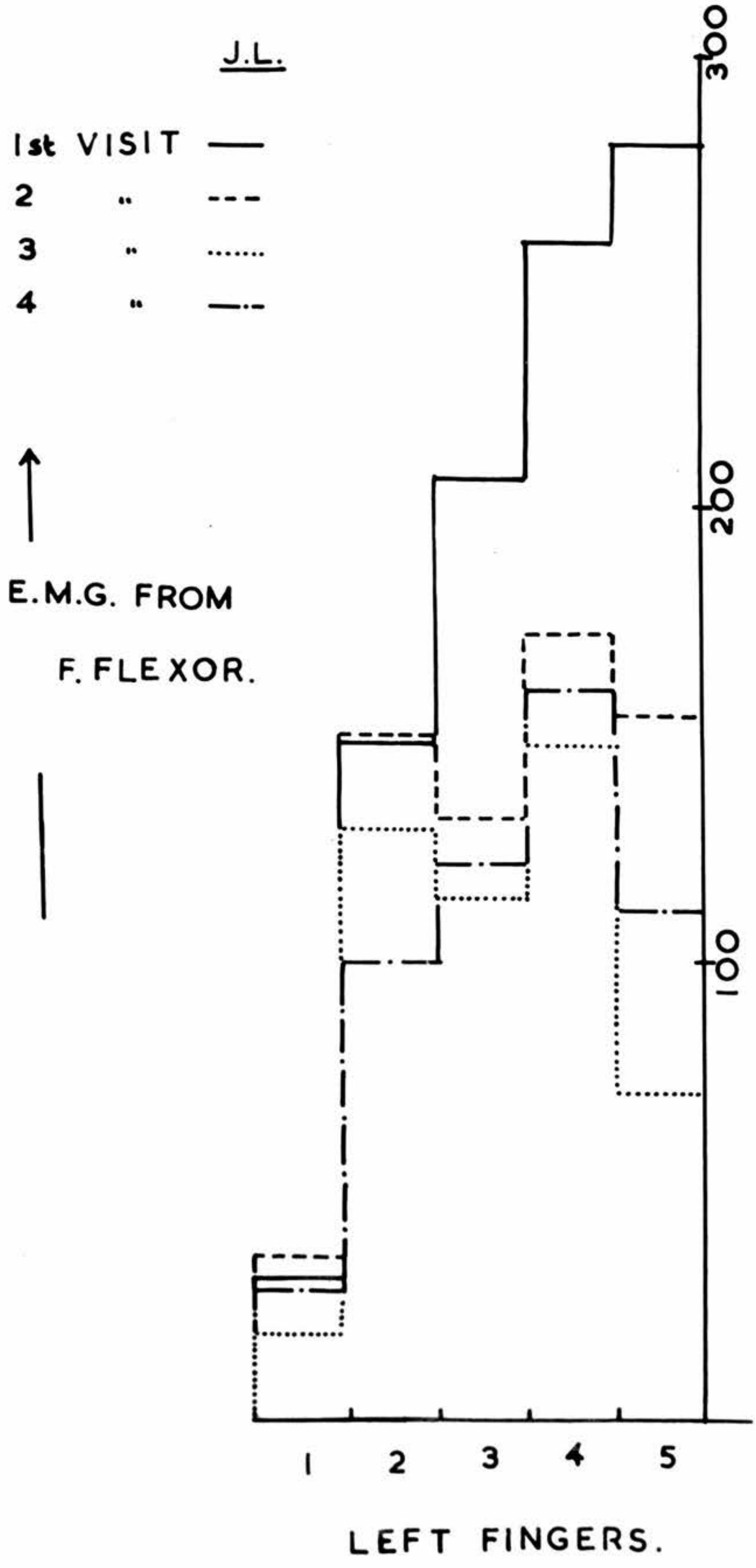
Figure 15 shows the left forearm flexor activity recorded from subject 2 (J.L.) on the first four experimental sessions when carrying out the tapping tasks.

Figure 16 shows the flexor activity recorded from the only left handed subject (M.B.) of the group, when performing the tapping tasks on the first, sixth and the ninth visits.

Figure 17 shows the electromyograms recorded from a highly skilled typist when tapping with the first to the fifth fingers of the right hand on the appropriate keys on the 'home row' of keys. The electromyograms are recorded from the 1st, 2nd, 3rd and 4th dorsal interossei and from the forearm flexor of the right hand. The electromyograms were recorded with surface electrodes on the Offner electroencephalograph.

Figure 18 shows the mean values of the forearm extensor activity recorded from the eight subjects when performing the tapping tasks on visits three, five and six.

FIGURE 15. Shows the left forearm flexor activity recorded from subject J.L. on the first four experimental sessions when carrying out the tapping tasks, and shows how the fifth finger is initially the weakest finger, but improves in strength such that the fourth is the weakest after two weeks of training in typing, and subsequently remains the weakest finger.



J.L.
1st VISIT
2 "
3 "
4 "
E.M.G. FROM
F. FLEXOR.
300
200
100
1
2
3
4
5
LEFT FINGERS.

FIGURE 16. Shows the forearm flexor activity recorded from the only left handed subject,M.B., when performing the tapping tasks. The graphs show how the right hand is not initially weaker than the left in this left handed subject.

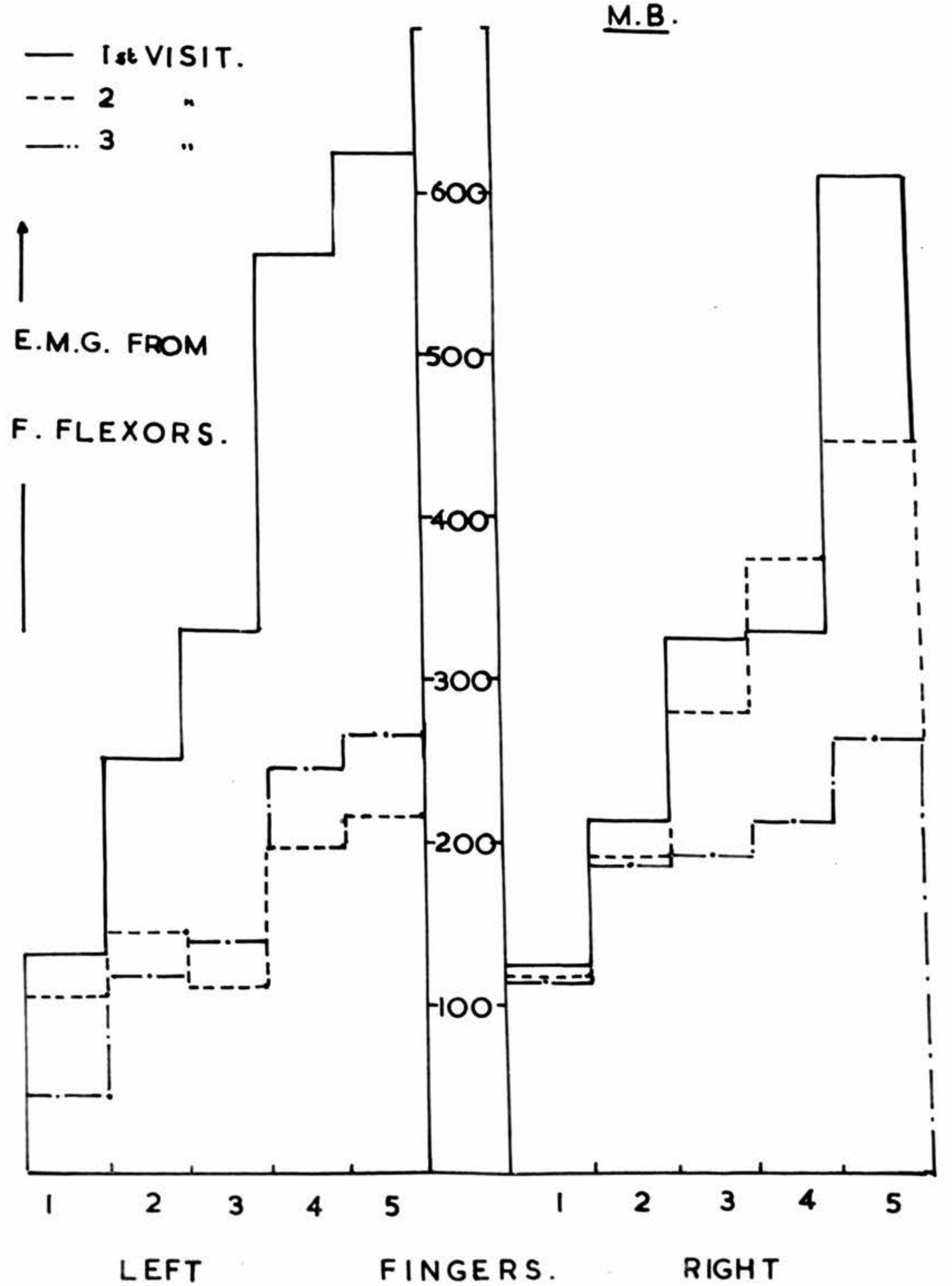

M.B.
1st VISIT.
2 "
3 "
E.M.G. FROM
F. FLEXORS.
600
500
400
300
200
100
1
2
3
4
5
1
2
3
4
5
LEFT
FINGERS.
RIGHT

FIGURE 17. Shows the electromyograms recorded from the forearm flexor, and the dorsal interossei when a skilled typist taps with the fingers of the right hand on the appropriate keys along the home row of keys, (i.e. h, j, k, l, ;). The figure shows how in the highly skilled person more activity is recorded from the forearm flexor when the skilled typist taps with the fourth finger.

R.P.

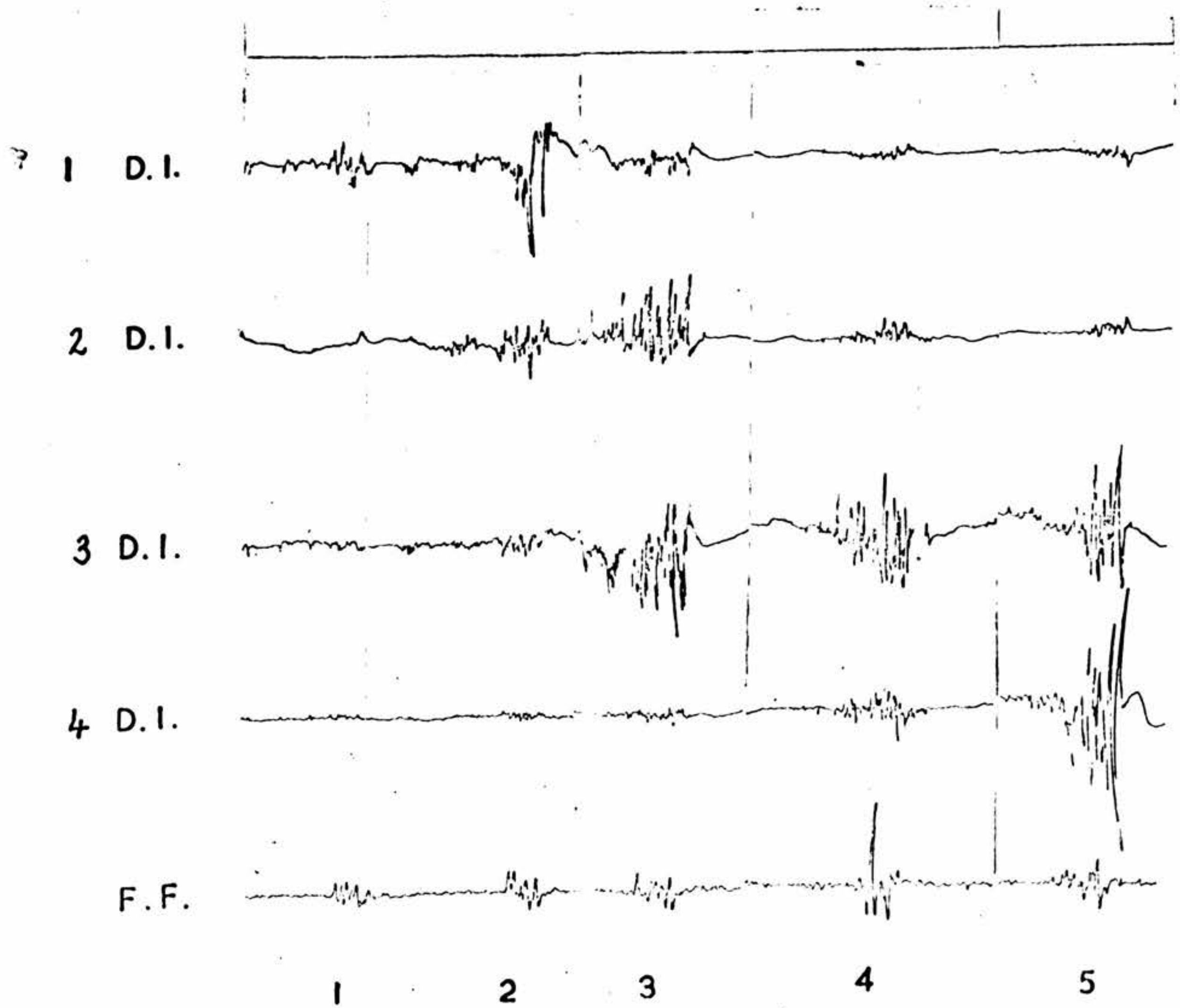
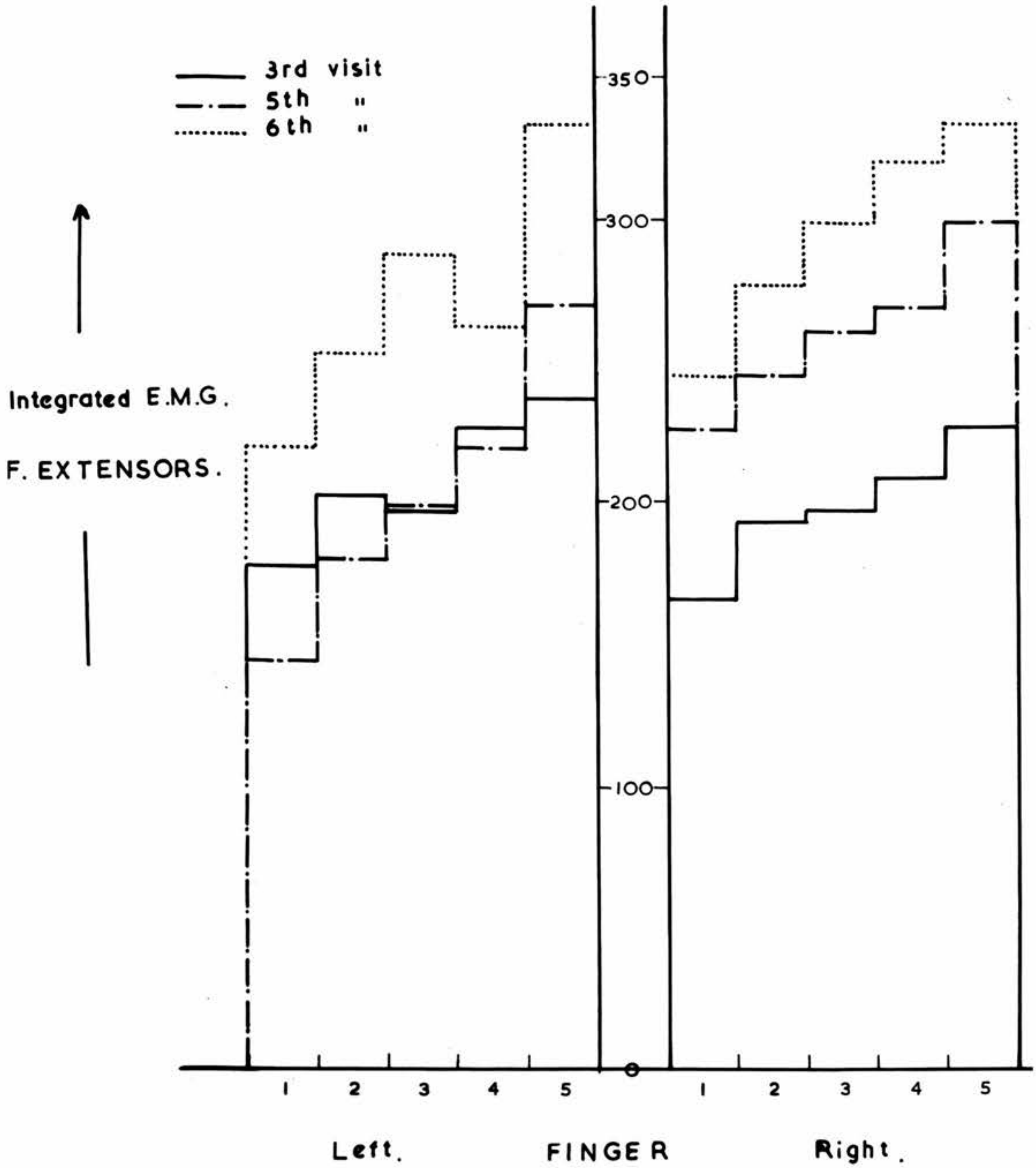


FIGURE 18. Shows the integrated E.M.G. recorded from the forearm extensors when the different fingers carry out the tapping tasks. Again the integrator count is expressed in digital form, whose magnitude is linearly related to the input voltage, and the results are the mean of the results recorded from the eight subjects on visits 3, 5, and 6.



