A STUDY OF ELECTROMYOGRAPHIC CHANGES ASSOCIATED WITH MENTAL WORK.

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Abstract.

Earlier research has shown that certain fluctuations are characteristic of mental work curves. Other investigations have revealed changes in muscular tension during mental work. The aim of the present experiment was to follow simultaneously these changes in output and in tension throughout a simple mental task. As the variations were likely to be rapid, recordings were made over short intervals of time.

Two methods were employed to modify and thereby illuminate the relationship discovered between the two variables: (1) Muscular tension was induced during work. (2) An attempt was made to change the mental set of the subjects towards the work.

Ten female subjects took part in the experiment and worked at addition sums under the three conditions:

1. N type when addition was performed at an easy steady speed "which could be kept up for ten minutes".
2. P type when addition was performed as above while a spring balance was pulled at half maximum effort.
3. M type when subjects worked at maximum speed.

The addition sums were of three lengths, 6, 11, and 21 figures per sum, and subjects added three sums of each length under each condition (27 sums in all). In order to prevent a possible slowing down due to the progressive increase in

the size of the addend, addition in pairs was employed. Subjects added aloud and each verbalization was recorded on a tape and a later check made for errors.

Electrodes were placed on the chin and the dorsal surface of the right forearm and leads taken to an electromyograph which recorded by "pen" on Teledeltos paper. The chin electrodes gave an indication of the moment of speaking and the arm electrodes a measure of tension in the forearm.

It was thus possible to correlate the speed of work, indicated by the distance between clusters of spikes on the chin record, and the level of muscular tension, indicated by the mean height of the waveform from the forearm during the period between the verbalizations. In this way variations in output and tension could be followed during the course of work.

It was found that a high negative correlation occurred between speed and tension under all three conditions. Starting and end spurts occurred over short time intervals in all sums in both time and tension curves. The longer sums led to slower work and tended to lead to more tension.

These results can be interpreted to support the hypothesis that tension facilitates work of this kind, a suggestion which is reinforced by the results from the induced tension conditions. Subjects worked more quickly under P conditions and became more tense under M conditions. Large individual differences were noted but not examined in detail.

The ways in which tension may facilitate mental processes and the relevance of this work to the peripheral theory of thought are briefly discussed.

Preface.

The origins of the motor theory of consciousness can be seen clearly revealed in the traditional approach to psychology of Wundt and Titchener. The problem for psychology then was to attempt to understand the nature of awareness by the analysis of the "stuff" of consciousness. By the introspective method Titchener had been led to recognize that consciousness was made up fundamentally of sensations, feelings and images being derived from them.

The Würzburg school could not agree. Imageless thought processes seemed to occur in their experimental work which was equally dependent on introspective evidence. They agreed with the Cornell group's insistence on the motor concomitants of thought, but denied that kinaesthetic sensations were the *sine qua non* of all mental activity. Thus ensued a long and fruitless controversy which did much to discredit the introspective method.

The pronouncements of the behaviourists, who identified thought with motor reaction, coupled with the publication of Washburn's book, "Movement and Mental Imagery", in which the first precise statement of the peripheral theory was put forward, did much to usher in more objective methods of recording motor reactions. Little direct experimentation was possible at the time (1916) with the crude measures available, and more precise attempts to test the theory had to await the advent of electrical amplifying techniques.

Two main types of approach proved possible:

(1) A search for cases in which the two phenomena (mental processes and muscular activity) were disjoined.

(2) A study of the co-variance of the two phenomena.

The first approach disturbs the normal state of the subject as it either removes or induces physical tension while changes in mental activity are recorded.

The second method investigates variations in muscular activity during mental work and attempts to correlate the two measures. This is not, of course, a crucial test of the peripheral theory as a high correlation could equally well be "overflow" from central processes, the muscular reaction being not the "cause" but the "effect". In any case the experimentation has suffered from a lack of precision, gross variations between work and rest have been noted, but the moment-to-moment correlation of tension and efficiency appears to have been ignored. This is unfortunate as much research has been done separately into mental work output and tension changes during work.

For example, Kraepelin demonstrated that certain changes in efficiemcy were characteristic of certain poitions of the work curve, a finding that has never seriously been doubted as it could easily be illustrated from everyday industrial experience. More recently David Katz appears to have shown the importance of both the spatial and temporal structure of a task as determinants of efficiency.

There is more doubt with regard to the fluctuations in tension during work, but some measure of agreement has been achieved.

There thus appears to be a need for an investigation which will take into account the complexity of the work curve, and which will seek to relate work efficiency with muscular tension during the course of work. This is the main purpose of the present experiment.

In the first four chapters an attempt is made to clarify the meaning of "tension", to compare the methods used to measure it, and to review a selection of the mass of literature on its rôle in mental work. The remaining three chapters are taken up with details of the experimental investigation.

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Chapter 1.

The Nature of Muscular Tension and its Measurement.

A characteristic of muscular tissue is its ability to exert tension between its ends. In the case of skeletal muscle these ends are attached through tendons to the bones which are articulated at the joints and act as a system of levers.

These facts about the function of muscular contraction were well known to the Greeks. Aristotle in his "De Incessu Animalium" analysed the act of flexion and its importance in locomotion. Later Galen taught that muscular contraction was brought about by the "animal spirits" which passed from the brain down the nerves to the muscles causing them to swell and contract longitudinally. This belief persisted until the 19th century and no further information about the mechanism of contraction was available until the discovery of "animal electricity". It is said that Galvani accidentally suspended frogs' legs by copper hooks from an iron balustrade and then noticed that they contracted spontaneously. His later experiments not only showed that muscular tissue could be excited by the potential resulting from the contact of two dissimilar metals, but that potential differences also existed in physiological tissues. This latter finding was not accepted for some years owing to the influence of Volta whose discovery of the battery led to a general acceptance of his views on animal electricity which were opposed to Galvani's, i.e. he did not accept the evidence for the existence of animal electricity although asserting that of dissimilar metals. In 1843 du Bois-Reymond observed that the current of a resting muscle diminished during tetanic stimulation; there was a "negative variation". By a series of experiments he proved that this "negative variation", later called an "action current", invariably accompanied tha contraction of muscles and the transmission of nerve impulses. These findings have served as a basis on which our present knowledge of the electrophysiological properties of muscle are founded. More recent work has analysed the electrical response much more closely into a "spike potential" and a succession of after-potentials which travel as a self-propagating electrical charge along the muscle or nerve fibre. It appears that between the onset of this electrical response and the beginning of the mechanical contraction of a muscle there intervenes a short latency period of approximately 1 msec. The wave of contraction then proceeds along the length of the muscle fibre slightly lagging the electrical events. As the junction between motor nerve fibres and muscle fibres lies near the middle of a muscle, the spike potentials and contraction waves pass "outwards" along the fibre in both directions simultaneously. According to Lloyd (1947) the transfer of excitation from the conductile mechanism is little understood, but it appears that the electrical current flow is a direct cause of activation of the contractile mechanism. It is not directly relevant to our purpose to consider these electrical events in any greater detail, but this short description may serve as a starting point from which to examine the techniques employed in recording the contractile condition of a muscle, its state of tension.