3rd visit
5th "
6th "
Integrated E.M.G.
F. EXTENSORS.
350
300
200
100
0
1
2
3
4
5
1
2
3
4
5
Left.
FINGER
Right.

C. Discussion of Results.

Flexor Activity.

On the occasion of the first visit, the graphs plotting flexor activity when each finger does comparable work, show that the amount of activity recorded increases in a step wise fashion, with the flexor activity required for the tapping with the thumb being least, and that for tapping with the little finger being the greatest. This step wise increase is apparent with both hands. This initial pattern has changed by the third visit of the subjects (that is after 4 to 6 weeks training in typing), so that now the little finger requires less flexor activity than the fourth. This change is seen with the right and left hands. This would indicate that the strength of the little finger increases more rapidly than that of the fourth, so that after training the little finger works more efficiently than the fourth, which then becomes the weakest finger (see Figures 14 and 15). This apparent fourth finger weakness has been commented on by pianists and others interested in features of keyboard operation and is illustrated well in Figure 17, showing the E.M.G. recorded from the dorsal interossei and the flexor muscles when a skilled typist tapped the right hand side row of 'home keys' with the right hand fingers. Jackson (1953) comments on the opinion of teachers of typing and high speed morse stating that the fourth finger is the most recalcitrant to training. Certainly from the results obtained with these subjects learning the typing skill, the fourth finger requires more forearm flexor muscle activity when doing simple tapping tests, after the first weeks of training.

It is rather interesting that the fifth finger though initially requiring much more flexor activity than the other fingers, eventually comes to require less than the fourth. Why it is that the fourth finger does not improve as much as the fifth with practise is an interesting question. Presumably it must be linked with the mechanical factors of the digit such as length and breadth, and studies investigating these properties of the fingers might throw light on these differences in relative improvement of strength which occur with training.

The differences between the right and left hand are also interesting. The right hand appears to be stronger than the left initially, requiring much less flexor activity to perform the exactly similar finger movements. The right hand then shows little improvement with the typing training of the subjects, but the weaker left hand shows substantial improvement in strength after the initial training. Once the strength has improved to some degree when now the left and right hands require much the same flexor activity for the finger movements, then very little further improvement occurs.

Only one of the eight subjects was left handed and the histograms plotted in her case do not show the left hand to be initially stronger than the right. The integrated flexor activity is much the same for both hands with this subject on the first visit, though on the sixth visit the left hand flexors do appear to use less activity. Since results were only obtained from one left handed subject, no definate conclusions can be made.

D. Extensor Activity during the Tapping Tasks.

Due to apparatus difficulties a mean value of the extensor activity during the tapping tasks on the first visit could not be recorded from all eight subjects. This is unfortunate since the main changes in the flexor activity occur between the first and third visits.

However the extensor activity does show how the fifth finger requires greater activity in the extensor muscles than do the other fingers. This is consistent with both the right and the left hands, and from visit 3 to visit 6. The general trend of the activity in the extensors during the finger tapping exercises as training in the typing skill progresses, (i.e. from visit 3 to visit 6) is that the extensor activity appears to increase as the training time progresses. Here we do not see an economy in muscle effort as training progresses and it appears that for the tapping tests to be carried out in a skilful manner the extensor activity increases.

Probably this increase in extensor activity can be explained partly by the subjects hitting the keys in these simple tasks with greater force. Duchenne comments on the participation of the extensors with the flexors in carrying out finger flexion movements with force. Again perhaps with training the extensor activity might increase in these simple tasks to effect greater control of the inactive fingers and whilst one finger performs flexion movement the extensors become more active to keep the other fingers quiet.

E. Conclusions from Tapping Tests.

The tapping tests were included in this series of experiments with girls learning the typing skill, since it was though that consideration of the electromyograms recorded in the performance of this sort of task by the fingers would give indication of the changes in finger strength that result from typing instruction and practise. The results may be summarised as follows:

1. On the first visit to the laboratory, with the subjects at the beginning of their typing instruction, forearm flexor activity is greatest when movements are carried out with the

fifth finger, and a step wise decrease in flexor activity occurs when passing from working with the fifth to the fourth, to the third finger and so on until the least activity is recorded as the first finger performs the tapping movements.

2. Movements of the fingers of the left hand (save for the one left handed subject) initially require much greater flexor activity than do movements of the right hand fingers.

3. The greatest reduction in the flexor activity occurs during the first few weeks of typing training, so that the fingers appear to gain strength in the very early stages of the typing training. After the initial reduction in flexor activity, no further reduction in the activity occurs with further typing practise.

4. Though the fifth finger of both hands is initially the weakest finger, in that it requires a great deal more flexor activity to perform the same task as the other fingers, the rate of improvement of performance with the fifth finger progresses faster than that of the fourth, so that as training in typing progresses the fourth finger now comes to require the greatest amount of flexor activity to perform the task. Even with highly skilled typists it is found that the fourth finger requires more flexor activity to perform finger flexions than does the fifth. Presumably this weakness of the fourth finger is related to the mechanics of this digit. It is

interesting to note that the rate of improvement in finger strength is related to the initial weakness of the finger. For example, the rate of decrease in flexor activity with movements of the fingers of the left hand, which is initially greater than the right, exceeds the rate of decrease in the flexor activity associated with finger movements of the right hand. Similarly the fifth finger of both hands which are initially the weaker fingers shows relatively much more improvement in strength, than do the other fingers which started off much stronger.

5. Training in typing does not have such dramatic effects upon the extensor activity associated with the finger movements involved in the tapping tasks. In general, throughout the training period extensor activity is greatest when the fifth finger of either hand carries out the movements, and the extensor activity decreases in a step wise fashion from fifth finger movements to first finger movements.

Since the extensors of the forearm act during individual finger flexions, to restrain the flexion of the other fingers when the one finger works alone, it seems that greater extensor restraining action is required when the fifth finger is the finger working alone. The extensors need to exert less restraining action as the finger flexions are performed with the fingers going towards the first finger, and the thumb is able to perform tapping movement with the least extensor activity accompanying the flexions.

6. Extensor activity recorded during the performance of the tapping tasks, as training in typing progresses, seems to increase, not to decrease as does the flexor activity. Since the extensors do not give any index of the strength of the fingers this is not in direct contrast to the results obtained with the flexors.

Person and Roshchina showed how flexion of one finger requires the activation of the extensors to keep the other fingers quiet . The ability to flex and move one finger independently of the others is a great part of the skill of the movement in typing, and perhaps this increase in extensor activity observed in the tapping tests, gives the more independent action of the individual fingers in this simple task.

4. Normal Typing Tasks.

Both sections 2 and 3 deal with the recording of muscle activity when the trainee typist works at normal typing tasks. In section 2 a visual picture of the electromyogram is obtained using the eight-channel Offner electroencephalograph, and in section 3 a quantitative value of the amount of muscle activity has been obtained using the four integrators.

5. Section 2.

Sentence Typing.

A. Method.

From the second visit to the laboratory the subjects typed two standard sentences. These same two sentences were used on every subsequent visit.

During the typing of these sentences electromyograms were recorded on the Offner, from the right and left forearm flexors, extensors, biceps, triceps, and the right median deltoid and the right trapezius in the clavicular region. Each sentence was typed twice so that all the muscle groups could be included.

B. Results.

Some typical results are displayed in Figures 19 and 20. Figures 19 and 20 show the electromyograms obtained from two of the learner typists on the occasion of their second visit to the laboratory, which was the first occasion on which they were asked to type the sentences. Figure 21 shows the E.M.G.'s obtained from a highly skilled typist.

C. Discussion of Results.

The results obtained during the standard sentence typing tests will be discussed together with the results obtained from the integrated E.M.G. measures taken during normal typing as described in Section 3 below.

FIGURE 19. Shows the electromyograms recorded from one of the learner typists when sentence typing on the occasion of her second visit, which was the first time the subjects attempted the normal typing tasks.

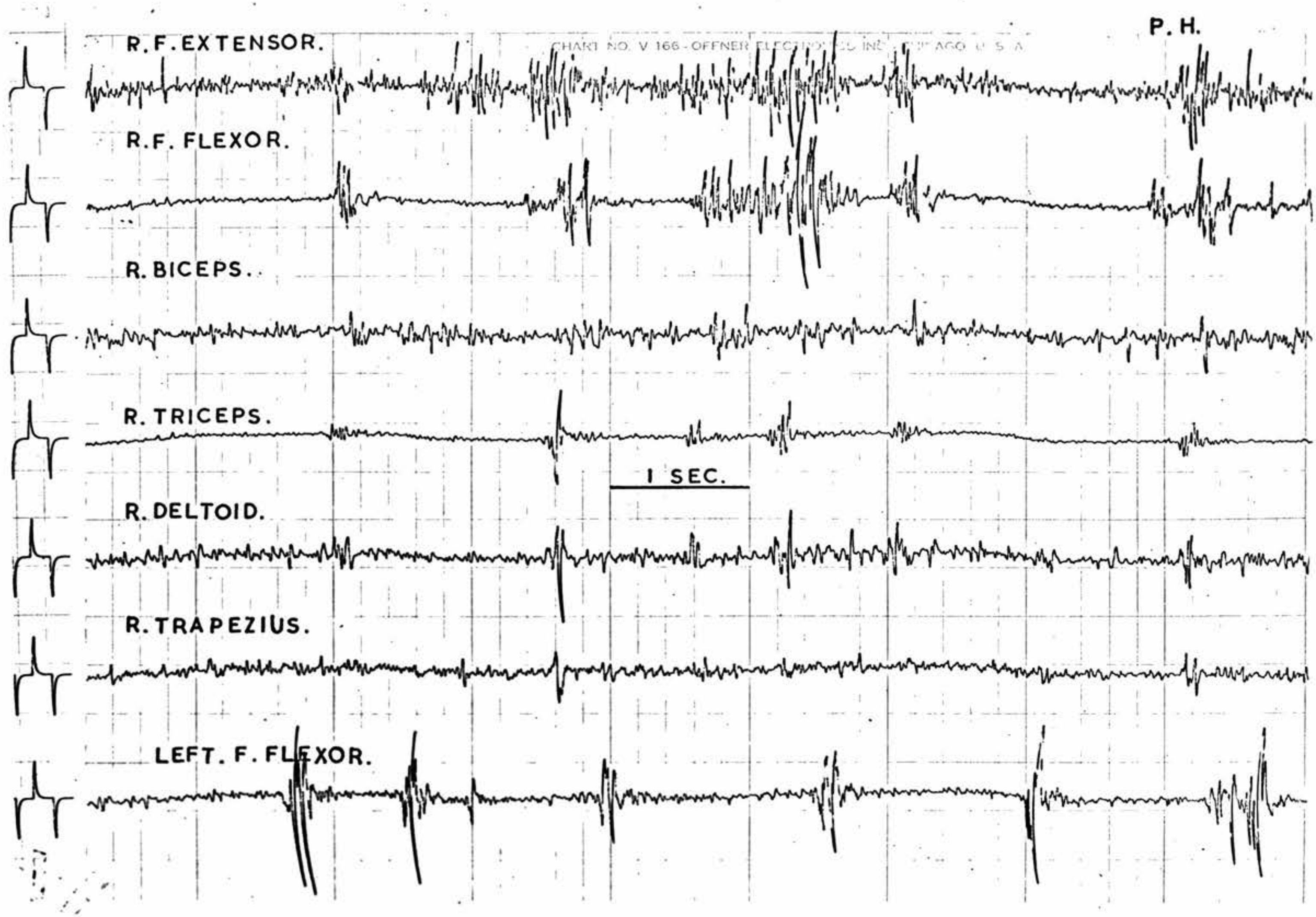
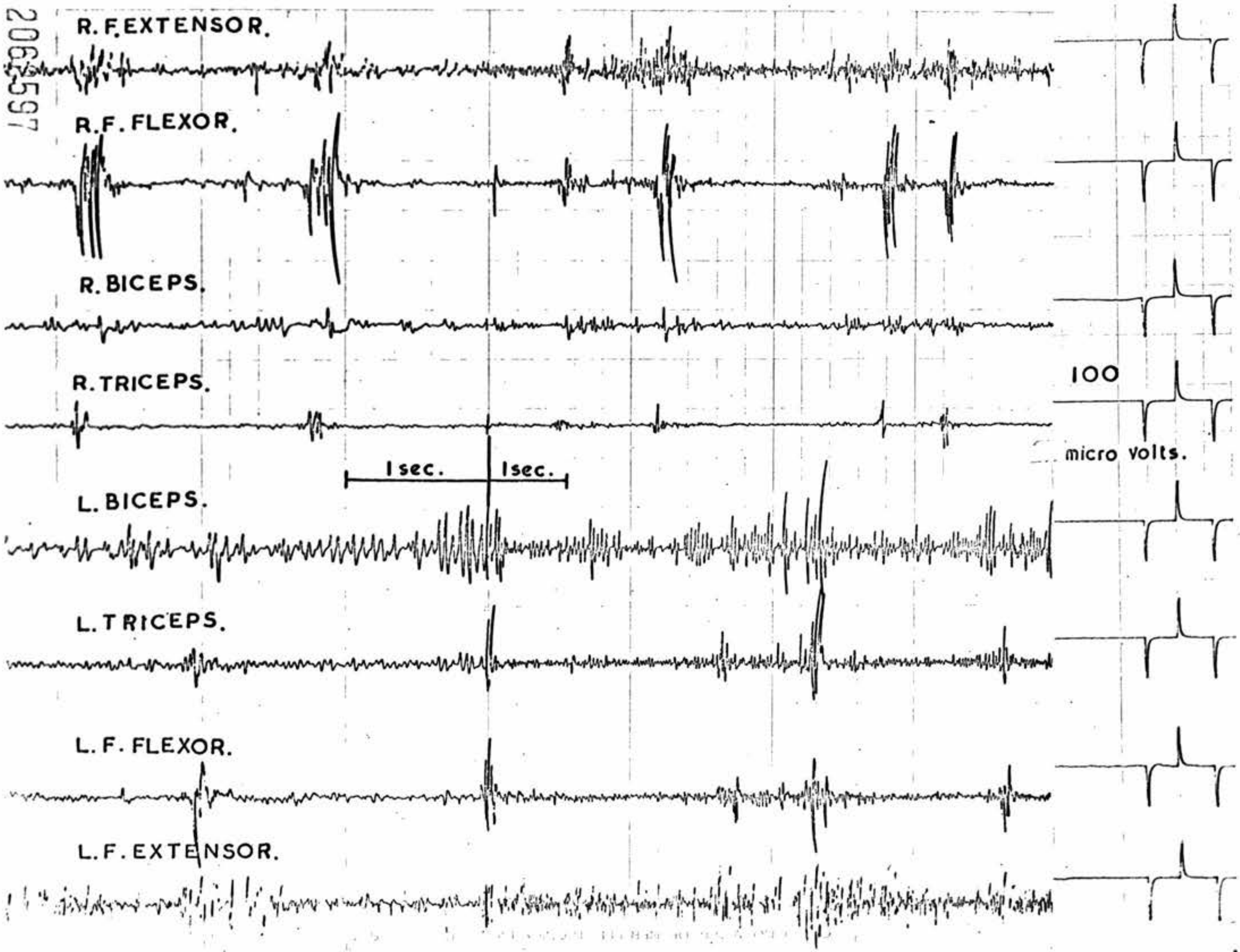
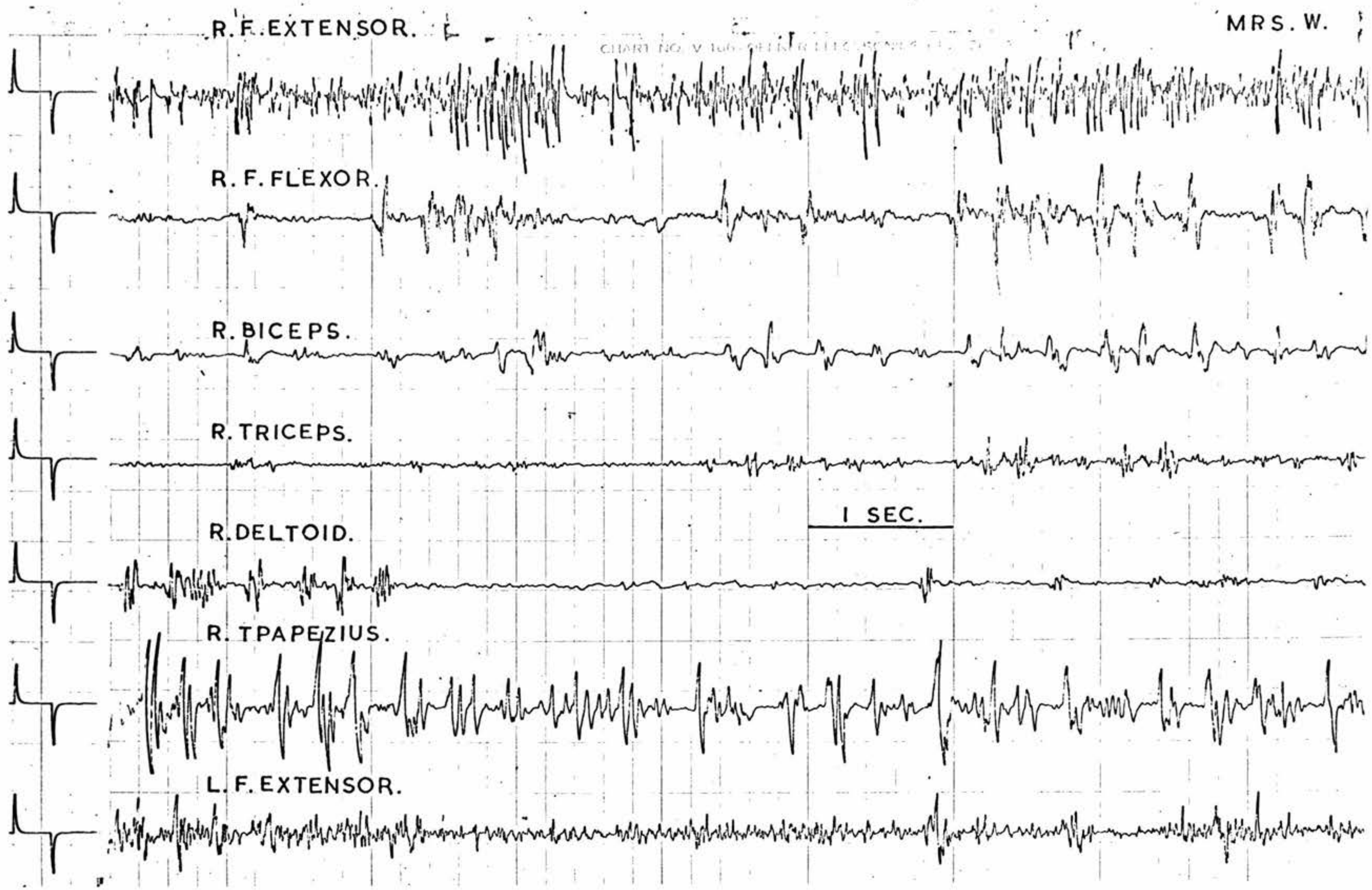