Before embarking on a description of these techniques it is necessary to clear up the confusion that has arisen in the past about the use of the word "tension". Strangely enough this word is but rarely found in the physiological literature. Instead the word "tonus" is more generally employed, but this term appears to have varied connotations. It was first used by Galen in his fourfold classification of movements. These were : (1) simple contraction, (2) lengthening, (3) passive movement, such as a limb dropping under its own weight, and (4) the maintenance of position, which must involve static contraction of the muscles involved. To this latter, he applied the word "tonus". This was then its original meaning, but it became generalized until A.H. Bennett in 1888 could define tonus as "that state of slight contraction which is the constant characteristic of healthy living muscle", and the existence or non-existence of this state became almost an article of faith for physiologists. Whether tonus was peripheral or central, whether it was reflex or not, and indeed whether it even existed, were all problems on which observers came to different conclusions. These contradictions continued to ensue until the functional significance of the mechanism became clearer.

The work of Magnus and de Kleijn (1912) on the postural mechanisms led to Sherrington's analysis in a paper of 1915 in which he showed that Bennett's "slight constant tension" is not always present in muscle. In the limbs it is most markedly developed in the extensor muscles. It is found in the masseter muscles of the jaw, the retractor muscles of the neck; in fact tonus is distributed in all the antigravity muscles. Its presence or absence in any particular group of muscles will depend on the rôle played by those muscles in the maintenance of an erect posture. In Sherrington's words:

> "Reflex tonus obtains in, and is confined to, those muscles which maintain the animal in an erect attitude. That it is so may be demonstrated by setting the decerebrate preparation on its feet; it is seen that the preparation stands. Thus this reflex tonicity, which when seen in a single isolated muscle prepared for the myograph, does not carry on the face of it any very obvious biological purpose, does carry a clear and unmistakable biological purpose when the phenomenon is followed in the musculature as a whole. The reflex tonus is postural contraction."
>
> (Sherrington, 1915)

And so the word regained its original meaning and the confusion reigning in the 19th century was cleared up once and for all. But a difficulty still remains. The word "tonus" as applied to skeletal muscle implies a peculiar sort of contraction, a particular kind of neuromuscular action. A distinction between tonic and phasic activity dates back at least to Johannes Müller. The tonic response was said to be slow and present in normal muscles at all times to some degree. The phasic response was said to be quicker and greater in intensity. Denny-Brown (1928) cast doubt on this distinction. He showed it was incorrect to assume that the red muscle fibres were responsible for the tonic contraction and the white components responsible for the phasic response. It was also incorrect to suppose that the sympathetic nervous innervation, with which skeletal muscle is supplied, was responsible for the tonic state. And when Fulton and Liddell's electromyographic studies at about the same time (1925) are taken into account, the only conclusion seems to be that we are dealing not with two different contractile mechanisms but with gradations in degree of a single one. Only mechanically are there different kinds of muscular contraction. Limbs can move quickly or slowly, or lock rigidly in place, or posture can be shifted.

But the underlying mechanism of muscular contraction remains the same. The moderate sustained contraction, known as "tonus", cannot be distinguished from the muscular tension found in a voluntary movement. Muscles are to a varying degree relaxed or tense at any particular moment. The amount of tension can be measured and expressed in quantitative terms. And from the psychologist's point of view little seems to be gained by retaining the word "tonus". Throughout this thesis I shall instead, following Cobb and Wolff's suggestion (1932), use the more neutral term "tension" to denote any contraction of a muscle, for whatever purpose recorded by any means.

Measurement Techniques.

In psychological studies of muscular tension interest lies less in the nature of the electrical events accompanying contraction than in the location and extent of such contractions in the intact organism. Measurement techniques are required which will give a reliable indication of such activity in the main muscle groups of the body. Several types of apparatus are now available to this end, but as results are to a great extent dependent on the particular device employed, it is necessary to determine what each type measures before results are comparable. In this field advances in knowledge have been so dependent on advances in technique that any attempt to survey the literature on the relation between muscular work and mental work would be misleading without a parallel account of the development of measuring apparatus. For, as Dunlap has remarked, motor phenomena have been discovered during more and more psychological processes as instrumentation has become more refined.

R.C. Davis (1942) in a review of methods of measuring muscular tension classifies techniques into six major groups:

> "(1) those applying external forces mechanically and recording resistance to movement offered by limb or muscle, (2) those recording slight movements of parts of the body, (3) those eliciting reflex responses, (4) those requiring the subject to perform some voluntary response, (5) those recording electrical properties of the skin, and (6) those recording the electrical properties of muscles." (page 331)

It is convenient to classify these six methods in turn. Methods 3 and 5 may be called indirect as they depend upon a pre-established correlation between the measure and muscular tension estimated independently. The remaining four methods are more direct.

Let us consider the indirect methods first.

Indirect Methods.

(1) Devices for recording reflexes.

The strength of the knee jerk and other tendon reflexes, and the eye blink reflex have served earlier investigators as indices of muscular tension.

Lombard had noted in 1887 that the knee jerk was reduced by about one half during sleep, and at about the same date Mitchell and Lewis had come to the conclusion that "the responsive jerk brought about by striking a stretched tendon is the most refined measure we possess of deciding as to the tone of muscle."

But Jacobson (1929) appears to have been the first to trace the diminution of the knee jerk during progressive relaxation. In none of these cases nor in several others appearing a little later in the literature was any separate measure of the tensile state of the muscles employed, although it was reasonable to suppose a certain parallelism. Courts in 1939 carried out a direct quantitative investigation into the relationship and found a positive correlation between the amplitude of the knee jerk (measured mechanically in terms of thickening of the quadriceps tendon) and the amount of pressure exerted on a dynamometer.

With regard to the eye blink reflex, Freeman (1938) reported that it was facilitated by tension induced in the lower limbs, whereas Courts (1940) found no facilitation with induced hand tension - the blinks being elicited in both experiments by a puff of air. Helen Peak (1942) suggested that in the latter case the responses may have been maximal to begin with, or the subjects were not relaxed, or time relations between reaching the necessary tension level and the occurrence of the air puff may be important. So any relationship that may exist has yet to be conclusively demonstrated; there has been little attempt to control the many variables that probably enter into the experimental situation.

There are three main criticisms of the use of tendon or eye blink reflexes as indices of muscular tension :
(1) The experimental work has shown that induced tension affects the size of the reflex, but it has not shown that the muscular tension is the sole possible cause of such an increase. An experiment is still needed in which an independent assessment of muscular tension can be obtained, measured by a better technique than that of Courts, while the size of the tendon jerk or eye blink is simultaneously

recorded.

(2) This method can supply no evidence about the location of the tension. It would seem likely that particular patterns of tension would interact with specific reflex arcs, and that therefore the reflex method probably serves as an indicator of localized tension, but whether this is true or not is not known.

(3) Interference with the subject must occur in eliciting reflexes. A blow on the patellar tendon every few minutes or a puff of air on the eyelid is not conducive to the maintenance of a psychological set, and it is impossible to say how far results may be artefacts of the experimental method.

The blink rate has been used as an indicator of generalized muscular tension and there seems something to be said in its favour. Interference with the subject is at a minimum and he need not be aware that this response is being studied. Unfortunately the evidence for its association with muscular tension is only presumptive; there has been no simultaneous recording. Changes in the blink rate have been found to accompany (i) changes in the difficulty of a task (e.g. Clites, 1935; Drew, 1951), (ii) changes in the illumination and glare during visual work (Luckiesh and Moss, 1942). The argument runs that as changes in muscular tension have been found to accompany similar conditions, the blink rate could serve as an indicator. Also, considered neurophysiologically, the motor representation of the eyelid is bordered on one side by the facial and tongue muscle centres and on the other by the huge representation for the hand (Penfield and Rasmussen, 1950), and it is quite likely that the blink response would be facilitated by activity in these neighbouring motor areas. The blink rate therefore could be an indicator of activity in these regions. However, contradictory results on the effect of prolonged visual work have been reported by Carmichael and Dearborn (1947) and Brozek et al (1950) who found no trends in the blink rate of their subjects. The discrepancies may partly be due to differences in experimental method. According to Wood and Bitterman (1950) the blink rate remains constant if the subject is aware that it is being recorded.

It would seem dangerous to accept the relationship on this evidence, and at present the blink rate cannot be seriously entertained as a valid measure of muscular tension.

(2) Devices for recording the electrical properties of the skin.

The advisability of using the galvanic skin response to serve as a measure of muscular tension is doubtful at the present time. Sidis (1910) considered the G.S.R. originated in the muscles and was therefore a direct measure of muscular action. It is now known that the G.S.R. is a quite distinct phenomenon dependent on the activity of the sweat glands. However, there is evidence from several sources that a negative correlation exists between skin resistance and muscular tension. White (1930), Wenger and Irwin (1936), and Freeman and Simpson (1938) have all induced three degrees of tension in their subjects, (i) generalized muscular contraction, (ii) localized muscular contraction, (iii) small tensions due to mental work, and found skin resistance varied inversely. It is possible, as Darrow (1932) suggests, that palmar sweating is an accessory to the grasping reflex (being controlled by the same brain area) and therefore might be a concomitant of tension in those muscles at least.

Once again the evidence is derived from induced tension experiments, which leave the same loophole as before, i.e. other factors besides muscular tension may produce changes in the G.S.R. As Davis (1942) has said, "Interesting for its own sake, skin resistance can be taken as an indication of muscular tension only with much caution".(p.336).

Direct Methods.

(1) The application of external forces.

McKinley and Berkwitz (1938) in their attempt to quantify muscle tonus appear to have been the first to use apparatus which measured the resistance of arm muscles to passive stretch. The subject's forearm was placed on a rotating arm-rest which was pivoted on a vertical axis so that it could move freely in the horizontal plane.

The release of a weight drove the arm-rest outwards or inwards, the angular distance and the velocity of the moving forearm being recorded on a smoked drum. It was thus possible to compare the acceleration of the arm-rest with and without the subject's arm attached to it. The deceleration effect due to the torque of the resisting muscles was taken as an index of muscle tension. This apparatus was used (with minor differences) by Allport and Vernon (1933) in their work on expressive movement. It was at the time one of the few methods available to measure tension while the subjects were inactive, and fairly satisfactory measurements of elbow flexor and extensor tension were obtained.

A refinement of this type of procedure was developed by Freeman (1930a). In this case a weight rests on the patellar tendon of the subject. When the quadriceps muscle is tense the tendon is only slightly depressed by the weight and the amount of depression can be used as an indication of the amount of tension, if suitably magnified by an optical lever.

There are several drawbacks to these procedures besides the obvious lack of sensitivity:

(1) In the case of the McKinley-Berkwitz apparatus we are not obtaining a measure of tension in any particular muscle group but rather an overall measure of tension in certain muscles and their antagonists, presumably the

algebraic sum of their tensions.

(2) The measurement entails gross interference with the subject's normal posture and must have proved distracting. It would also be extremely difficult for the subject to refrain from making voluntary movements.

(2) <u>Devices for recording slight movements and voluntary responses</u>+.

Golla and Antonovitch (1929) used a mechanical device to record movement of the foot. As the anterior tibialis muscle contracted, the foot rose, and it was possible to obtain an indication of the tenseness of this muscle during mental work.

In this study the movement could take place freely with little interference from the apparatus. Other workers have used pneumatic bulbs which offer resistance to the bodily movement involved, i.e. Duffy (1932) had her subjects hold in their disengaged hand a rubber bulb connected via a tambour to a kymograph, while with the other hand they responded to a reaction time experiment.

Luria (1932) has pointed out that results would be more meaningful if the tension was relevant to the task at hand, i.e. tension recorded in the writing hand during writing is preferable to a measure of tension recorded in the same way during mental activity in which the hand

+These methods have been classed together as the techniques employed are similar and the same considerations apply to both methods.

is not directly involved. Luria's own techniques are well-known. During a word-association test the subject had to respond by pressing a pneumatic bulb with the fingers at the same time as he responded with a word. As the fingers rested on the bulb throughout the experiment, a recording of the tremor of the hand could be obtained. The other hand rested on a similar bulb but was not required to make a response. Interesting tracings can be obtained in this way and the technique is still used occasionally, but it is difficult to know what measure is being obtained. As in the method in which external forces are applied, the measurement obtained is a gross measure of flexor and antagonist muscle groups. For example, in Golla and Antonovitch's technique there could be extreme tension in the calf and anterior tibialis muscle and the foot would not rise at all, these antagonistic muscles balancing one another. It is not strictly possible to consider movement equivalent to tension, which is the rationale behind these methods.

(3) Electrical properties of muscle.

Methods of recording the electrical activity of muscle are the most direct available. There need be little interference with the subject, either gross movements or isometric contractions can be recorded, and a record can be obtained of any degree of precision required, i.e.

activity of single muscles or even of single motor units can be recorded.

The earliest observations of the electrical response of muscle were made with the astatic needle galvanometer. When Lippmann produced the capillary electrometer in 1872 the accuracy of observation of action currents was considerably enhanced. Einthoven's string galvanometer (1901) led to still further accuracy in recording, but suffered, though less than earlier instruments, from too much inertia. An ideal electrical recording instrument should not only be sensitive to voltages of the order of a millionth of a volt, but also to very rapid oscillatory change of potential. With the development of the thermionic valve an undreamt of degree of amplification became possible and not long elapsed before Erlanger and Gasser were able in 1922 to perfect the cathode ray oscillograph in which the beam of electrons constitutes an inertia-free recording system.

The first use of the electrical method in studies of a psychological nature has been attributed to Jacobson, although Golla (1921), using a string galvanometer to study preparatory adjustments, preceded him by six years. Jacobson's use of amplifiers in 1927 does however mark a turning point in the history of measurement techniques. Later investigators have nearly all used variants of his method.

Before this method can be employed, many technical difficulties inherent in the use of such sensitive electronic equipment have to be overcome. These are the requirements of the amplifiers, electrodes, and recording devices. The amplifiers should generally be of the resistance-condenser type and four stages of amplification are usually necessary to give an overall gain of at least 3,000,000. The frequency response of the amplifier should ideally be linear between about 10 and 400 cycles per second to utilize all potentials. (Davis,1942; Davis,1953). The amplification can easily be obtained, but to ensure a steady base line and no interference is another matter.

The recording device can either record the momentary changes in potential, in which case a "lever" of low inertia is required, or summate them. The oscillograph is the most sensitive recorder available to-day, but the trace has to be photographed to obtain a permanent record. This is a costly procedure if used over any length of time, and the delay in obtaining a developed record entails further difficulties in setting up the apparatus and in relating variations in experimental conditions to fluctuations of the trace. Several ink-writers are available similar to those used in E.E.G. work, and Kelvin-Hughes have produced a device recording by electric spark on Teledeltos paper which achieves a practically frictionless tracing. Although the frequency range of these "pen recorders" is not as wide as that of a cathode ray oscillograph they can be obtained with a response that is linear over the greater part of the range.