P. H.
R. F. EXTENSOR.
R. F. FLEXOR.
R. BICEPS.
R. TRICEPS.
1 SEC.
R. DELTOID.
R. TRAPEZIUS.
LEFT. F. FLEXOR.

FIGURE 20. Shows the electromyograms recorded from a second subject when sentence typing on the occasion of her second visit to the laboratory.


R. F. EXTENSOR.
R. F. FLEXOR.
R. BICEPS.
R. TRICEPS.
1 sec.
1 sec.
L. BICEPS.
L. TRICEPS.
L. F. FLEXOR.
L. F. EXTENSOR.
100
micro volts.
2062597

<u>FIGURE 21</u>. Shows the electromyograms recorded from a highly skilled typist, when carrying out normal typing tasks.


R.F.EXTENSOR.
MRS. W.
R. F. FLEXOR.
R. BICEPS.
R. TRICEPS.
1 SEC.
R. DELTOID.
R. TPAPEZIUS.
L. F. EXTENSOR.

6. Section 3.

Three Minutes Continuous Typing.

A. Method.

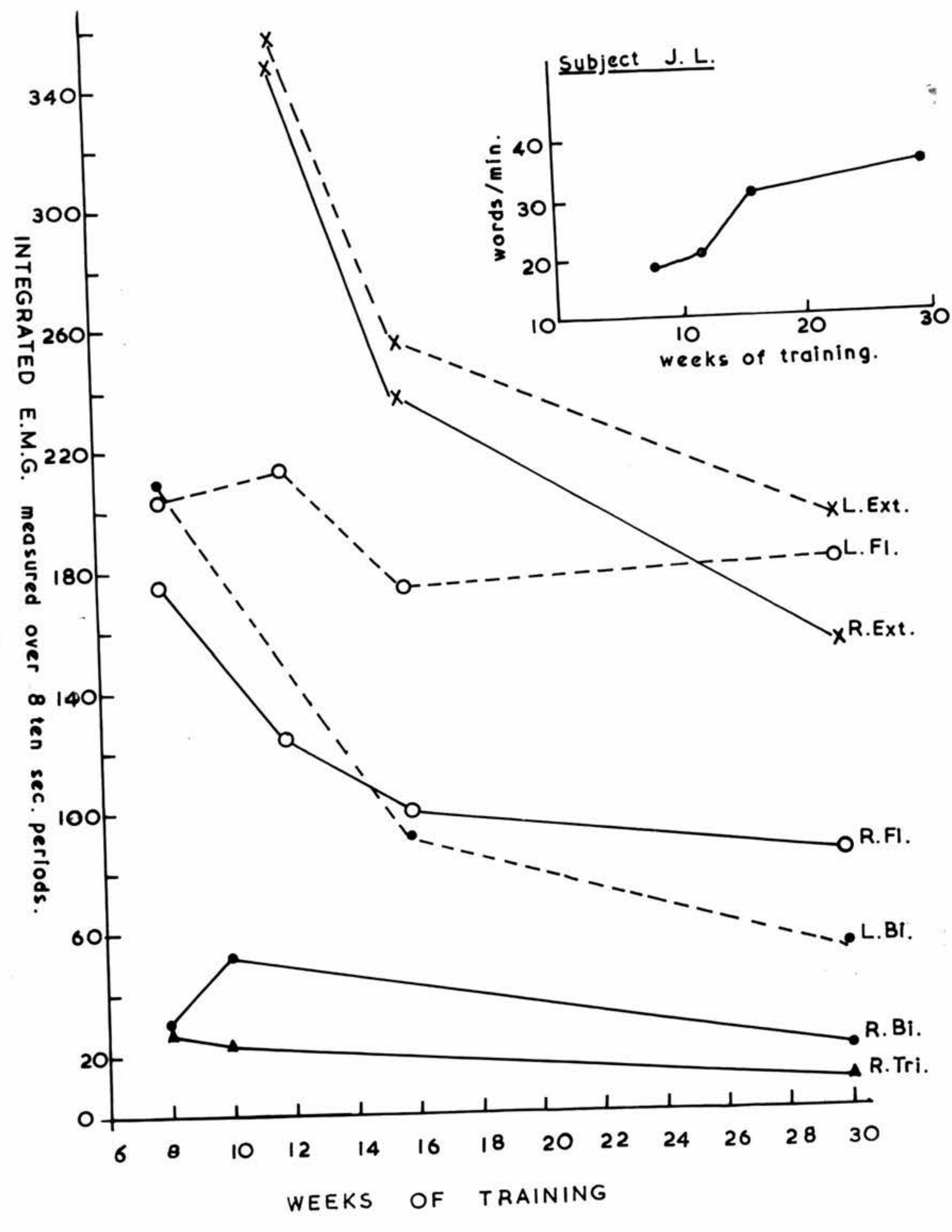
From the third visit onwards the girls were asked to type from the same section of English prose copying as much as they could before they were asked to stop. They were not asked to type at maximum speed but did tend to try and do so. Their typing speed was assessed by the experimenter who afterwards counted the number of strokes typed during the three minute period, from the typist's copy.

Integrated electromyograms were taken from the right and left biceps, triceps, forearm extensors and flexors. The integrated E.M.G. was taken over a ten second integration period, and the integrals were taken eight times during the three minute tasks. A resting integral was first taken and the muscle activity required for typing was found by meaning the eight observations and subtracting the resting integral from the mean of the working integrals. The task was repeated with the integrals taken from the right side muscles the first time, and the second time the integrals from the muscles of the left side taken.

B. Results.

Some typical results are shown in Figures 22, 23, and 24.

FIGURE 22. Shows the integrated E.M.G. results obtained from subject J.L. when performing the three minutes normal typing. Results from the forearm flexor, biceps, triceps and the forearm extensor are shown. The inset shows the increase in typing speed with time from the beginning of training. This graph is typical of all the eight subjects. The integration value is the mean of eight ten second readings taken over the three minute typing period.



Subject J. L.
words/min.
10
20
30
40
10
20
30
weeks of training.
INTEGRATED E.M.G. measured over 8 ten sec. periods.
0
20
60
100
140
180
220
260
300
340
6
8
10
12
14
16
18
20
22
24
26
28
30
L. Ext.
L. Fl.
R. Ext.
R. Fl.
L. Bl.
R. Bi.
R. Tri.
WEEKS OF TRAINING

FIGURE 23. Shows the integrated E.M.G. recorded from the right forearm flexors for all eight subjects over the training period, when they are carrying out the normal typing task. The integration values are the mean of eight ten second readings taken during the three minute typing period.

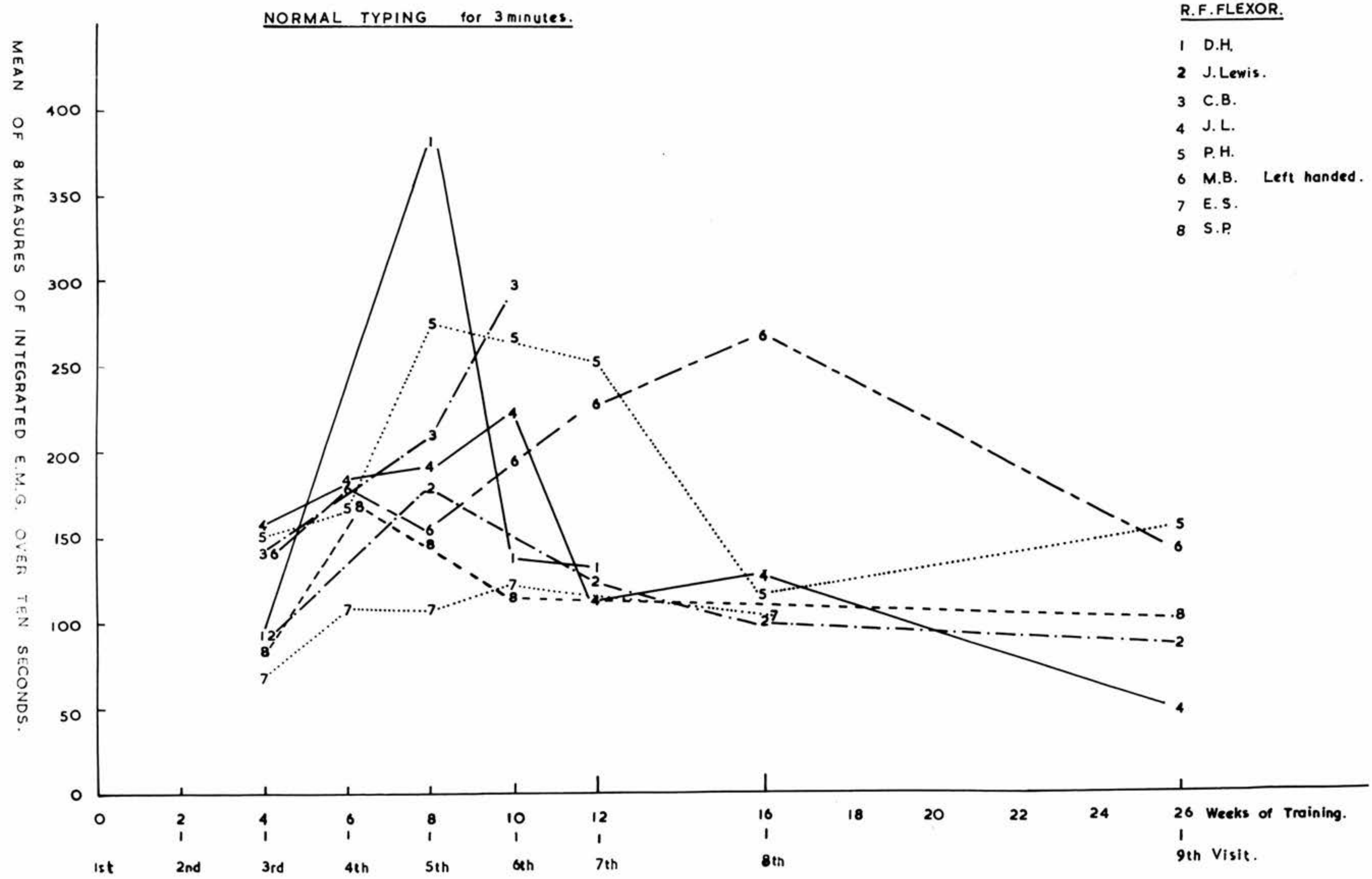
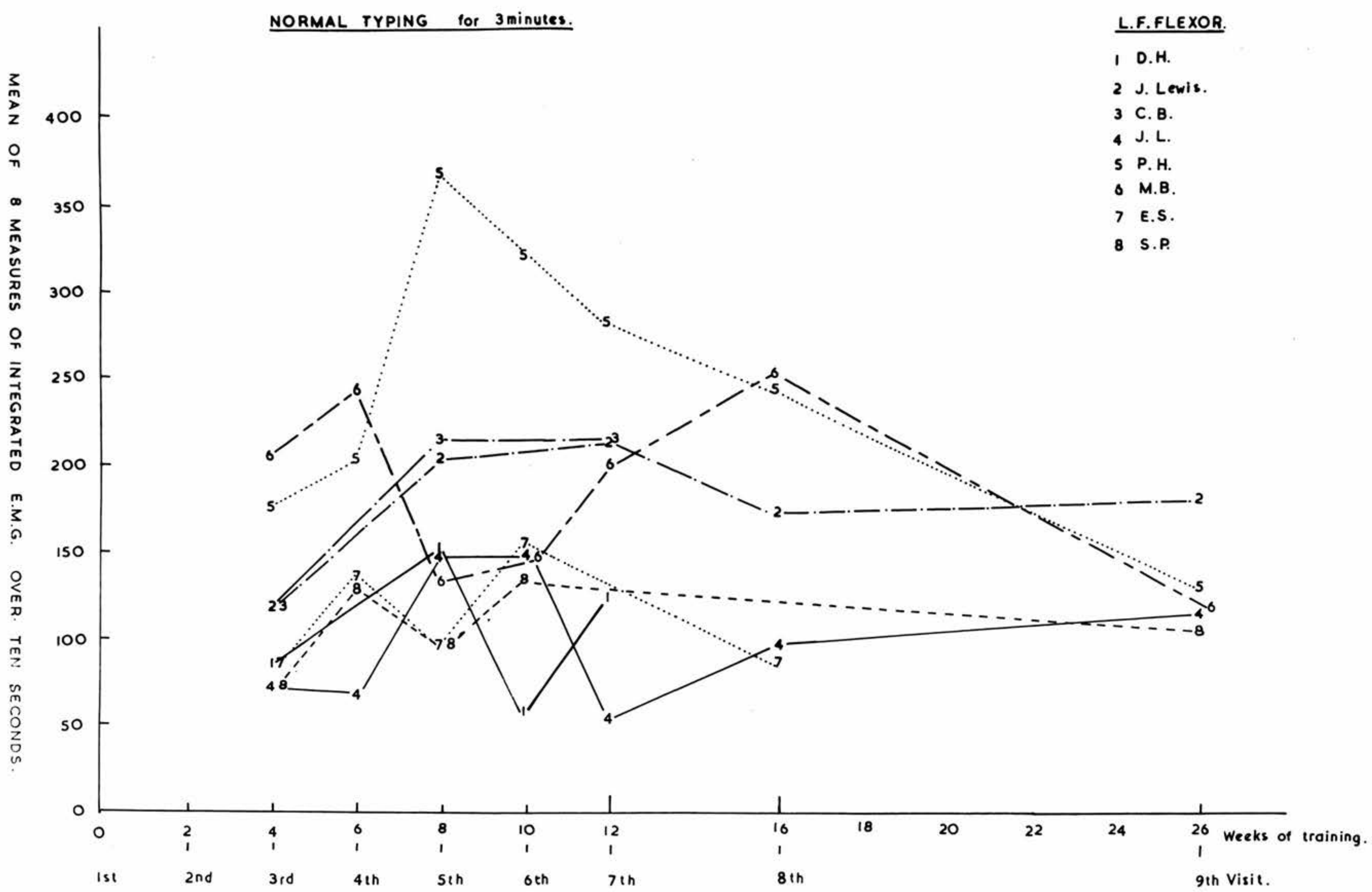

NORMAL TYPING for 3 minutes.
R.F. FLEXOR.
1 D.H.
2 J. Lewis.
3 C.B.
4 J.L.
5 P.H.
6 M.B. Left handed.
7 E.S.
8 S.P.
MEAN OF 8 MEASURES OF INTEGRATED E.M.G. OVER TEN SECONDS.
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
12
16
18
20
22
24
26 Weeks of Training.
1st
2nd
3rd
4th
5th
6th
7th
8th
9th Visit.