The summating type of recorder was developed by Jacobson (1939) and can be used when exact timing of the occurrence of particular tensions is not required. In its present form (see Ryan, Cottrell, and Bitterman, 1951) it generally consists of a condenser which is charged by the rectified output of the amplifiers, and so summates the total input to the amplifiers. When the condenser discharges, it moves a counter or a pen on a moving trace and thus gives an indication of the amount of activity occurring over a specified time.

The electrodes employed in psychological work are usually very simple. Needle or skin electrodes can be used. Risk of polarization can be ignored as potentials are momentary rather than steady. The insertion of a needle directly into the muscular tissue is more widely employed in physiological studies such as that of Weddell et al (1944) in which the form and frequency of the electrical response are studied under normal and pathological conditions. From a psychological point of view the needle is likely to disturb the subject and such precise recording is rarely needed. The psychologist is more often interesred in when and how much a muscle group is contracting and for this purpose surface electrodes can be just as satisfactory if good contact can be maintained with the skin. Travis and Kennedy (1947), for example, employed cubes of sponge 1 cm. square soaked in saline with eminently satisfactory results. The action potential recorded in this way from a whole muscle wil be the resultant of a complex of a large number of unit potentials, differing in amplitude, duration and even form, but it will serve as an indicator of activity at a molar level.

Location of electrodes on the subject's body is not a simple matter. Davis (1935) has shown that the body is a volume conductor and that it is possible to apply principles governing the distribution of fields in such a conductor to muscle action potentials. Among other findings Davis has discovered that a steep gradient surrounds a wave, i.e. an electrode must be within a few cms. of the excitatory locus to record all but the largest waves.

Bipolar or single electrodes can be used. When bipolar leads are used, the electrodes are generally placed close together and are thus both affected by the same electrical field. Or a single electrode can be placed over the muscle and the second electrode treated as a neutral point and attached to an inactive part of the body. A difficulty then arises from the interference of the electrocardiogram, or if recording from face or neck the electroencephalogram. This can be overcome by the choice of an isoelectric placement for the inactive electrode, or if comparative studies are being made, say, comparisons of the tension level under one set of conditions with that under another, it may be possible to treat the E.K.G. as a constant, but this is obviously not as satisfactory as its elimination.

A further difficulty arises if we wish to record from several muscle groups simultaneously. At present this requires a separate amplifying circuit for each recording and a multi-channel pen recorder or a multiple-beam oscilloscope. A switching device can be used and several electrode placements on the subject sampled in succession, but overloading of the switch occurs and means a delay of several seconds between one record and the next. In short, any attempt to record patterns of activity necessitates at present an extremely elaborate and costly apparatus.

Lastly, precautions must be taken to shield and earth the apparatus, leads, and subject. Earthing is particularly difficult, a basement room is preferable and the correct choice of earth points in the circuit is important; it is all too easy to introduce a 50-cycle interference from the mains. Fluctuations in the supply voltage are usually unavoidable, but can be minimized by the choice of a suitable time of day for experimentation. When these many technical errors have been eliminated, there remains one final and crucial problem which all too often has been ignored by investigators. It is known that electrical changes are a constant accompaniment of normal muscular activity, but is the relationship between electrical activity and muscular tension a direct and linear one or not ?

Inman et al (1952) give a clear answer to this question. By employing amputees who were to be fitted with artificial limbs as subjects, it was possible to isolate muscles from their bony insertions and record directly the force exerted by these muscles during various degrees of voluntary effort. At the same time, E.M.G. tracings were taken. Provided the muscle was not allowed to shorten, the amplitude of the electromyogram paralleled the degree of muscular tension exerted.

Earlier Travis and Lindsley (1931) had obtained a similar linear relationship when either needle or brass surface electrodes were used. This work has recently been confirmed by Malmo (1951) who found that the amplitude of the electromyogram recorded with surface electrodes varied directly with the amplitude of the tension exerted by the muscle up to a pull of 6 kg.

It would seem justifiable to conclude that the electromyogram can be used to indicate (1) the time at which a muscle contracts to within a millisecond, and (2) the intensity with which it contracts <u>isometrically</u>; the time of occurrence and the height of the wave form being the respective indicators.

This method would appear to be the most suitable for psychological investigation. It has, in Davis' words, "definitiveness, uniqueness, sensitivity, and produces a minimum of distraction".

Chapter 2.

Muscular Tension Accompanying Mental Work.

Rodin's "Le penseur" is an example of the commonly held belief that intense mental work is accompanied by a set facial expression, furrowed brow and tense posture.

The experimental literature appears on the whole to justify this belief. Investigations into the supposed relationship between mental and peripheral activity can be classified as attempts to answer two questions:

(1) When a person performs mental work, do changes occur in his skeletal muscles ?

(2) If tension is induced in the skeletal musculature are there changes in the level of mental performance ?

It is convenient to treat these two aspects separately in reviewing the literature, and it is to the chronologically earlier approach that this chapter is devoted. The review attempts to be selective rather than comprehensive, although it must be borne in mind that the results of a single experiment, however impeccable the design and instrumentation, can rarely be accepted without confirmation by other workers. Many of the discrepancies between research findings appear to be due to the non-comparable methods of measurement employed. So it is probably more difficult to generalize in this than in most other fields. As the various measurement techniques have been considered in Chapter 1, they will not be referred to in detail here. Instead as a general rule the recording devices used by different investigators will only be mentioned in passing, and the corresponding advantages and drawbacks should be held in mind.

Part (1) Muscular Tension Accompanying the Onset of Mental Work.

The earlier experimenters, working with the knee jerk, invariably obtained an enhancement of the jerk when mental activity began, e.g. Lombard (1887), confirmed by Tuttle (1924), found a tenfold increase in the jerk in all his seven subjects. Féré (1889) found mental work led to an increase of as much as 25% in the subjects' maximum squeeze on a dynamometer. Mosso (1894) too found an increased ergographic output resulted when a subject engaged in strenuous mental work. On the other hand, Loeb had found in 1886 that mental activity led to a slackening of pressure on a dynamometer, and Lehmann (1900) confirmed this with an ergograph.

Comparison of these experiments is difficult. The number of subjects used was small (e.g. Lombard used himself as a subject), no statistical evidence of significance could be supplied, the tasks differed (they ranged from studying German to mental arithmetic), and instructions and posture are unlikely to have been similar. But in most instances the published accounts are not full enough to permit closer examination.

The more recent work generally agrees that an increase in muscular tension occurs when mental work begins.

Golla (1921) and Golla and Antonovitch (1929) attempted to record muscular tension both before and throughout a work period. Recordings were taken simultaneously from the leg and arm. The subjects' toes were attached to the lever of an optical myograph of Sherrington's pattern which magnified the movement 30-40 times. Subjects also wore a glove to which a thread was attached. The arm lay in a trough, the wrist hanging over the end, and movements were transmitted by the thread to a magnifying device. We have already considered the faults inherent in this recording technique.

Several tasks were performed, including addition of columns of figures, reading, and recitation. <u>In all cases a rise in tension was seen at the inception of mental work</u>. Golla considered this rise was probably a form of preparatory reaction, a bodily concomitant of an emotional state.