FIGURE 24. Shows the integrated E.M.G. recorded from the left forearm flexors for the eight subjects over the training period, when they are carrying out the normal typing task. The integration values are the mean of eight ten-second readings taken during the three minute typing period.


NORMAL TYPING for 3minutes.
L.F. FLEXOR.
1 D.H.
2 J. Lewis.
3 C.B.
4 J.L.
5 P.H.
6 M.B.
7 E.S.
8 S.P.
MEAN OF 8 MEASURES OF INTEGRATED E.M.G. OVER TEN SECONDS.
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
12
16
18
20
22
24
26
Weeks of training.
1st
2nd
3rd
4th
5th
6th
7th
8th
9th Visit.

C. Discussion of Results.

It can be seen from Figures 22 to 24 that with training in typing, though the number of strokes typed during the ten second integration period increases, the integrated E.M.G. after 8 to 10 weeks of training begins to show a drop in magnitude.

In Figures 23 and 24 the integrated E.M.G. recorded from the forearm flexors during normal typing has been plotted for all eight subjects. From these curves it can be seen that a reduction in the integrated E.M.G. does not occur until about the eighth week of training.

Before this time, the integrated E.M.G. increases together with the increase in the number of strokes typed, thus before this time it appears that neuromuscular co-ordinations which effect the eventual reduction in muscle activity have not been established.

After about the eighth week, typing speed increases more rapidly and the integrated E.M.G. taken over the ten second integration period begins to show a drop in magnitude. The beginning of the change in direction of the integrated E.M.G. curves varies slightly from subject to subject in time (i.e. from beginning of the training) but generally the trend is for the integrated E.M.G. to begin to decrease for all muscle groups investigated after the eighth to tenth week of training.

Thus the results recorded with the integrators and obtained during the performance of the typing task, show that during the initial weeks of typing training, an increase in the amount of work done results in an increase in the integrated E.M.G. recorded from the muscles, giving the logical increase in muscle activity with increase in the number of typing strokes made per ten seconds. It will be shown in the following chapter that the integrated E.M.G. does show almost a linear increase with an increase in work done (i.e. words typed per minute), when skilled typists work at varying speeds.

Therefore, in the initial stages of the training in typing the trainee typists show no economy in muscle activity, but show an increase as they come to type more strokes in the ten second integration periods.

However, after varying time periods, these being dependent upon individual differences, but generally about the eighth to tenth week from the beginning of the training, the relation between the work done and the integrated E.M.G. is disrupted, and now the typist's speed begins to improve more rapidly, but the values for the integrated E.M.G. begin to show a drop in magnitude.

The values for the integrated E.M.G. continue to fall though now the typists are performing more work per unit of time, and the forearm flexor activity recorded on the ninth visit to the laboratory approximates to that measured on the first experimental session (3rd visit) though now the typing speed and hence the actual work done per unit time has increased some threefold, with the typing speed improving to values of about 35 words per minute from the original speed of about 10 words per minute.

The muscle activity recorded per unit of work done, i.e. per word typed, has therefore decreased to a third of its original value after about 26 weeks of training. This observed decrease in the recorded muscle activity occurring in the normal typing task after the eighth week of training is not due to increase in finger strength, since it is shown from the tapping tests that finger strength is developed during the first six weeks or so of training, and after this initial improvement in strength to a certain value attained by the sixth week, little if any further improvement in strength occurs.

The only conclusion that can therefore be reached is that after two months or so of training in typing, changes occur in the neuromuscular system which effect co-ordinations which result in an economy of muscular activity enabling the trainee typist to perform more work with less muscle activity.

It is quite evident from the results displayed for the forearm flexor muscles, and from the results obtained with other muscle groups that some time is needed before the trainee is able to work in a more economical way. This delay of eight weeks of so, before the economy in muscular effort is observed must be due to the time required for the building up and consolidating of co-ordinating pathways in the central nervous system, i.e. the time required to build up the pathways which form the basis for the typing of connected discourse. This delay is presumably similar to the plateaus observed by Bryan and Harter, and Book in their studies on telegraphers and typists respectively which they postulate to be due to a delay in the learning of connected discourse until the lower order habits had been firmly established.

It would appear therefore that during the first two months of learning the typing skill, the typists develop:

1. Finger strength as shown in the tapping tasks. After the first six weeks little further changes in finger strength occur.
2. The neuromuscular co-ordinations required to deal with individual letters and perhaps words.
3. They begin to build up co-ordinating pathways based on those set up in 2. to enable them to deal with connected discourse.

After the eighth week, the co-ordinating pathways for dealing with the larger units required for typing connected discourse begin to become established, giving a more efficient use of muscle energy and enabling the typists to improve their typing speed more rapidly.

It is necessary to refer to the visual picture of the electromyograms obtained with the Offner during the sentence typing tests described in Section 2 to see how the reduction in the integrated E.M.G. is brought about.

Person showed the development of alternating periods of activity and rest in muscles used in the filing task as skill progressed, and also the development of a reciprocal relationship between antagonistic muscles.

In the typing task, even at the beginning of training (see Figures 19 and 20) in many of the muscle groups investigated, the muscle action potentials do tend to be concentrated into bursts of activity followed by periods of electrical silence. So even before any training in typing it is found that excitation of the muscle fibres occurs associated with the striking of the key, and is then followed by rest in the muscle. This is particularly noticable with the forearm flexor muscles. Some continuous activity does exist in other groups.

Also at the beginning of training a clear reciprocal relationship exists between the antagonistic muscles, the biceps and triceps, with increased activity in the agonist accompanied by almost rest in the antagonist. In typewriting the movements of the elbow joint cannot be of a precise nature, but all the precise movements involved in the typing task are carried out by the fingers. Person showed that in less precise movements a reciprocal relationship exists between the biceps and triceps.

Thus in the movements of the elbow joint in typing, even before training a reciprocal relationship is the normal activation pattern of the biceps and triceps.

A feature of the biceps and to a lesses extent the triceps activity which does change with practise and training can be seen from Figures 19 to 21. Figure 21 shows the E.M.G.'s recorded from a highly skilled typist, Mrs.W., who participated in some of the experiments. (Mrs.W. could type at rates up to 120 words per minute).

At the initial stages in training, it was found that electric activity, signifying muscle activity could be recorded between the main bursts of the action potentials which are associated with the actual striking of the keys. This is particularly evident with the left biceps and generally with all subjects on the first few visits, and is well illustrated in Figure 19. It was also shown to a lesser extent by the right biceps. (See Figure 20).

As training progresses, this activity between the main bursts decreases until in some of the subjects by the eighth and ninth visits biceps activity was restricted to the main bursts of action potentials associated with the actual striking of the typewriter keys, giving the type of electromyographic picture as shown in Figure 21.

The same effects were seen with the deltoid and the trapezius. Again some continuous activity could be recorded from these muscles in the initial stages of training, but as the skill improves and typing speed increases the electric activity recorded from these muscles tends to become concentrated into the bursts of potentials associated with the hitting of the keys.

The electric activity recorded from the forearm flexors and extensors has much the same overall appearance throughout the training period, in that extensor activity occurs concurrently with the flexor activity, flexor activity is concentrated into bursts and followed by periods of electrical silence, and extensor activity can be recorded continuously though some concentration of excitation and greater activity is recorded when the key is hit. This type of activation pattern remains throughout the training time and is seen in the electromyograms recorded from highly skilled typists.

However, changes can be seen in the E.M.G.'s which account for the drop in the value of the integrated electromyogram. The changes that are most apparent in the flexor activity with training are the marked changes in both the frequency and amplitude of the action potentials associated with the contractions needed for the striking of the keys. The most obvious change is the change in the frequency of the action potentials, and this is well illustrated when comparisons are made of the electromyograms from the forearm flexors of the unskilled girls with that recorded from the same muscle in the highly skilled person. Though the change in the amplitude of the spikes is not particularly evident, it can be seen that great synchronisation of the potentials occurs with the skilled subject, so that the flexor burst associated with the hitting of the key is in appearance a single diphasic waveform, quite different in appearance foom the multi frequency action potential bursts recorded from the unskilled girls.

Great synchronisation of activity also occurs in the triceps and biceps muscles with training and also in the trapezius and deltoid, where the multi frequency action potential waves observed in the untrained person gradually give place to almost diphasic type waves.

This change has also been shown in comparisons made on pianists and non pianists when executing simple movements on piano keys when the skilled person shows E.M.G.'s exhibiting a high degree of synchronisation, as compared with the multi frequency waves obtained from the unskilled person. *see note below.

The reduction in the frequency of the action potentials observed from the eight subjects during their first six months of typing training, and exhibited when comparisons are made of the E.M.G.'s of skilled and unskilled persons can be explained in the following manner.

With surface electrodes, one is recording the muscle action potentials from a relatively large section of muscle tissue, which contains many motor units. The curve which one obtaines therefore using this method of recording is a summating curve for a great many motor units lying beneath the electrodes. Bearing this in mind we can therefore deduce that at the beginning of training, or before training, the unskilled person performs the tasks with the motor units being activated in asynchronous rhythm, giving the electromyograms with multi frequency waves. This type of electromyographic picture would suggest that nerve fibres supplying the muscles are being excited in a haphazard fashion, with probably motor units being recruited throughout the actual striking of the key

* In experiments carried out with Miss V. Floyd.

in response to sensory stimuli from the muscle proprioreceptors.

The reduction in frequency of the potentials which occurs with training, must be the result of a more synchronous excitation of the motor units, which results in the combining of several impulses from several separate motor units into one common potential wave which is seen in the electromyograms recorded from the skilled person. This synchronous excitation of the motor units must mean that the motor neurones are firing together simultaneously in time with the action becoming automatised, and with sensory stimuli aroused during the striking of the key not resulting in the recruitment of further motor units.

The results obtained in this study are similar to those observed by Stephanov with weight lifters, where he finds most striking synchronisation of the action potentials to be a feature of this skill, therefore it seems that the synchronisation is a general change occurring with the development of skill, whether it be a gross muscular skill such as weight lifting or a finer skill, involving small muscle groups, as in typing and piano playing. The synchronisation of the excitation of the motor units is determined by activity of a similar nature in the motor neurones from which they receive their innervation, and thus it must be concluded that training is accompanied by considerable changes in the mechanisms co-ordinating the activities of the nerve centres.

The other notable condition where the electromyographic pattern changes to a synchronous type, with changes in the state of the muscle, is that recorded in fatigue.

In fatigue the electromyographic pattern changes in much the same way with the organisation of electric activity recorded from whole muscle groups using surface electrodes undergoing considerable modification. Buchtal and Madsen (1950) and Lippold et al (1960) have commented on the synchronisation of the motor unit potentials that occurs with fatigue.

It seems highly questionable whether the synchronisation observed in muscle fatigue has anything in common with its appearance with the development of skill, but it is perhaps possible that in the onset of fatigue the neuromuscular system begins to work in a rhythmic fashion giving synchronous excitation of motor neurones in an attempt to work more efficiently, since it seems that the synchronous firing of the neurones is the more skilful and efficient method of working.

7. Conclusions from Normal Typing Task.

1. The integrated E.M.G. results show two distinct trends throughout the first six months of typing training.

a. During the first eight to ten weeks of training the integrated E.M.G. increases with increase in the number of strokes typed during the ten second sampling period.

b. After about ten weeks of training the integrated E.M.G. begins to show a drop in magnitude though the typing speed is now increasing more rapidly. After about six months of training in typing, the integrated E.M.G. to type a given amount of work has dropped to about a third of its original value. This drop is not due completely to increased finger strength, but must be due to some re-organisation in the neuromuscular system.

2. The differences that occur in the E.M.G. after the eighth week of training which could account for the drop in magnitude of the integrate E.M.G. are threefold.

a. Muscle activity becomes concentrated into bursts associated with the hitting of the keys. Originally on the third visit of the subjects electric activity could be recorded from the biceps, deltoid, triceps, and trapesius continuously, though the main excitation occurred with the hitting of the keys, but after a few months of training the activity recorded between the main bursts becomes reduced and finally the muscles show periods of excitation followed by rest in these muscles.

b. Small changes in the amplitude of the recorded potentials occur but these are not very marked.

c. The frequency of the action potentials associated with the hitting of the keys change throughout the training period. After about ten weeks of training the frequency of the potentials decreases, and the activity of the motor units tends to become more synchronous, with the multi frequency spikes giving way to single diphasic type action potential waves.

General Conclusions on the Neuromuscular Changes which occur with the Development of Motor Skills.

Two studies have been carried out to investigate the neuromuscular changes which occur with the development of skill.

The first study involved the comparison of highly skilled typists with less practised typists when performing on two machines where different key pressures were required.

Here it was found that the more practised group could economise on both total energy expenditure and in localised muscle activity when working with the lighter pressure machine, whilst the less practised typists were not able to take advantage of the opportunity to economise on muscle activity to any great extent when using the lighter pressure machine.

The more skilled typists when using either machine worked with less muscle activity in almost all muscle groups investigated, though recordings with strain gauges showed that the forces applied on the keys of the typewriters were of much the same magnitude.

The more practised typist has developed a more efficient method of working due to her richer motor experience. It seems that the more skilled person is able rapidly to judge how much effort is required to depress the particular key, and she is able to apply just this force to the key which then travels under the imparted momentum. The less experienced person is not able to judge in advance how much force is required, and she applied the force when she encountered resistance in the key. This limits her typing speed and also causes wastage of effort.

The second study involved the recording of the electromyograms from a group of subjects during the first six months of their typing training.

The first changes that occurred with training were changes in the strength of the fingers. The fingers appear to attain sufficient strength during the first six weeks of training.

Up to about the tenth week of training the electromyograms show that an increase in the work done results in an increase in the muscle activity, but after this time the electromyograms begin to show changes in frequency, amplitude and form which are reflected in a reduction in the integrated E.M.G.

CHAPTER 6.

The relation between typing speed, the force exerted on the typewriter keys, and the integrated electromyogram.

1. General Introduction.

It has been stated in the previous chapter that one would expect the integrated electromyogram to increase in a linear fashion with the speed of typing, giving a relationship between the muscle activity and the amount of work done. However, the integrated electromyogram might not show a linear increase with increase in typing speed, or amount of work done per unit time, if the forces exerted on the keys varied as typing speed varied.

A series of experiments was therefore carried out to investigate these relationships. This study will be divided into two sections for convenience of presentation, with Section one dealing with the force/velocity relationship, and Section two dealing with the relationship between the typing speed and the integrated electromyogram.

2. Section 1.

The relationship between typing speed and the forces exerted on the typewriter keys.

A. Introduction.

Much work has been carried out using isolated animal muscle to investigate the force/velocity of contraction relationship.

It is now well established that isolated muscle, when stimulated artificially, shortens more quickly as the opposing force is decreased, or conversely, if muscle is made to contract at a predetermined speed, then the force which it can exert diminishes as the speed of shortening decreases.

In isotonic contractions, the relationship between the force exerted by a muscle and the velocity of contraction was first investigated by Fenn and Marsh (1935), who using frog and cat muscle preparations obtained a curve relating the two variables. The curve obtained was found to be concave towards the origin, and fitted the exponential expression;

$$P = P_o e^{-aK} - K V,$$ in which a and K are constants

P is the force at velocity V, P_o is the maximum force exerted at zero velocity, i.e. in isometric contraction conditions. A second equation relating the force of contraction and the velocity was proposed by Hill in 1938 when he derived the following simple equation;

$$(P + a)(V + b) = \text{constant} = (P_o + a) - b.$$

where P is the force of contraction, V is the velocity of shortening of the muscle, a and b are constants, and P_o the maximum force at zero velocity.

This equation fitted the data of Fenn and Marsh, and has been shown to fit further subsequent data.

Wilkie (1949) investigating the force/velocity relationship in the intact human muwcle, obtained much the same exponential type curve as originally given from Fenn and Marsh, with the same relationships existing between the two variables as had been found with isolated animal muscle. A point of further interest from Wilkie's paper is the observation that the maximum forces exerted by different individuals varies greatly (from 12 to 20.5 mega dynes in these experiments) but the maximal velocity of shortening of the muscles is remarkably constant.

Biggland and Lippold (1954) have investigated the relation between the force of contraction, the velocity of contraction and the integrated E.M.G. Again the results relating force and velocity of contraction agree with the Hill equation. Thus as a general rule, both isolated animal muscle and intact human muscle are seen to exhibit a definite relationship with regard to the force of contraction and the velocity at which the muscle contracts. Consideration of these factors should enable manufacturers of everyday appliances to design them such as to enable the tasks to be performed at optimal rates of working.

From Hill's equation, the rate of doing work is zero when

$$P = 0, \text{ or when } P = P_o$$

and is maximal when

$$\frac{P}{a} = \left(1 + \frac{P_o}{a}\right)^{-1}$$

Thus fast movements, such as required from the typist where speed is all important cannot be achieved theoretically in the presence of heavy loading of the keys.

Theoretically, basing ones arguments on the well established force/velocity relationships existing in muscle, we might expect that as a typist works at greater speeds, the force with which her fingers strike the keys will increase. But is this relationship perhaps too simple in the case of the typist? It has been shown that the skilled typist conserves her energy when working with a lighter pressure machine by adjustment, through sensory proprioreception, of the number of motor units activated. It therefore seems rather unlikely that skilled typists will waste muscle energy when typing at faster rates hitting the keys with more force than they actually require.

The experiments have been carried out to find what changes occour in the forces exerted by the typist on the typewriter keys when she is made to type at very different rates.

B. Experimental Method.

A piece of standard English prose of 100 words in length was selected. (1 word = 5 strokes of the typewriter keys.) This passage was recorded by the experimenter on magnetic tape with the experimenter recording the passage at seven different dictation speeds, so that the typists following the passage when read from the tape would type at speeds of 25, 30, 40, 50, 60, 80, and 100 words per minute, with the total typing time being 4 mins., 3mins. 20 sec., 2 mins. 30 sec., 2 mins., 1 min. 40 sec., 1 min. 15 sec., and 1 min respectively.

The order of presentation of the passage was varied, so that some subjects started with the lower speeds and others with the faster speeds.

All of the subjects were allowed to listen to the passage, to be typed by them, before the start of the experiment until they were familiar with its contents and its general meaning, before they were asked to type the dictation. In this way it was hoped to eliminate any muscle tensions due to difficulty in following the passage in the first presentations. The subjects were asked to keep in time to the spoken words in the slower passages, which were dictated at speeds well below their capacity, and with the faster dictations they were asked to attempt to keep pace with the words, and if they fell behind the dictation to leave out words in order to catch up with the spoken word.

Twelve typists took part in the experiments which lasted about 2 hours including rest periods, and two typewriters were used. The typewriters were an Imperial 77 manual machine and an I.B.M. electric machine.

The subjects could be divided into three groups - Group 1 being typists with experience of manual typewriters only, Group 2 having experience with both manual and electric typewriters and Group 3 being fully trained and experienced with electric typewriters. The three subjects in the Group 1 category used only the Imperial manual typewriter, the three inGroup 2 used both the electric and manual typewriters, and the six subjects in Group 3 used the electric machine.

The forces exerted on the keys were measured by means of strain gauges placed on the lever of key A on each machine. The positioning of the strain gauges and a general description has been given previously. Due to the difficulty of attaching the strain gauge and also due to the laborious method of estimating the forces (to be described below) only the force exerted on the key A by the little finger of the left hand was measured. However, it seems reasonable to suppose that changes in the force exerted by the little finger with changes in the typing speed will reflect changes for all the fingers.

Figure 11 shows the deflection of the pen of the Offner occurring each time key A was hit when a subject was typing the passage at a speed of 50 words per minute on both the electric and the manual typewriter. From Figure 11 it can be seen that even with the same typewriter and with the subject typing at a fixed speed of 50 words per minute some variation in the size of the voltage change (or the force applied to key A) exists from letter to letter. It was therefore thought necessary that the size of each deflection should be measured for each speed, and the mean values of the force deflection compared. The letter <u>A</u> occurred 28 times in the passage, therefore each deflection was measured at each speed (in 32nds of an inch) and the mean value found of the 28 measures. Two measures were taken from the force deflections registered on the Offner, the first measure gave the amplitude of the deflection, and the second measure taken was of the duration of the deflection. These two measures were multiplied together to give the area under the force curve, which is proportional to the force. The measurements were made in 32nds of an inch and could be accurately read to $^1/64$th of an inch. Due to the differing action of the electric and manual machines it was not found possible to calibrate the force deflections in terms of dynes/inch^2 so the results are expressed in the arbitrary units of 32nds of an inch. Thus the measures of the forces applied on the key A are suitable for comparative purposes but are not expressed in force units.

The mean value of the force exerted on the key A, with force being the multiple of the amplitude x the duration of the deflection was found for 28 readings with each subject typing at the seven speeds for both machines.

C. Results.

The following Table shows the mean of the 28 readings of the force exerted on key A, for each of six subjects when typing at the seven speeds, when using the manual typewriter.

Table 11. Mean of 28 readings of force exerted on key A, for each subject, and at all speeds. MANUAL typewriter.

Subject	Typing Speed (words/min.)						
	25	30	40	50	60	80	100
1	37.17	44.96	37.93	38.13	37.48	38.27	36.71
2	65.50	65.10	55.50	60.80	57.80	-	61.30
3	47.97	67.60	60.51	61.47	68.56	56.75	68.74
4	68.40	68.20	67.20	61.10	61.20	60.40	60.90
5	26.44	31.77	28.90	27.34	36.52	-	26.40
6	44.74	47.07	45.17	42.01	41.65	-	-
Sum	290.22	324.70	295.21	290.85	303.21	155.42	254.05
Mean	48.37	54.12	49.20	48.47	50.54	51.81	50.81

Table 12 shows the mean of the 28 readings of the force exerted on key A, for each of the seven subjects when typing at seven different speeds, when using the electric typewriter.

Table 12. Mean of 28 readings of force exerted on key A, for all subjects and at all speeds. ELECTRIC typewriter.

Subject	Typing Speed (words/min.)						
	25	30	40	50	60	80	100
1	17.88	18.79	18.76	15.37	18.82	23.01	19.77
2	23.78	18.47	22.31	23.06	19.05	24.95	18.31
3	20.47	21.16	25.83	19.43	27.88	21.19	14.78
4	13.42	14.68	14.62	13.79	12.38	13.08	13.86
5	-	26.70	22.90	26.41	23.25	15.50	23.29
6	-	21.41	18.90	28.42	25.03	23.48	29.83
7	-	33.79	25.08	36.78	25.40	-	-
Sum	75.55	155.00	154.97	163.26	151.81	121.21	119.84
Mean	18.88	22.14	22.14	23.32	21.68	20.20	19.97

The mean value of the force, for all subjects, at the different speeds is plotted against the typing speed as shown in Figure 25.

D. Analysis of Results.

It appears from Tables 11 and 12 that the forces exerted on the typewriter keys do not change with changes in speed. Figure 25 also indicates that the force remains almost constant throughout the speed ranges of 25 to 100 words per minute.

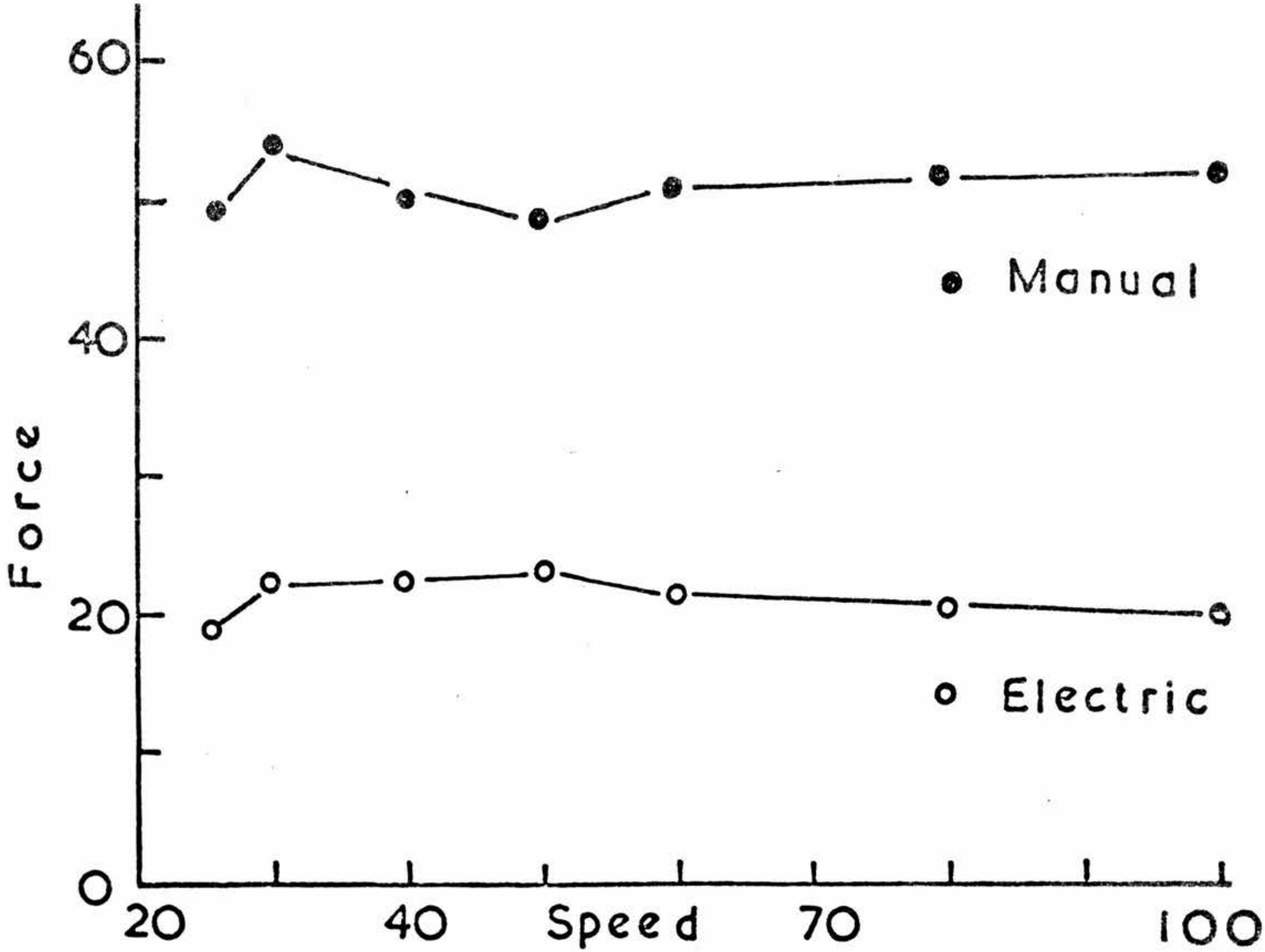
A two-way analysis of variance was carried out with the results obtained for the two groups of results, i.e. with the electric and manual typewriter. (Moroney, 1962). Using this test and the results obtained with the subjects using the manual typewriter,

$F = 3.26$ which is not significant at the 5% confidence level.

Thus with the results obtained from the manual machine, we may accept the null hypothesis, that the force exerted on the keys of a manual typewriter when typists work at speeds ranging from 25 to 100 words per minute, do not change in any significant fashion, with changes in typing speed.
Using the same test, and the results obtained with the typists who used the electric typewriter,

$F = 2.51$ whichis not significant at the 5% confidence level.

FIGURE 25. Shows the mean values of the product of amplitude and width of the output from the strain gauges on each of the typewriters and for all subjects plotted for the seven dictation speeds.


Force
60
40
20
0
20
40
Speed
70
100
Manual
Electric

Again the null hypothesis may be accepted.

E. Discussion of Results.

When typists work at differing typing speeds it cannot be shown that the force exerted on the typewriter keys varies with variation in typing speed. From basic muscle physiology it might be expected that as the typing speed increases, and the velocity of contraction of the muscles increases, the force exerted on the keys would increase. This is not shown to be the case with skilled typists where the force exerted on the keys remains practically constant over the speed range from 25 to 100 words per minute.

Comparison of the results shown in Tables 11 and 12 and displayed in Figure 25 indicated that the force required and used by typists in the operation of the electric machine are almost half that required and used to operate the manual machine. This cannot be stated more precisely since no calibration of the strain gauge deflections have been carried out due to the fundamentally different mode of operation of the keys of the two types of typewriter.

These results point to the fact that the skilled typist uses just the force required to operate the keys of a particular machine and that she uses and applies just this force irrespective of the speed at which she types. An increase in typing speed does not result in an automatic increase in the force applied on the keys but this force remains constant over wide ranges in typing speed.

3. Section 2.

The relation between the integrated electromyogram and the typing speed.

A. Introduction.

One of the basic assumptions made when using the integrated E.M.G. is that the value of the integrated E.M.G. is linearly related to the amount of work done by the muscle.

It has been demonstrated that in voluntary isometric contractions there does exist a linear relation between the tension exerted and the muscle action potentials recorded. (Lippold, 1952; Inman et al, 1952; Davis, 1958). One of the requirements for this relationship to hold is that the muscle must not change in length.

Biggland and Lippold (1954) investigated the relation between the force of contraction and the integrated electromyogram in voluntary isotonic muscle contractions. They found that when the force against which the muscle had to contract was varied but the velocity of contraction was kept constant, the integrated E.M.G. showed a linear increase with increase in the opposing force. A linear relation existed at different constant velocity, with the slopes varying with the velocity. In a second series of experiments, they kept the force constant and varied the velocity of contraction, and they found a linear relationship to exist between the velocity of muscle contraction against a constant force and the integrated E.M.G. These results are in agreement with experiments carried out by Biggland, Abbott and Ritchie (1953) when they measured the oxygen consumption of subjects whose leg muscles were working at differing velocities of shortening. They found that oxygen consumption increased with increase in the velocity of shortening against a constant force. This increase in oxygen consumption reflects the increase in the number of active motor neurones as the velocity of contraction increases and is reflected in the increased integrated electromyogram.

Small and Gross (1958) investigated the relation between the integrated electromyogram and the velocity of contraction when subjects lifted weights at different rates. They showed the integrated muscle activity to increase both with the increase in weight and also with the rate of lifting, but they did not find a linear relation between the integrated electromyogram and the rate of lifting the weight.