Freeman (1930b) followed up this work by employing his method of patellar deformation to give an indication of tension in the isometric quadriceps muscle. Records were taken every 30 seconds from four subjects under working and rest conditions, both of which lasted ten minutes. The tasks entailed continuous addition, and counting verbs and adjectives. As Freeman's results are expressed as increases or decreases in tendon deformation as measured in mm. on a scale, it is impossible to translate them into microvolts of tension. However, his results are undoubtedly significant statistically. He obtained a small increase during the rest period for all subjects (mean = +.95 mm.), and a much larger increase, again for all subjects, between resting level and the beginning of mental work (mean = +18.22). However, individual differences were marked, the mean of 18.22 being calculated from the four individual readings of 15.4, 13.2, 35.7, and 8.6. (It is interesting to note in passing that two of the four subjects were naive, the other two being trained. The readings of 35.7 and 8.6 were given by the naive subjects.)

The photograph of Freeman's apparatus appearing in the 1930 paper gives rise to certain misgivings. He describes it as " a device resembling an ancient pillory or stocks", and the peculiar sitting position adopted by his subjects leads to the suspicion that he was probably measuring postural tensions during the straining forward to read the work sheet.

Edmund Jacobson's work is well-known. We will not enter here into the full details of his experiments, but merely indicate their relevance to the present theme. As we have seen he was the first to employ amplifiers and a string galvanometer giving a sensitivity to potentials of less than a microvolt (Jacobson,1934). Camera recording was employed for three-second samples taken every 17 seconds throughout a half-hour session. Fifteen subjects were especially trained in methods of relaxation over a period of several months beforehand (Jacobson, 1929).

During the experimental session they were told to begin imagining various activities at a given signal and to stop imagining at a second signal. All subjects showed an increase in muscular tension during imaginative activity, this tension being localized in the muscles which would have been involved in carrying out the activity (e.g. in the right biceps when asked to imagine bending the right arm).

Twelve untrained subjects, employed in a further series of experiments, gave slightly different results in that although muscular tensions were invariably recorded during any mental activity, these tensions were not as localized as in the former case.

Jacobson's conclusion is that:

> "the total physiological activity present when there is imagination of voluntary movement includes neuromuscular processes in the locale comprised in the imaginary act".
>
> (Jacobson, 1930a, p.607.)

In a further series of papers these findings were elaborated and modified (Jacobson, 1930b,c,d; 1931a,b,c). Employing trained subjects with instructions to visualize bending the right arm, Jacobson obtained action currents from the eye muscles and not from the arm. Instructions to imagine bending the arm gave, as before, localized activity in the arm. But recording from eye <u>and</u> arm under the latter instructions showed that beside the activity always present in the arm, there was sometimes movement of the eye as well. Subjective reports supported these findings:

> "they imagine bending the right arm either through a muscular experience as of bending the right arm or through visual images of the arm performing the act ... frequently (on instructions to imagine) they engage in both of the above experiences".
>
> (Jacobson, 1931a, p.120.)

This is the first demonstration of specific loci of tension in the musculature to be elaborated later by Freeman. It is unfortunate that Jacobson did not attempt simultaneous electrical recording of the muscular activity at these two loci, mechanical registration of the arm movement served instead.

A further and most important aspect of Jacobson's work is seen in the results obtained from completely relaxed subjects when they attempted to think. These trained subjects found it quite impossible to think and remain relaxed; as soon as a thought process began, muscular tension would be reported or measured. Jacobson (1929) says,

> "We find the experience of muscular tenseness a <u>sine qua non</u> of imagery, attention and thought process".
>
> (Jacobson, 1929, p.186.)

The main conclusions relevant to our immediate purpose seem to be:

(1) Muscular tensions are always present in some part of the body during mental activity even in the case of subjects trained to relax.

(2) When muscular tensions are relaxed away, mental activity cannot occur.

(3) There are different distributions of tenseness in the musculature dependent on (i) the amount of practice the subjects have had, (ii) the instructions given, and (iii) the nature of the mental activity.

Jacobson's work was a valuable step forward although it is difficult to assess the efficiency of his recording technique from the published account (Jacobson, 1939). The main objections to the immediate acceptance of his findings are:

(1) His over-reliance on trained subjects and their retrospective reports.

(2) The little quantitative treatment of results and the complete lack of statistical measures of reliability and significance.

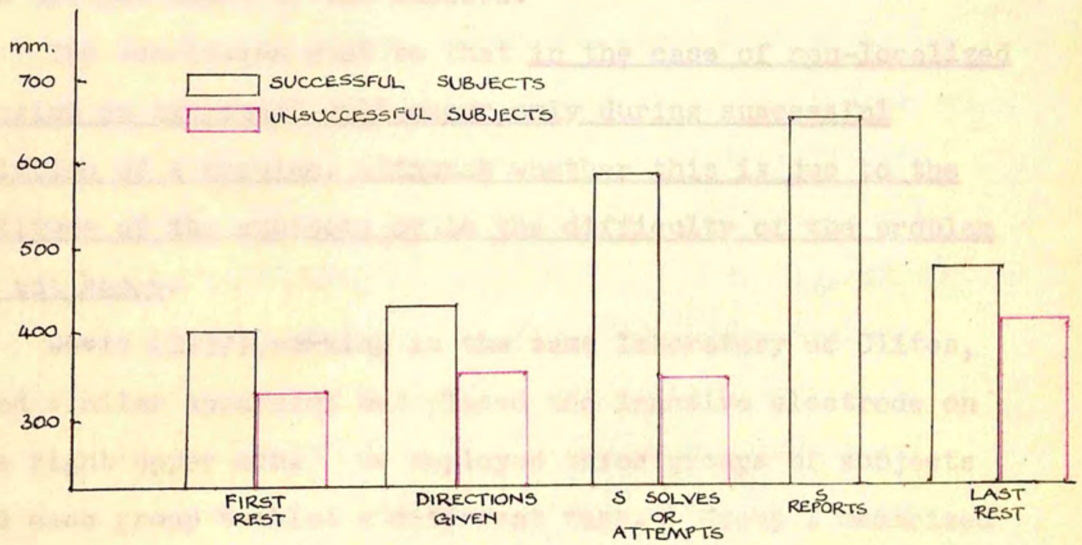
(3) The lack of clarity in his verbal instructions to subjects, and the use of "higher" forms of mental activity.

Clites (1935, 1936) working with R.C. Davis conducted a carefully controlled investigation into the difference between successful and unsucessful subjects in the average increment recorded in tension level between rest and work conditions. The subjects were seated inside a shielded cage, an active electrode being led from the right forearm, the inactive electrode taking the form of a saline bath in which the right foot was placed. (This meant no localized tensions would be recorded and the electrocardiogram would be introduced into the records.) At the same time, by means of a tambour connected to the right hand, indications of the steadiness of the subject's hand were obtained. Subjects were given a problem from the Superior Adult level of the Binet Test. Records were taken during an initial rest period, while reading, solving and reporting the answer to the problem, and during a final rest period.

The muscle action potentials were recorded photographically from an oscilloscope. In the treatment of the results, the relatively enormous fluctuations of the base line due to the electrocardiogram were ignored and all deflections of more than 3 mm. were measured and summed to determine the total activity occurring per second. Averages were then computed for each of the five different periods. The bar graphs and tables given on the following page are modified from Clites' 1936 paper and show quite clearly that a significant increase in tension occurred during successful problem solving. The unsuccessful do not show any increase over their resting level.

Table II.1. Average total tension levels for successful and unsuccessful subjects. (Modified from Clites, 1936.)