Related to the work on muscle activity, as measured by the integrated electromyogram, and the rate of working (or the speed of muscle shortening) are energy expenditure studies. Many studies have been carried out to measure the energy expenditure of a given task when performed at various rates.

In the extensive review of energy expenditure studies published by Passmore and Durnin (1955), a composite graph including the results from four laboratories has been composed, which shows the enrgy expenditure of subjects when walking at different speeds. Here within certain limits a linear relationship is shown to exist between the energy expenditure and the speed of walking. The energy expenditure per minute recorded when a task is performed at different rates must reflect to a large degree the changes in muscle activity in the muscles involved in the task, and therefore one would expect the muscle activity as recorded by the integrated electromyogram to increase in a parallel way to the total energy expenditure as the task is carried out at a faster rate.

It has been shown above that the force exerted on the keys when the typist works at different speeds remains constant, so there exists the situation where the typist works at differing velocity but against a constant force. We might therefore expect that the linear relationship between the velocity of typing and the integrated electromyogram would be observed. But perhaps again in the typing task this relationship is too simple, for in the typing task the typist is more skilled when working at a particular rate, which she has developed through practise. Also the dynamic factors of the hand and wrist might possibly have some influence on the ease of working at certain rates.

This study was therefore planned to find whether the general relationship between the speed of contraction of the muscles and the integrated E.M.G. does in fact hold in muscles involved in the typing task where persons have become skilled at certain rates.

B. Experimental Method.

This part of the study was carried out simultaneously with Section A above. Thus the typists worked typing from dictation at the seven different rates as described above.

Muscle activity was recorded from the left and right forearm extensors and flexors of the wrist. The muscle action potentials were picked up using surface electrodes, and the inputs were fed into the four amplifiers of the Ediswan, from which they gave the visual record of the E.M.G. recorded on the four pens and also the value of the integrated E.M.G. from the four-channel integrator.

The total muscle activity to type the complete task was integrated with the experimenter starting the period of integration at the commencement of the recorded passage, when the typist hit the first key, and stopping the integration at the end of the passage. This was done by means of a switch on the timer connected to the integrator. Thus the time taken to type the passage and the integrated value of the E.M.G.'s recorded from the flexors and extensors was found.

The muscle activity to type the whole passage was found for each typing speed, and from these results the integrated E.M.G. per minute could be calculated. Since the basic pulse count recorded from the integrators per minute is constant the results have been presented as the pulse count read directly from the integrators.

C. Results.

Table 13. Integrated muscle activity to type whole passage at 25 words per minute. Subjects using Electric typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	19.680	23.059	21.028	27.944
2	20.752	21.060	29.281	19.081
3 & 4		No	results	
5	21.392	23.871	22.075	26.090
6	20.563	37.138	18.943	26.558
7	22.343	22.621	18.443	22.096
8	23.654	22.289	20.258	23.180
9	20.701	21.794	21.445	24.220
Sum	149 .085	171.832	151.473	169.169
Mean	21.298	24.547	21.639	24.167

Table 14. Integrated activity per minute, typing at 25 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	4.920	5.764	5.257	6.986
2	5.188	5.265	7.320	4.770
3 & 4		No	results	
5	5.348	5.968	5.519	6.522
6	5.140	9.284	4.735	6.639
7	5.585	5.655	4.610	5.524
8	5.913	5.572	5.064	5.795
9	5.175	5.448	5.361	6.055
Sum	37.269	42.956	37.866	42.291
Mean	5.324	6.137	5.409	6.042

Table 15. Integrated muscle activity to type whole passage at 30 words per minute. Subjects using Electric typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	18.970	20.498	18.758	25.678
2	17.959	18.263	26.100	16.402
3	20.231	17.976	18.775	19.371
4	18.944	No result	19.453	No result
5	18.582	20.137	18.072	21.545
6	17.799	31.390	16.263	23.226
7	19.085	19.288	15.887	18.704
8	20.402	18.231	17.282	20.304
9	18.385	19.177	18.941	21.571
Sum	170.357	164.960	169.531	166.801
Mean	18.928	20.620	18.837	20.850

Table 16. Integrated activity per minute, typing at 30 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	5.691	6.149	5.627	7.703
2	5.387	5.478	7.830	4.920
3	6.069	5.392	5.632	5.811
4	5.683	No result	5.835	No result
5	5.574	6.039	5.421	6.463
6	5.339	9.417	4.878	6.967
7	5.725	5.786	4.766	5.611
8	6.120	5.469	5.186	6.091
9	5.515	5.753	5.682	6.471
Sum	51.103	49.483	50.857	50.037
Mean	5.678	6.185	5.651	6.255

Table 17. Integrated activity to type whole passage at 40 words per minute. Subjects using Electric typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	13.504	16.652	14.300	19.067
2	14.003	14.058	19.640	12.574
3	16.009	14.017	14.677	15.291
4	15.371	No result	15.106	No result
5	13.832	15.881	13.931	16.838
6	13.613	24.587	12.348	17.391
7	14.822	14.767	12.167	15.333
8	15.627	14.955	13.243	15.740
9	13.992	14.574	14.467	16.608
Sum	130.773	129.491	129.879	128.842
Mean	14.530	16.186	14.431	16.105

Table 18. Integrated activity per minute, when typing at 40 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	5.401	6.660	5.720	7.626
2	5.601	5.623	7.856	5.029
3	5.870	6.116	6.403	5.606
4	6.148	No result	6.042	No result
5	5.532	6.352	55.572	6.735
6	5.445	9.834	4.939	6.956
7	5.928	5.906	4.866	6.133
8	6.250	5.982	5.297	6.296
9	5.596	5.829	5.786	6.643
Sum	51.771	52.302	52.481	51.024
Mean	5.752	6.538	5.831	6.378

Table 19. Integrated muscle activity to type whole passage at 50 words per minute. Subjects using Electric typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	11.015	12.928	11.549	15.637
2	12.487	11.878	17.013	10.478
3	13.243	11.570	12.323	13.631
4	11.981	No result	12.597	No result
5	12.404	13.731	11.311	15.297
6	11.236	19.727	10.046	15.113
7	9.611	11.544	11.816	11.932
8	12.413	11.862	10.753	12.582
9	12.287	12.132	12.489	14.107
Sum	106.677	105.372	109.897	108.777
Mean	11.853	13.171	12.211	13.597

Table 20. Integrated activity per minute, typing at 50 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	5.507	6.464	5.774	7.818
2	6.243	5.939	8.506	5.239
3	6.621	5.785	6.161	6.815
4	5.990	No result	6.298	No result
5	6.202	6.865	5.655	7.648
6	5.618	9.863	5.023	7.556
7	5.908	5.966	4.805	5.772
8	6.206	5.931	5.376	6.291
9	6.143	6.066	6.244	7.053
Sum	54.438	52.879	53.842	54.192
Mean	6.048	6.610	5.982	6.774

Table 21. Integrated muscle activity to type passage at 60 words per minute. Subjects using Electric typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	8.878	11.447	9.735	13.025
2	9.873	9.366	13.478	8.265
3	10.527	9.194	9.577	11.102
4	9.703	No result	10.500	No result
5	10.185	11.610	9.160	12.443
6	8.915	16.219	7.967	11.960
7	10.294	9.940	8.077	9.491
8	10.132	9.830	8.567	10.514
9	9.484	9.838	9.613	11.179
Sum	88.091	87.444	86.676	87.979
Mean	9.788	10.930	9.631	10.997

Table 22. Integrated activity per minute, typing at 60 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	5.386	6.868	5.841	7.815
2	5.923	5.619	8.086	4.959
3	6.316	5.516	5.746	6.661
4	5.821	No result	6.300	No result
5	6.108	6.966	5.496	7.465
6	5.349	9.731	4.780	7.176
7	6.176	5.964	4.846	5.694
8	6.079	5.898	5.141	6.308
9	5.690	5.902	5.767	6.707
Sum	52.848	52.464	52.003	52.785
Mean	5.872	6.551	5.778	6.598

Table 23. Integrated muscle activity to type passage at 80 words per minute. Subjects using Electric typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	8.046	10.392	8.566	11.374
2	8.685	7.984	11.578	7.042
3	9.563	8.008	8.366	8.945
4		No	results	
5	8.607	10.268	8.064	11.111
6	7.695	14.809	6.826	10.151
7	8.663	8.415	6.949	8.081
8	8.980	8.684	7.494	9.397
9	9.221	8.938	8.586	11.280
Sum	69.460	77.548	66.429	77.381
Mean	8.683	9.694	8.304	9.673

Table 24. Integrated activity per minute, typing at 80 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	6.436	8.313	6.852	9.099
2	6.948	6.387	9.262	5.633
3	7.650	6.406	6.692	7.156
4		No	results	
5	6.885	8.208	6.451	8.888
6	6.156	11.184	5.461	8.121
7	8.663	8.415	6.949	8.081
8	7.184	6.947	5.995	7.517
9	7.376	7.190	6.868	9.024
Sum	57.298	63.050	54.530	63.519
Mean	7.162	7.881	6.817	7.939

Table 25. Integrated muscle activity to type passage at 100 words per minute. Subjects using Electric typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	7.167	8.181	7.425	9.765
2	6.943	6.563	9.153	5.892
3	7.568	6.316	6.825	6.846
4		No	results	
5	6.896	8.302	6.458	9.050
6	6.543	12.807	5.763	8.718
7	7.342	7.172	5.898	6.814
8	7.144	7.434	6.018	7.382
9	7.171	7.243	7.038	8.267
Sum	56.774	64.018	54.578	62.734
Mean	7.097	8.002	6.822	7.842

Table 26. Integrated activity per minute, typing at 100 words per minute.

Table as above since typing of passage at 100 words per minute took one minute only for completion.

Table 27. Integrated muscle activity to type passage at 25 words per minute. Subjects using Manual typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	23.997	21.486	31.574	19.071
2	21.853	21.563	18.746	21.368
3	17.291	No result	22.994	No result
4	24.894	21.348	22.228	25.115
5	21.717	20.588	17.031	20.809
6	No results		20.712	31.459
Sum	109.752	84.985	133.285	117.822
Mean	21.950	21.246	22.214	23.564

Table 28. Integrated activity per minute, typing at 25 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	5.999	5.371	7.893	4.767
2	5.463	5.391	4.686	5.342
3	4.322	No result	5.748	No result
4	6.223	5.337	5.557	6.278
5	5.429	5.147	4.258	5.202
6	No results		5.178	7.865
Sum	27.436	21.246	33.320	29.454
Mean	5.487	5.311	5.553	5.891

Table 29. Integrated muscle activity to type passage at 30 words per minute. Subjects using Manual typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	22.183	18.932	28.050	16.625
2	18.957	18.501	16.103	18.440
3	21.385	No result	20.222	No result
4	21.387	18.312	19.723	20.804
5	19.185	17.744	15.010	17.832
6	No result	No result	19.529	28.160
Sum	103.097	73.489	118.637	101.861
Mean	20.619	18.372	19.773	20.372

Table 30. Integrated activity per minute, typing at 30 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	6.654	5.679	8.415	4.987
2	5.687	5.550	4.831	5.532
3	6.415	No result	6.066	No result
4	6.516	5.493	5.916	6.241
5	5.755	5.323	4.503	5.349
6	No result	No result	5.856	8.448
Sum	30.927	22.045	35.587	30.557
Mean	6.185	5.511	5.931	6.111

Table 31. Integrated muscle activity to type passage at 40 words per minute. Subjects using Manual typewriter.

Subjects	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	17.101	14.915	21.619	13.084
2	15.189	14.700	12.879	14.457
3	18.407	No result	15.909	No result
4	16.767	14.293	15.698	16.209
5	14.294	14.073	11.928	14.012
6	No result	No result	14.051	21.919
Sum	81.758	57.981	92.084	79.681
Mean	16.351	14.495	15.347	15.936

Table 32. Integrated activity per minute, typing at 40 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	6.840	5.966	8.647	5.233
2	6.076	5.880	5.071	5.783
3	7.362	No result	6.363	No result
4	6.706	5.717	6.279	6.483
5	5.717	5.629	4.771	5.605
6	No result	No result	5.820	8.767
Sum	32.701	23.192	36.951	31.871
Mean	6.540	5.798	6.158	6.374

Table 33. Integrated muscle activity to type passage at 50 words per minute. Subjects using Manual typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	15.678	12.510	19.535	10.847
2	13.893	12.991	11.716	12.788
3	17.505	No result	13.151	No result
4	13.443	11.724	13.027	13.503
5	11.180	11.504	9.800	11.471
6	No result	No result	12.474	19.981
Sum	71.699	48.729	79.703	68.590
Mean	14.340	12.182	13.284	13.718

Table 34. Integrated activity per minute, typing at 50 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	7.839	6.255	9.767	5.423
2	6.946	6.495	5.858	6.394
3	8.752	No result	6.575	No result
4	6.721	5.862	6.513	6.751
5	5.590	5.752	4.900	5.735
6	No result	No result	6.237	9.991
Sum	35.848	24.364	39.850	34.294
Mean	7.169	6.091	6.642	6.859

Table 35. Integrated activity to type passage at 60 words per minute. Subjects using Manual typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	12.581	9.881	15.389	8.604
2	10.899	9.932	8.556	9.639
3	12.824	No result	11.342	No result
4	11.885	9.658	10.843	10.989
5	10.618	9.652	8.142	9.423
6	No result	No result	9.822	16.221
Sum	58.807	39.123	64.094	54.876
Mean	11.761	9.781	10.682	10.975

Table 36. Integrated activity per minute, typing at 60 words per minute.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	7.548	5.928	9.233	5.162
2	6.539	5.959	5.134	5.783
3	7.694	No result	6.805	No result
4	7.131	5.794	6.505	6.593
5	6.371	5.791	4.885	5.654
6	No result	No result	5.893	9.732
Sum	35.283	23.472	38.455	32.924
Mean	7.056	5.868	6.409	6.585

Table 37. Integrated activity to type passage at 80 words per minute. Subjects using Manual typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	10.492	8.494	13.266	7.391
2		No	results	
3	10.615	No result	8.281	No result
4	10.615	8.364	9.441	9.818
5		No	results	
6	No result	No result	8.047	15.116
Sum	31.522	16.858	39.035	32.325
Mean	10.507	8.429	9.759	10.775

Table 38. Integrated activity per minute, typing at 80 words per minute.

Subject	R.F.Flxor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	8.393	6.795	10.612	5.912
2		No	results	
3	8.492	No result	6.624	No result
4	8.332	6.691	7.552	7.854
5		No	results	
6	No result	No result	6.438	12.088
Sum	25.217	13.486	31.226	25.854
Mean	8.406	6.743	7.806	8.618

Table 39. Integrated activity to type passage at 100 words per minute. Subjects using Manual typewriter.

Subject	R.F.Flexor	R.F.Extensor	L.F.Flexor	L.F.Extensor
1	8.493	6.779	10.270	5.846
2	7.429	6.965	6.338	6.831
3	10.126	No result	6.935	No result
4	8.284	6.577	7.399	7.557
5	7.374	6.806	5.792	6.620
6	No result	No result	6.132	11.336
Sum	41.706	27.127	42.366	38.190
Mean	8.341	6.782	7.144	7.538

Table 40. Integrated activity per minute, typing at 100 words per minute.

Table as above since typing of passage at 100 words per minute took one minute only for completion.

D. Discussion of Results.

The results are presented in Tables 13 to 40. All the results have been presented to show certain general features which will be discussed below.