	Initial Rest	Directions given	S attempts solution	S reports	Final Rest
Successful Subjects					
N	16	16	15	11	15
Average	393	429	578	640	469
C.R. (v.initial rest)	.94	+ 3.7	+ 3.9	1.8	
Unsuccessful Subjects					
N	12	11	12	Too few cases to justify computation.	12
Average	332	349	345		405
C.R. (v.initial rest)		.22	.40		



Graph II.1. Sum in mm. of deflections per sec. during each of the specified activities for successful and unsuccessful subjects. (Clites, 1936.)

It would seem then that an increase in muscular tension recorded in this manner is not a necessary concomitant of mental work. It is, of course, assumed that the failing subjects at least attempted the problem, and yet no increment in tension occurred. It may be that they did not attack the work as vigorously as the successful subjects and their attitude to the task may well have been different. Unfortunately, no record is given of the few failing subjects who reported a wrong solution rather than no solution at all. The high tension recorded from successful subjects in the work period might be an effect of S's conviction of having reached a solution. Tension remained high for successful subjects when they reported their solution, which may be further support for the idea that an emotional effect was brought about by the success.

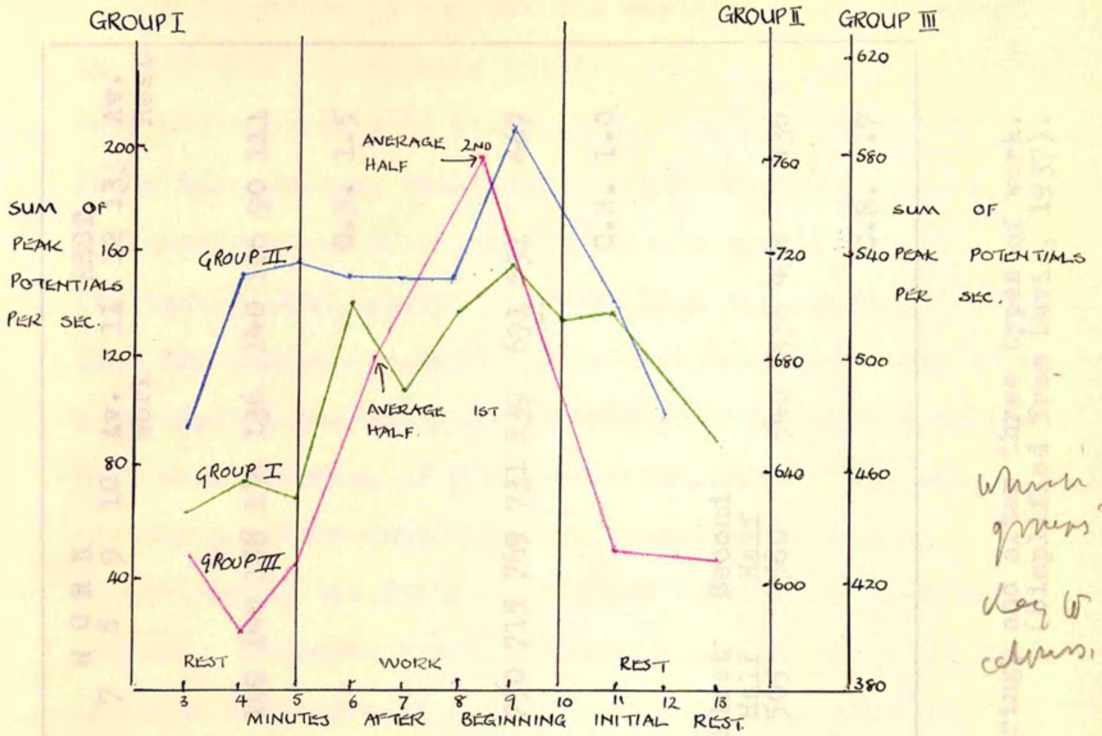
The conclusion must be that in the case of non-localized tension an increment will occur only during successful solution of a problem, although whether this is due to the attitude of the subjects or to the difficulty of the problem is not known.

Davis (1937), working in the same laboratory as Clites, used similar apparatus but placed the inactive electrode on the right upper arm. He employed three groups of subjects and each group tackled a different task. Group I memorized a difficult poetic passage for five minutes; Group II performed repetitive mental addition for three minutes; Group III multiplied a three-place by a two-place number until an answer was reached. There appear to have been 35 subjects in the first group, 23 in the second, and 34 in the third. Records were taken at the end of the third, fourth and fifth minutes of the preliminary five-minute rest period, and at the end of each half-minute during addition. As the work period varied in length for Group III, averages were taken for the first and last halves of the work period. Finally, in all cases potentials were recorded every minute during a subsequent rest period of five minutes.

The camera was run for three to ten seconds and the whole record for this period divided into intervals each representing a second. In each of these intervals the maximum deflection was measured in units of 1/50th of an inch and these measurements were then averaged for the run.

This particular method of measuring records is not perhaps the best. Any treatment is somewhat arbitrary, but to measure only the largest fluctuations in a sample period may be misleading. No estimate can be made of the representativeness of such a reading nor is any account taken of the variation occurring within a period.

All three groups agree in the major trend of their results. There is an increase in the average muscular activity recorded during the work period. The graph on the following page illustrates the trend.



Graph II.2. Trend of muscular activity during rest and work. (Modified from Davis, 1937.)

Table II.2. on the following page is a composite of several of Davis' tables. From the critical ratios it can be seen that only in the cases of Groups II and III is the mean difference between work and preliminary rest significant.

Minutes	REST 3	4	5	Av. Rest	WORK 6	7	8	9	10	Av. Work	REST 11	12	13	Av. Rest
1. Memorizing														
Average Tension	67	76	69	69	143	109	140	158	134	136	140	106	90	111
Work v. Rest			C.R.	4.3									C.R.	1.5
2. Addition														
Average Tension	664	720	720	697	716	750	715	769	731	739	691	651		667
Work v. Rest			C.R.	0.6									C.R.	1.0
3. Multiplication						First Half		Second Half						
Average Tension	440	430	436	435		505		580		540	438	434		436
Work v. Rest			C.R.	2.9									C.R.	2.7

Table II.2. Tension levels before, during, and after three types of work. (Simplified from Davis, 1937).

With groups II and III the amplifier is working at an increased sensitivity (at 1.8 and 4.45 mm. per microvolt respectively compared with 0.5 mm. per microvolt for Group I). Taking this into account there is still a remarkably small increase of activity for Group II. The rest period activity is very high and Davis suggests that the subjects were probably working during this time, a suggestion supported by reports from some subjects that they were thinking of possible short cuts. It seems equally possible that there was some difficulty in understanding the instructions and committing them to memory. Subjects were told they would be given a number to which they were to add 4, 5, 6 and 7 in rotation, to the resulting sum add 4, 5, 6 and 7 again, and so on until told to stop. By these instructions, a quite different and much more active preparatory set would be induced compared with the preparation necessary to multiply or to memorize a passage.

The conclusion seems to be that provided the subjects are allowed to relax between the giving of simple instructions and the beginning of the task itself an increase in localized muscular tension will ensue when work begins.

Davis (1939) again used similar apparatus in a later investigation, although further electrodes were arranged to sample localized activity in the left calf and arm as well as in the right arm. An unspecified number of subjects took part (1t appears to have been 31) and performed two tasks, mental multiplication and memorizing nonsense syllables.