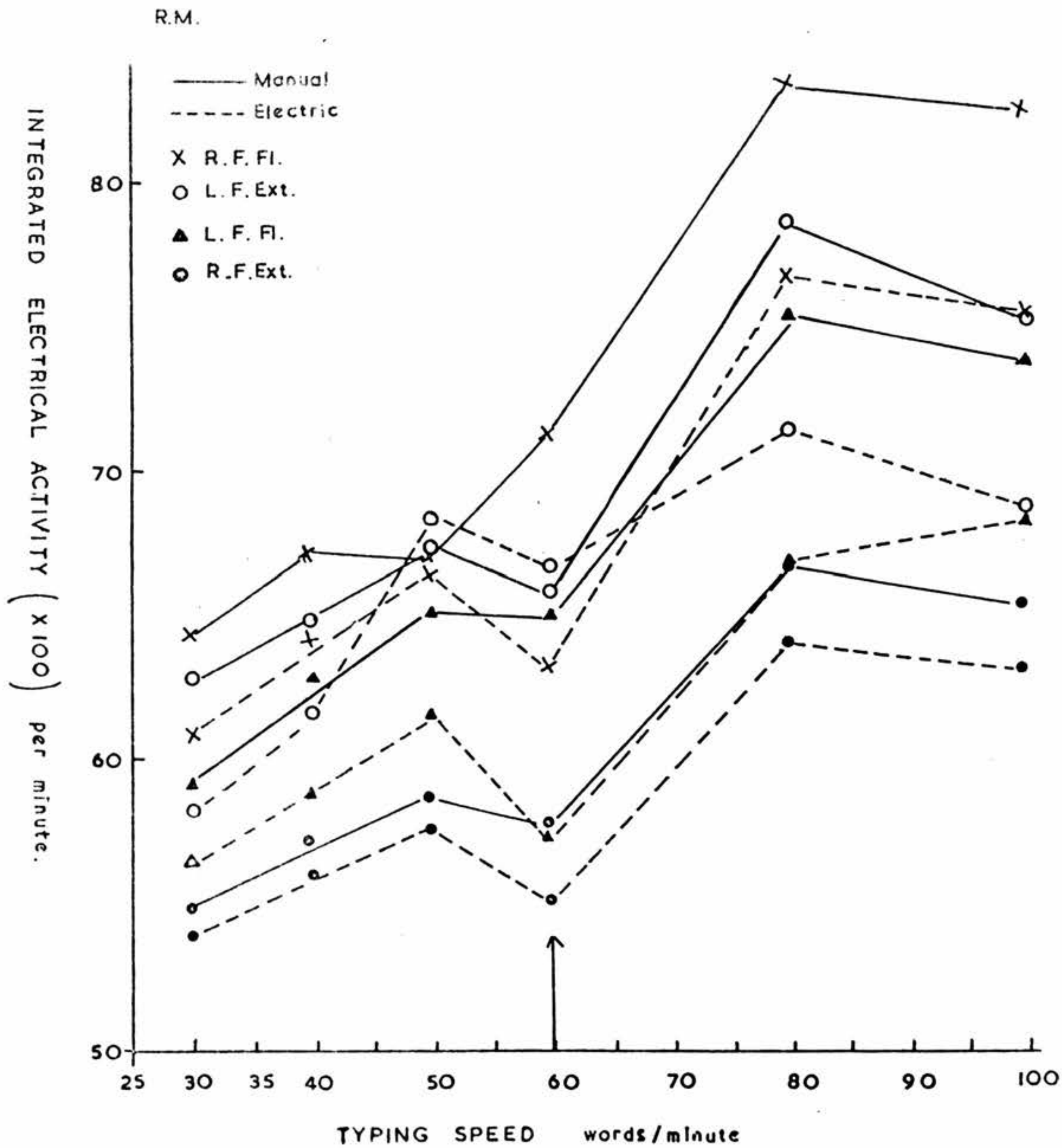
Figure 26 shows the results obtained from one subject who used both the manual and electric typewriter to type the passage at the different typing speeds. The muscle activity is recorded from the left and right forearm extensors and flexors of the wrist. From Figure 26 it can be seen that the integrated muscle activity per minute in all four muscles tends to increase linearly with typing speed, with the value from 30 to 80 words per minute lying on a straight line, for all four muscles, and with the typist using both machines.

The value of the integrated activity at 60 words per minute, however, lies well off the line, with the actual value lying well below what might be expected at this typing speed. This was observed for almost all of the typists who took part in the experiment, see Tables 13 to 40 and Figure 26 is a typical graph for all subjects. The dipping of the line at 60 words per minute will be discussed more fully later.

From the graph it can also be seen that the values of the integrated potential at 100 words per minute also lies off a line passing through the points at 30, 40, 50 and 80 words per minute, but the most probable explanation for this is that

<u>FIGURE 26</u>. Shows the relation between the dictation speed and the integrated muscle activity <u>per minute</u> recorded from subject R.M. who used both the electric and manual typewriters. This graph is typical in form for all of the subject.

Ordinate	Integrator pulse count recorded per minute.
Abscissa	Dictation speed in words per minute.



R.M.
Manual
Electric
X R.F.Fl.
O L.F.Ext.
▲ L.F.Fl.
o R.F.Ext.
INTEGRATED ELECTRICAL ACTIVITY (X 100) per minute.
80
70
60
50
25
30
35
40
50
60
70
80
90
100
TYPING SPEED words/minute

the typist was not able to type the whole passage at this speed. This was the general rule with all the subjects used; they all performed reasonably successfully when typing at 80 words per minute but at 100 words per minute none were able to complete the passage, and hence it is not a true result but has been included for the sake of completeness, but can be ignored as a false result.

Figure 27 shows the graph obtained when the mean value of the integrated muscle activity results from nine subjects using the electric typewriter are plotted against the typing speed. Again the integrated muscle activity is per minute, where the total muscle activity to type the passage has been divided by the time taken to give the activity per minute at the different speeds.

Figure 28 shows the mean of the results obtained with the six subjects using the manual machine.

If we ignore the mean value of the integrated E.M.G. per minute at the speed of 100 words per minute, for the reasons given above, then it is apparent from the graphs shown that for each of the four muscle groups investigated, and for six subjects using the manual machine, and nine subjects using the electric machine, the muscle activity increases in a linear fashion with increase in typing speed, save for the dramatic drop in the integrated E.M.G. recorded

FIGURE 27. Shows the mean value of the integrated muscle activity per minute recorded from the extensors and flexors of all nine subjects using the electric typewriter plotted against the dictation speed in words per minute.

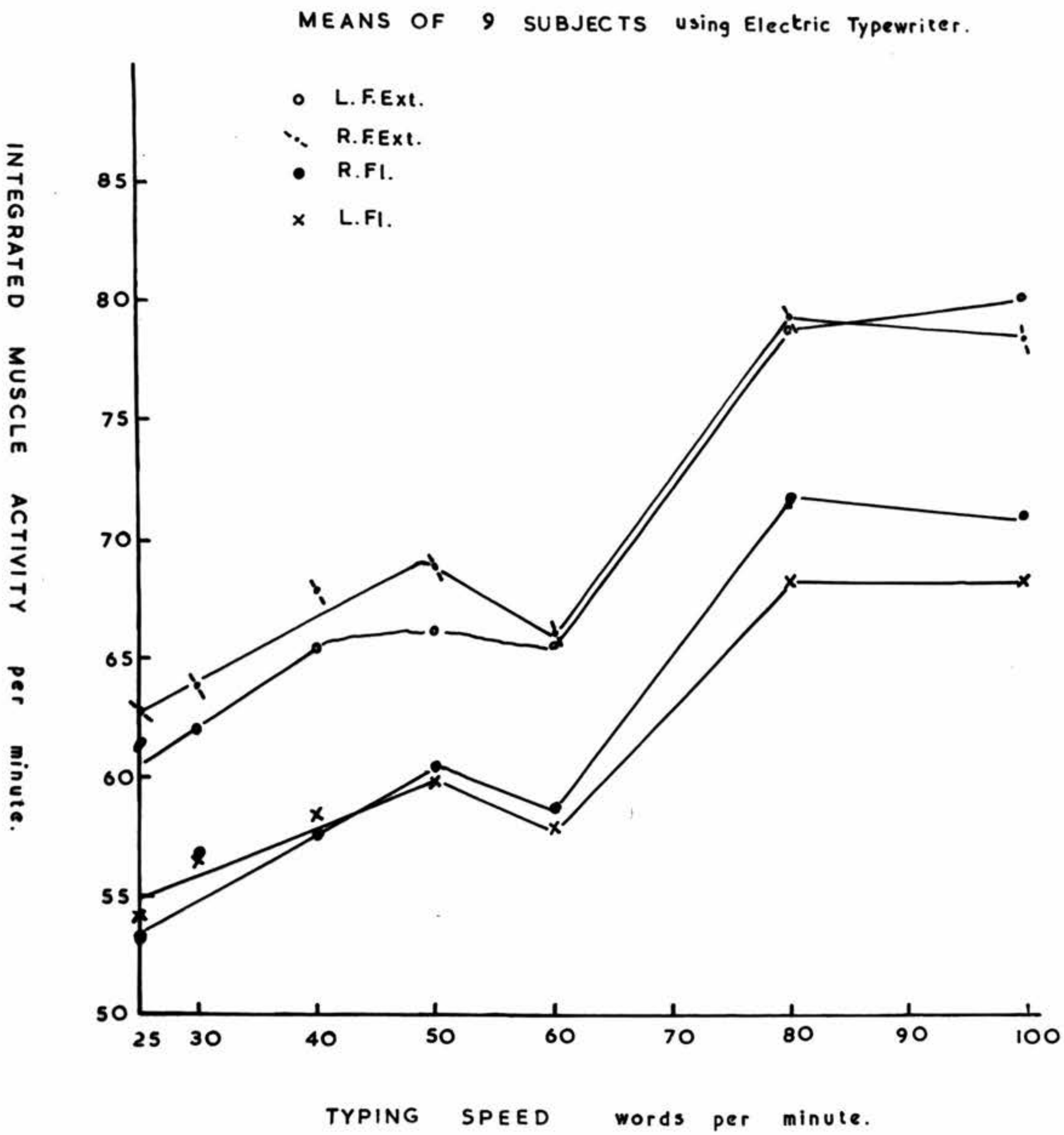
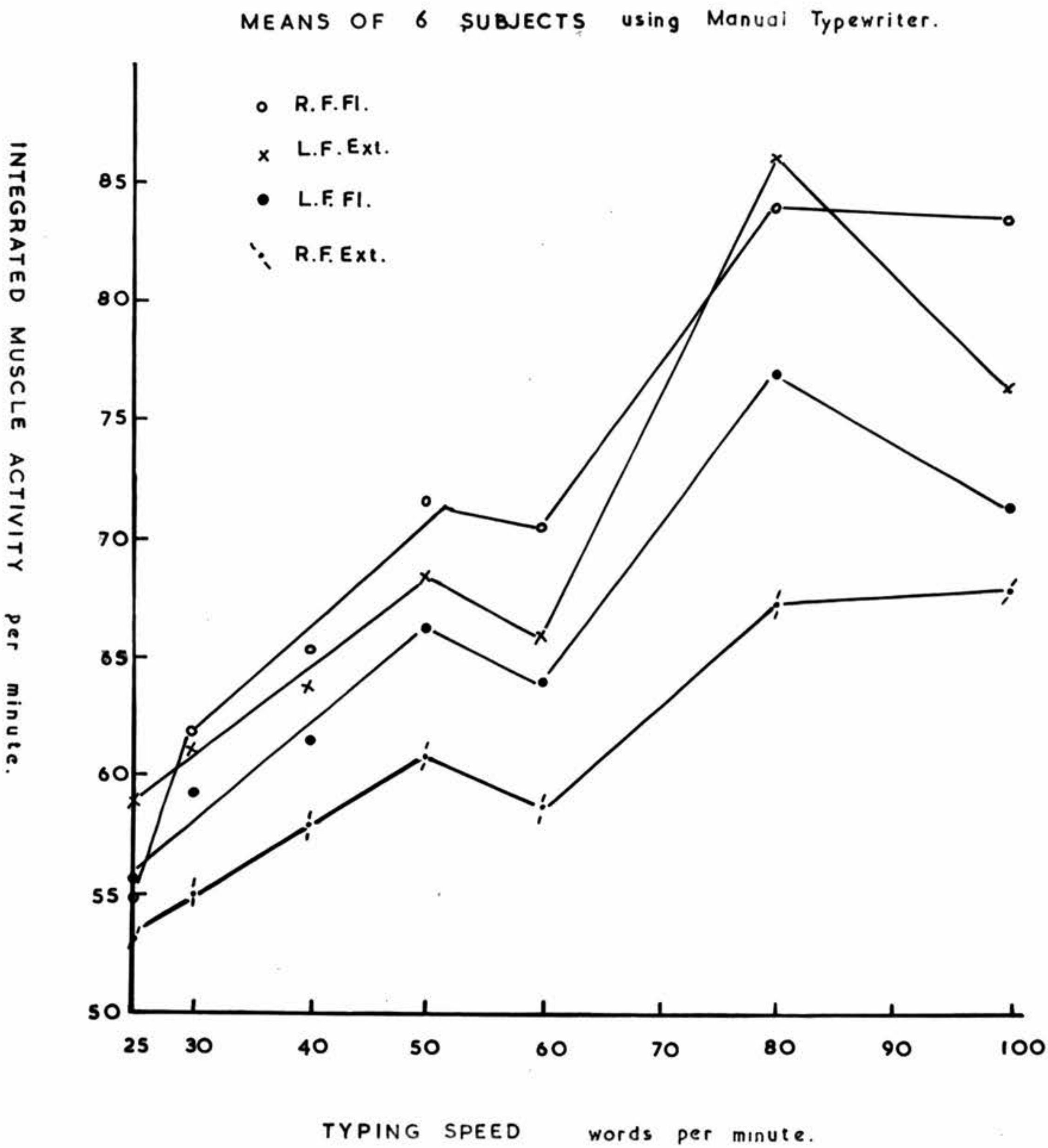

MEANS OF 9 SUBJECTS using Electric Typewriter.
o L. F. Ext.
R. F. Ext.
● R. Fl.
× L. Fl.
INTEGRATED MUSCLE ACTIVITY per minute.
85
80
75
70
65
60
55
50
25
30
40
50
60
70
80
90
100
TYPING SPEED words per minute.

FIGURE 28. Shows the mean value of the integrated muscle activity per minute recorded from the extensors and flexors of all six subjects using the manual typewriter plotted against the dictation speed in words per minute.


MEANS OF 6 SUBJECTS using Manual Typewriter.
R.F.Fl.
L.F.Ext.
L.F.Fl.
R.F.Ext.
INTEGRATED MUSCLE ACTIVITY per minute.
85
80
75
70
65
60
55
50
25
30
40
50
60
70
80
90
100
TYPING SPEED words per minute.

from almost all subjects at the speed of 60 words per minute. Since the force results in Section A show that the force exerted on the keys does not change in any significant fashion with changes in typing speed, these results obtained with typists working at normal typing tasks parallel the results obtained by others when investigating the velocity of contraction integrated E.M.G., and energy expenditure relationships.

One of the rather unexpected results obtained in this study is the drop in muscle activity in all four muscle groups and with almost all subjects at the typing speed of 60 words per minute. From the tables showing the integrated activity per minute at the various typing speeds, it can be seen that the value of the integrated E.M.G. at the typing speed of 60 words per minute is often less than that obtained when typing at 50 or even 40 words per minute. The graphs plotted in Figures 26,27,28 show how a linear relationship tends to exist between typing speed and the integrated electromyogram with a straight line passing through the points at speeds of 30, 40, 50, and 80 words per minute, but how the integrated electromyogram of all four muscles at 60 words per minute lies well below this straight line.

There are a few explanations which might account for this drop in the integrated E.M.G. at this typing speed.

The first explanation which would account for the integrated E.M.G. being below an expected value could be that the twelve typists were skilled to work at about this rate, and had developed rhythmic patterns of working which functioned best at 60 words per minute, and gave the reduction in the E.M.G. Unfortunately this does not seem to be the case, since the girls were asked to give their estimated typing speed before they were selected as subjects, and though the majority (i.e. 8 of the 12 subjects) did quote 60 words per minute as being their typing speed when following dictation, two subjects quoted 80 words per minute and the other two working with manual machines quoted 50 words per minute.

A second reason which might be given for the drop in the integrated E.M.G. values at 60 words a minute for subjects using one particular type of machine might be dependent upon the workings of the machine, involving factors of key inertia, momentum, etc., which might make the machine easier to operate at this speed. However, this drop was observed with two quite different types of typewriter where the mode of operation, key pressures and so on are fundamentally different. This explanation must therefore be rejected.