Action potentials were recorded photographically during the rest period (where less than five microvolts of activity were required) and during mental work. From each camera run of three to five seconds' duration three sample periods of 1/12th second were selected, one near the beginning, one near the middle, and one near the end. In each of these periods the difference between the most positive and the most negative point was measured to 1/50th of an inch (equivalent to 0.3 to 0.6 microvolt). These readings were averaged and converted into microvolts. Further averages were calculated for the whole rest period and for the whole time spent in work. These work averages were then expressed as percentages of the rest periods.

It would seem that three 1/12th second periods are not likely to afford a representative sample of five seconds of activity. However, Davis obtained a measure of reliability by having assistants measure new samples, and found satisfactory correlation coefficients on the whole.

Employing this technique, Davis found:

(1) 98% of the readings during mental multiplication were

greater than the rest averages. In learning nonsense syllables the corresponding figure was 85%.

(2) A focus of activity occurred. In multiplication this focus seemed to be in the right arm. All subjects were right-handed, and sometimes spontaneously reported a strong tendency to write. However, the critical ratios are low except between the upper and lower limbs. The evidence then is more conclusively in favour of a gradient between upper and lower limbs than between right and left arms. No tendency to write was reported during the other task and no focus of tension was found.

The conclusions to be drawn are that:

(1) During mental work there is an increase in tension in at least three muscle groups, i.e. the left calf and the left and right forearms, the amount of increase depending on the type of mental activity.

(2) Greater activity occurs in the right forearm than in the left leg during mental multiplication, but no such focus occurs in nonsense syllable learning.

There have been a few instances in which mental work has not been accompanied by an increase in muscular tension.

Golla and Antonovitch (1929) claim that certain of their records do not show the expected increase. In fact, some records reveal a lower tension level during the periods of mental work than during the rest period. It is not clear from their statement whether individuals differ in this way, or occasional records taken from the one person. They do tell us on another occasion that the reliability of an increase in tension from one recording to the next for some people is low, so perhaps we may make the inference that this is an intra-individual phenomenon.

Henley (1935) is another worker who found no general increase in tension. He used a modified form of the McKinley-Berkwitz type of apparatus which records the movement of the arm, and tested 26 normal men and 26 normal women subjects and an equal number of psychopathic cases. The work period was taken up by a standard intelligence test, and Henley found in nearly all cases an alteration in tension compared with a rest period. This was by no means a universal <u>increase</u>, for there were as many subjects whose tensions decreased as subjects in whom an increase occurred. It was impossible to predict in advance whether there would be an increase or decrease in tension for a particular subject working at a particular task. An interesting finding was the fact that an initial record was invariably higher than subsequent records in the same situation, i.e. at the beginning of work higher than later in the work period, although the average tension during work might or might not be higher than during rest.

The discrepancy between these results and those of other workers may well be due to the more complex task employed by Henley. In this respect Clites' experiment is the most comparable, and in that case an increase was only obtained from the successful problem solvers. Possibly attitude is of more significance in complex tasks of this nature than in simple repetitive ones, but there is no firm experimental basis for such an assumption. It is perhaps more likely that Henley's apparatus was at fault for it gave an indication of tension around the elbow joint only by the measurement of movement. A shift in tension always occurred when work began and this seems significant and may not contradict other findings as the tension may have shifted to the precise locales studied by others.

Max, in 1937, reported one of the final experiments in his series of investigations into the peripheral theory of thought. In the earlier work he had employed deaf subjects and had recorded the electrical changes occurring in their forearms under various conditions. He had found a progressive decrease in action potentials during the transition from waking to sleep, and could in many instances detect the onset of dreams by the appearance of relatively large potentials in this region. If a motor theory of consciousness holds, Max argues, there should be an increase in electromyographic responses as consciousness reappears on waking, and these responses should become more extensive as consciousness becomes more complex.

In the paper which is of immediate concern to us he traced the course of action potentials both during rest and during imaginative and abstract thought processes.

Technically the work was first class. Recordings were taken from deaf and normal subjects from the flexores digitorum of the forearm and from the leg muscles. Plate type electrodes were used and two amplifiers giving a very high gain. The subjects lay flat on a bed and the problem was presented written on a card after a period of rest. This was superior to Jacobson's method of presentation in which S was given a problem and told to relax until the ready signal was given when he was to begin thinking about it. The subject in that case would be aware of the problem throughout the foreperiod which would not serve as a satisfactory control. In support of this contention Max obtained lower levels of activity during the foreperiod. On the other hand, Max's procedure entailed reading the instructions and the problem during the work period and gave no indication of the time at which "pure" mental work began.

The amplified action potentials were rectified and the area between the base line and the upper limits of the curve was measured with a planimeter. Average levels were then computed for the various activities. The sensitivity of the instrument can be imagined when it is realized that voltages of more than nine microvolts were too big to be measured as they represented full-scale deflection.

The average level of activity recorded from 18 deaf subjects (both forearms) working at various tasks is given in Table II.3. below.

Table II.3. Average tension levels recorded from forearms of deaf mutes during different tasks. (Max, 1937.)

Activities	Average Tension	% positive responses (increases during work)
Reading	1.6	52
Rearranging sentences	2.0	84
Memorizing	3.7+	94
Addition	4.2+	91
Syllogisms	5.7	96

There were wide variations in individual responses, the average reading for addition, fo example, being derived from a range 0 to 7.0 microvolts.

Control readings taken from the gastrocnemius muscle of the calf gave only 19% positive responses compared with 73% positive responses from the arm (91 records from five deaf subjects).

Readings were also taken from the gastrocnemius muscle and forearms of 16 normal subjects (374 records). We are not told the nature of the task worked. In this case only 31% positive responses were obtained compared with 84% positive responses in the deaf. The average amplitude was also lower, being 0.8 microvolt in the normals and 3.41+ microvolts in the deaf.

It is most important to realize that Max's deaf subjects were highly trained, some having had 15 month's practice in relaxation. The normal subjects were not available for more than a few hours, as they were employed in full-time occupations. These two groups are not comparable, and here, as in Jacobson's work, we do not know whether the specificity of response in the trained deaf subjects is not due to their training. But, nevertheless, the normal subjects were not as responsive as most other investigators have reported. Reasons can only be conjectural, and may lie in the nature of the task and the experimental procedures, the personalities of the subjects, or the evocation of different emotional attitudes. The normal subjects were unlike those employed by most investigators who generally choose university students. The motivational attitude of strangers to a laboratory might be considered the crucial variable.

It is risky to attempt a final conclusion to the query, are there changes in muscular tension which accompany the

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It is risky to attempt a final conclusion to the query, are there changes in muscular tension which accompany the onset of mental work ? But it is not too inaccurate to say that the bulk of experimental work shows that there is an increase in muscular tension in certain muscle groups in the majority of subjects when work begins, the locus of maximum increase depending on the nature of the task, the subjects employed, and the instructions given to them.

Part (2) Changes in Muscular Tension Occurring during the Course of Mental Work.