The third explanation which perhaps is the most feasible is that the dynamic properties of the hand and wrist joint enable persons to work with less effort at this rate. A speed of 60 words per minute means that the typists are working at a rate of 5 strokes per second. Various authors have found that maximum tapping rates on keys come to values about the rate of 5 taps per second. Telford and Spangler (1935) carried out experiments with 26 pianists and 16 non-pianists to find the maximum rates at which they could tap on telegraph keys. They found that with exercises involving the use of different fingers, the following rates were obtained:

Test	Musicians	Non-musicians
Alternation of 5,4,3,2 fingers	5.56 taps/sec.	4.18 taps/sec.
Alternation of 1,4,5 fingers	5.07 taps/sec.	4.22 taps/sec.

Jackson (1953) found wrist and finger tapping rates in a group of twenty subjects, and found a mean wrist tapping rate of 6.02 taps per second and rates for fingers to be:

F1	F2	F3	F4	F5	
5.23	5.63	5.68	5.47	5.04	taps/sec.

with a mean all over rate for the wrist and fingers to be 5.51 Kvasov (1951) noted the rhythm at which his subjects flexed their fingers when asked to work at their preferred rhythm. He found this rhythm to be between 80 to 120 movements per minute or between 1.33 and 2 movements per second.

The rate of 5 strokes per second, corresponding to the typing speed of 60 words per minute where the drop in the integrated E.M.G. was found in the experiments described above, means that each hand must be tapping at rates of 2.5 strokes per second. From these results and others quoted above, I would suggest that the fingers and hands, due to their dynamic properties and the elastic properties of the joints etc., have some preferred frequency of working around the value of 2.5 movements per second. The values for the tapping rates found by various authors are multiples of this fundamental frequency of working.

Figures 29 and 30 show the mean integrated muscle activity recorded from the flexors and extensors to completely type the task of 100 words. From the graphs it can be seen that it is less costly in terms of muscle activity to type the task if the typists work at faster rates. Thus the total integrated activity required to complete the task decreases as typing speed increases through the speeds of 25 to 100 words per minute.

This would suggest that in light work situations, when a person has a given amount of work to perform then the work will be carried out more efficiently with regard to muscle activity if the work is performed at maximum rates of working.

FIGURE 29. Shows the mean of the total integrated muscle activity used to type the 100 word passage recorded from the nine subjects at the seven different typing speeds when using the electric machine.

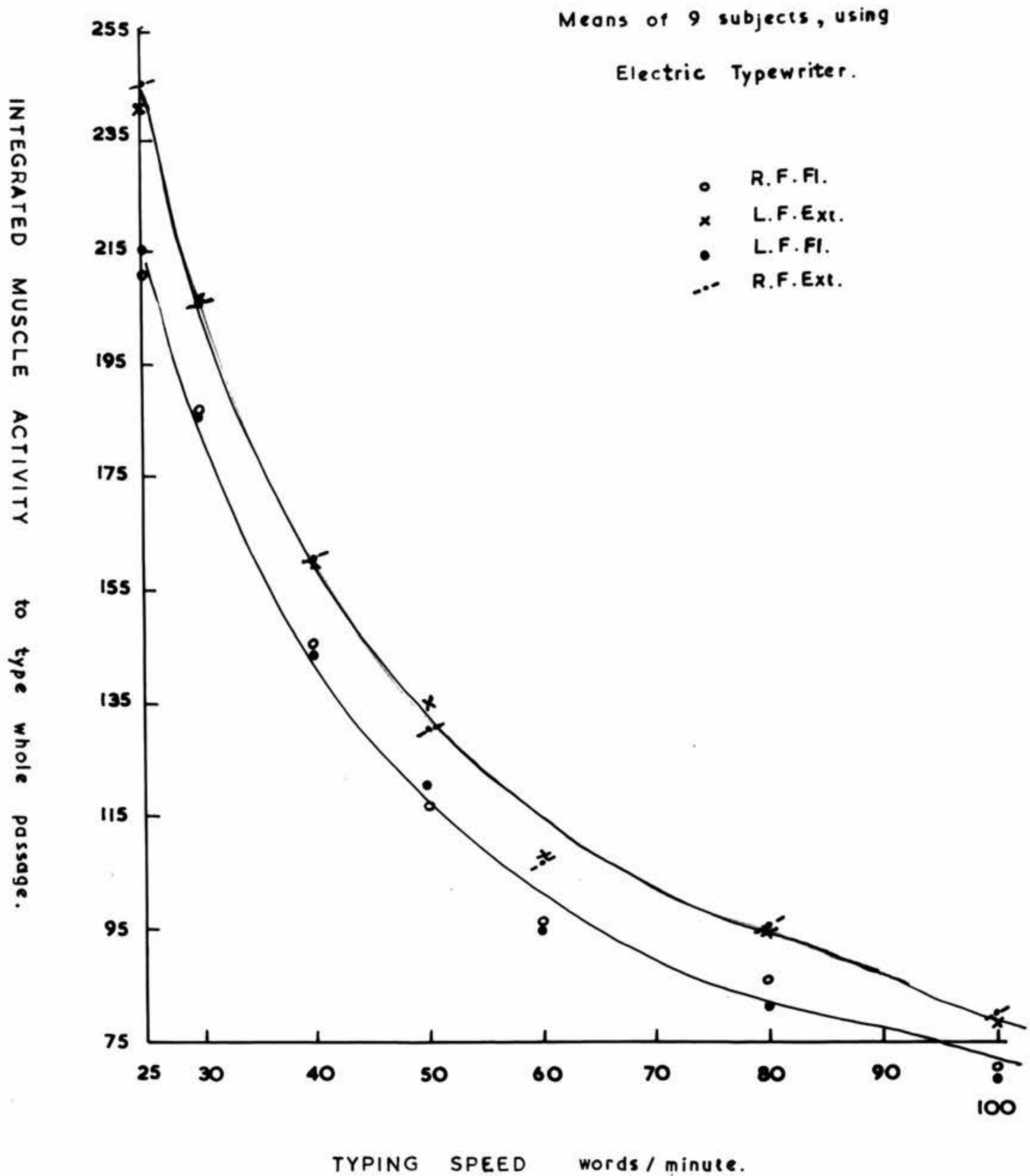
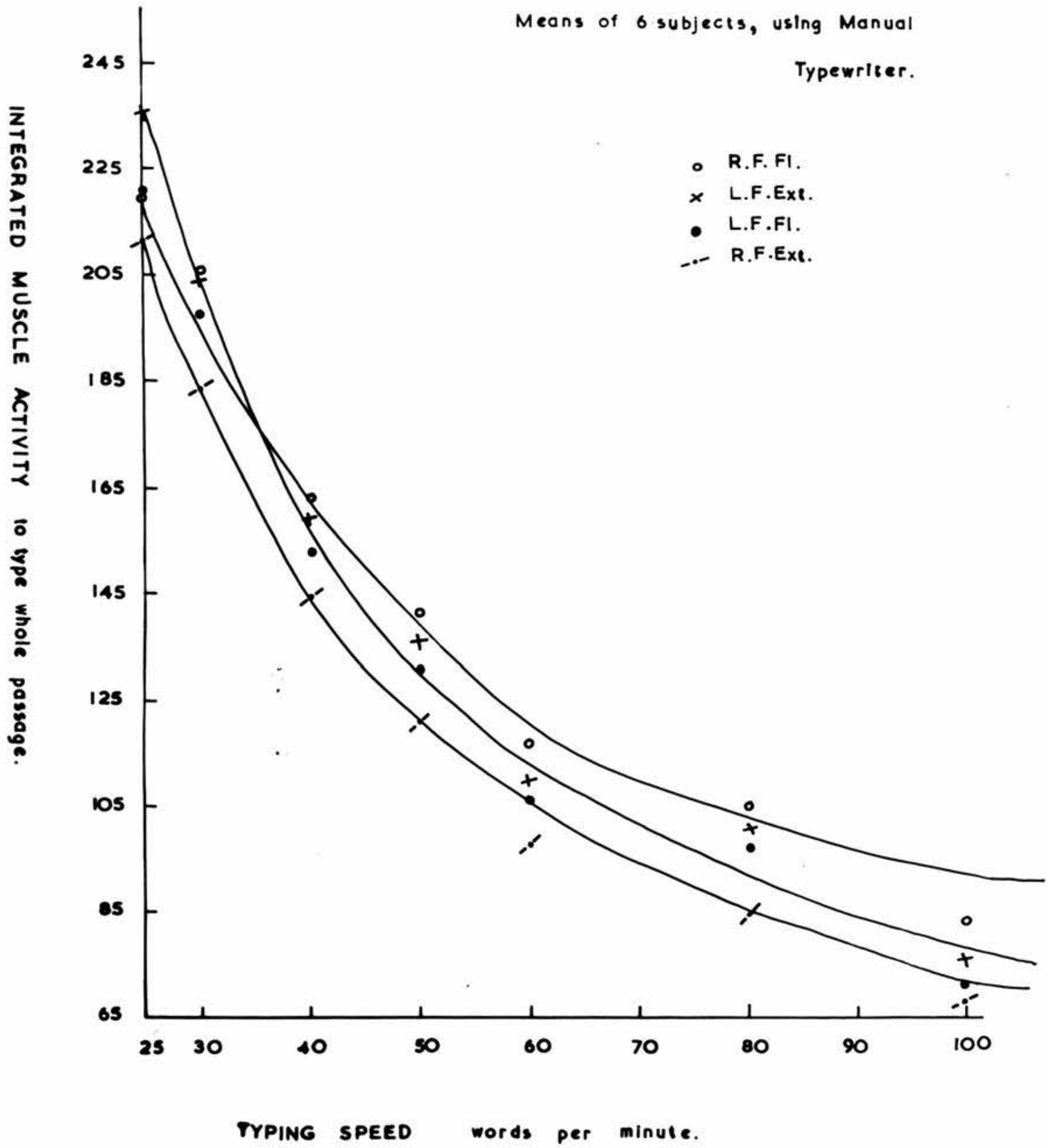

Means of 9 subjects, using
Electric Typewriter.
R.F.Fl.
L.F.Ext.
L.F.Fl.
R.F.Ext.
INTEGRATED MUSCLE ACTIVITY to type whole passage.
255
235
215
195
175
155
135
115
95
75
25
30
40
50
60
70
80
90
100
TYPING SPEED words / minute.

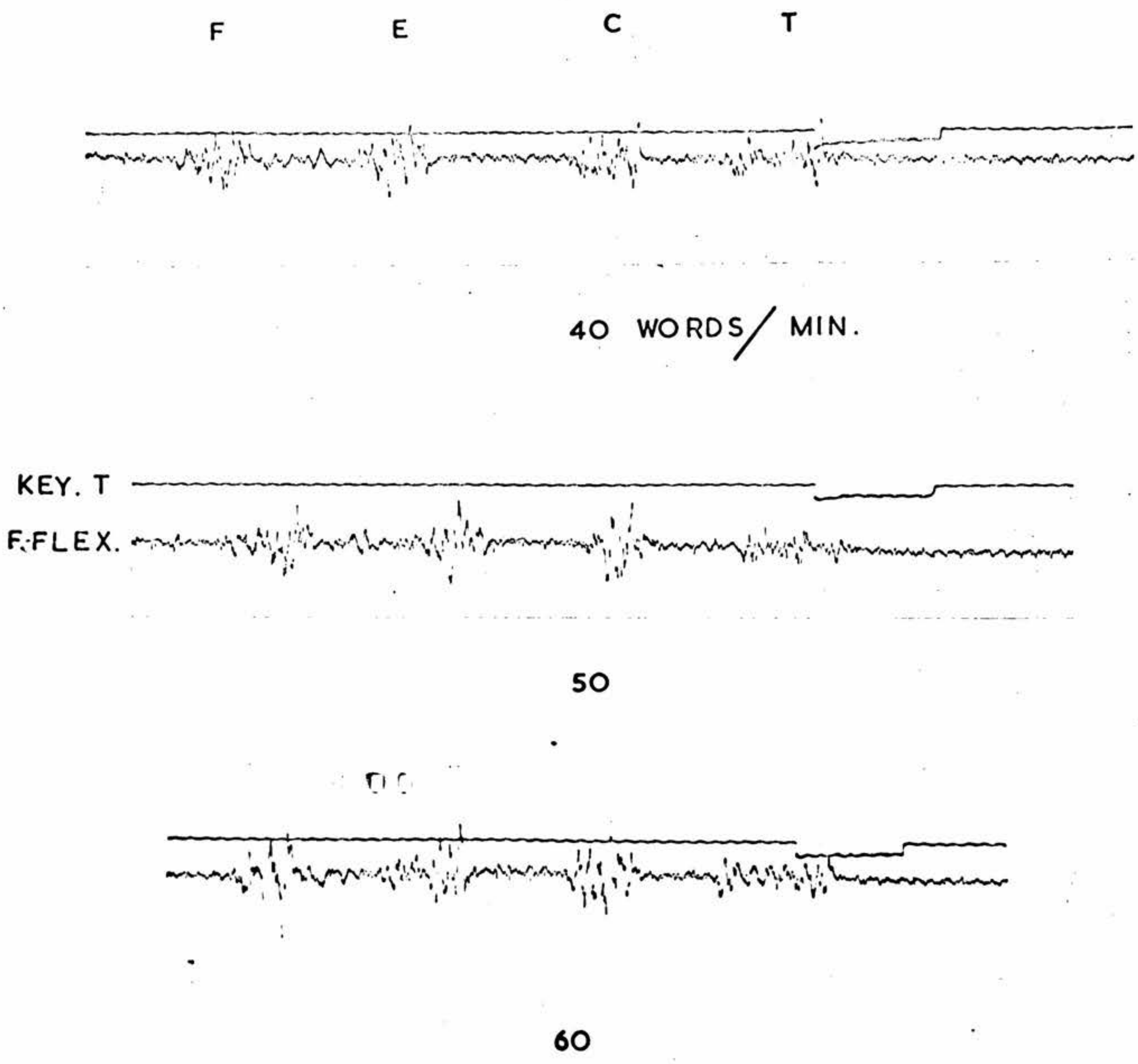
FIGURE 30. Shows the mean of the total integrated muscle activity to type the 100 word passage, recorded from the six subjects when using the manual machine at the seven different typing speeds.


Means of 6 subjects, using Manual
Typewriter.
o R.F. Fl.
x L.F. Ext.
● L.F. Fl.
-·- R.F. Ext.
INTEGRATED MUSCLE ACTIVITY to type whole passage.
245
225
205
185
165
145
125
105
85
65
25
30
40
50
60
70
80
90
100
TYPING SPEED words per minute.

A further experiment was carried out with five subjects, recording the right forearm flexor activity, when typing at speeds of 40, 50, 56, 60, 66, and 70 words per minute, on the Nagard oscilloscope to see if any further information relating to the drop in activity at 60 words per minute could be found from more detailed examination of the action potentials.

A typical result when the subject is typing at 40, 50 and 60 words a minute is shown in Figure 31. Also shown on the Nagard trace is a marker which is activated when the key T is touched. This experiment did show that the time which the fingers stay on a particular key does decrease as typing speed increases, but examination of the more detailed electromyogram could not show how the reduction in the E.M.G. occurred at the 60 words per minute typing speed.

FIGURE 31. Shows traces obtained using the Nagard Oscilloscope. The top trace shows a marker that is activated during the time a finger is touching the letter T. The lower trace shows the muscle action potentials recorded from the left forearm flexor. The letters being typed as the record was taken are shown at the head of the figure, and traces have been recorded at typing speeds of 40, 50 and 60 words per minute.



F
E
C
T
40 WORDS/ MIN.
KEY. T
F.FLEX.
50
60

CONCLUSIONS.

1. The force exerted on typewriter keys does not vary with changes in the typing speed, but remains at a constant value which is dependent upon the resistance offered by the keys.

2. The integrated E.M.G. per minute recorded from the extensors and flexors of the wrist tend to increase in a linear fashion with increases in typing speed, save for a drop from the straight line observed with all the subjects when working at a rate of 60 words per minute or 5 strokes per second.

3. This drop in the integrated E.M.G. from the expected value at a typing speed of 60 words per minute is thought to be due to dynamic properties of the hand and the wrist joint, giving a fundamental frequency of about 2.5 cycles per second as the natural frequency of the wrist joint.

4. In the typing task, the muscle activity required to perform a given task decreases as typing speed increases. Therefore typists must work more efficiently at higher typing speeds when muscle activity per unit of work is considered.

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