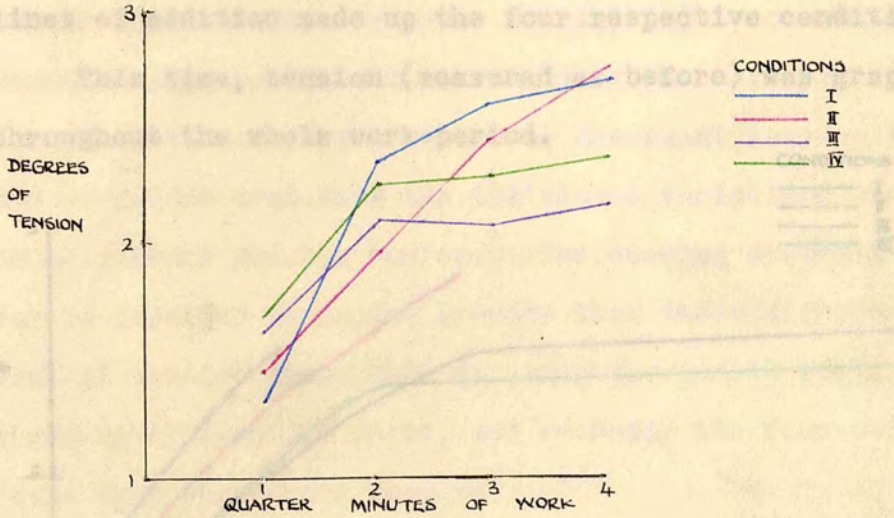
Golla and Antonovitch, it will be remembered, obtained a rise in muscular tension at the onset of mental work. In the same experiment they also attempted to follow the course of tension throughout the work period, which was of unspecified length. The initial rise appeared to be sustained for a brief period before tension returned gradually to its original (rest) level, although the work was still under way. The period of maximum tension for any one subject varied from three to six minutes in duration, and the period of decline to normal from six to twelve minutes.

A similar initial rise and subsequent drop was reported by Freeman (1930b). In the same experiment discussed in Part 1 of this chapter, he continued to take tendon deformation readings every 30 seconds during a work period which consisted of either continuous addition, counting verbs, or counting adjectives in a passage of prose. He found that after the initial rise in tension there was a decline. Subtracting each reading from the preceding one and then averaging these figures for each subject, he obtained a mean decrease for his four subjects of 3.35 mm. of deflection from the level at the beginning of the task after nine minutes working. Subjects were not very variable, all showed the decrease, the respective figures being 3.8, 2.9, 2.6, and 4.1. This quantitative procedure is apparently fairly representative, although greater regularity is implied than in fact occurred, for momentary and even sustained increases in tension were noticed during the period of usual decrease. These were possibly due to extraneous stimuli, or to an increase in effort, or even, in Freeman's opinion,to an unrelated spread of muscular or visceral activity affecting the locus of recording. It was not possible to say which.

Bills and Brown were two other workers at about the same time (1929) who obtained evidence for the initial rise in tension, although no subsequent drop was recorded. They employed 20 subjects who worked at four similar tasks of different length. These consisted of pairs of digits arranged on an addition sheet, which subjects added over periods of one minute (condition I), two minutes (condition II), five minutes(condition III), or ten minutes (condition IV). A signal was given every 15 seconds, whereupon S made a check mark on the page to show the point reached.

Tension was recorded in a primitive manner by having the subjects write their answers on five sheets of paper, placed one on top of another and interleaved with carbon papers. An indication of the amount of pressure exerted on the pencil point would be given by (a) the number, and (b) the clarity of the carbon tracings, the former giving the more objective measure. Two judges independently rated each subject's work for degree of tension on a four-point scale at each quarter minute.

The following graph, Graph II.3., shows the degrees of tension recorded during the first four quarter-minutes of work.

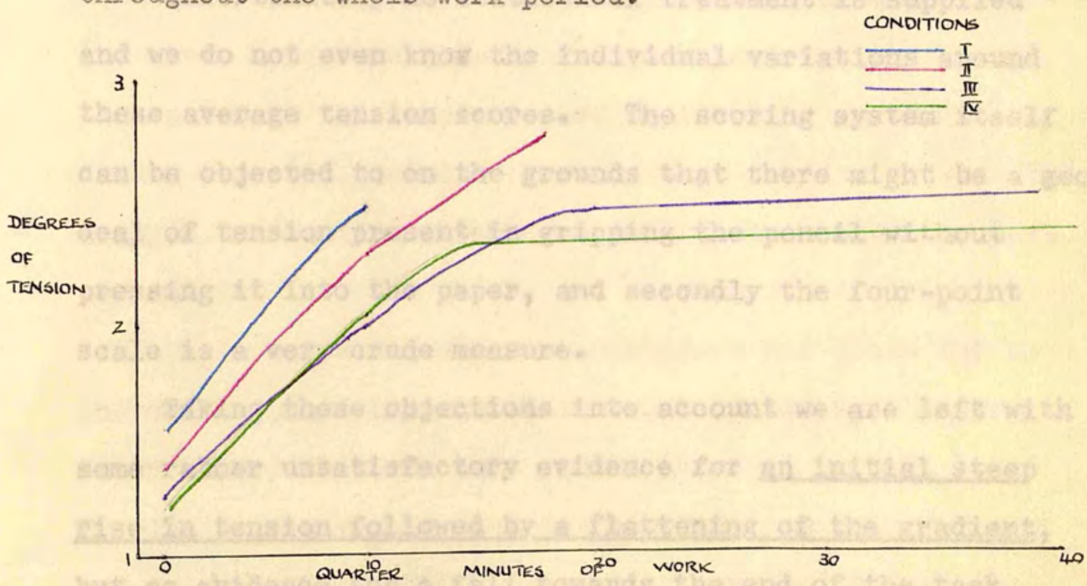


Graph II.3. Degrees of tension recorded during work under a time-set.

(Bills and Brown, 1929)

In all cases there is a rapid increase in tension during the first half-minute of the task and a slower rise during the second half-minute. The shorter tasks tend to have lower initial tension and to increase more sharply than the longer tasks. In a second experiment, in which 24 subjects were employed, four different length sums were again worked, but this time the actual number of lines of work to be completed constituted the task given rather than the time allowed. Three, six, twelve, and twenty-four lines of addition made up the four respective conditions.

This time, tension (measured as before) was graphed throughout the whole work period.



Graph II.4. Degrees of tension recorded during work under a task-set.
(Bills and Brown, 1929.)

Graph II.4. resembles the earlier graph in showing a sharp increase of tension, irrespective of the length of the task, at the beginning of the work period, an increase which flattens to a virtual asymptote at the thirtieth quarter-minute. However, the sharp rise at the beginning of the graph is not, as in the former experiment, sustained for only half a minute, but extends over two and a half minutes. A further difference is found when the effect of the length of task is examined. The shorter tasks do not in this case have a lower initial level of tension, but remain higher throughout the whole of the work period.

Unfortunately no statistical treatment is supplied and we do not even know the individual variations around these average tension scores. The scoring system itself can be objected to on the grounds that there might be a good deal of tension present in gripping the pencil without pressing it into the paper, and secondly the four-point scale is a very crude measure.

Taking these objections into account we are left with some rather unsatisfactory evidence for an initial steep rise in tension followed by a flattening of the gradient, but no evidence for a fall towards the end of the task. Freeman recorded tension in the quadriceps muscle whereas Bills and Brown were obtaining a gross measure of hand and forearm tension and this might well account for the discrepancy.

Davis, in his 1937 paper which has been discussed in Part 1 of this chapter, reported an increase in tension during the work period. The graphs on page 35 show the apparent trend. Davis claims that it can be seen from the tables accompanying these graphs (condensed into Table II.2. on page 36) that during the second half of each work period (minutes nine and tem) the tension is greater than that recorded during the first half (minutes six and seven) in all three tasks, the increase being most marked for the third group of subjects, those working at mental multiplication. However, in the case of the memorizing and addition tasks it is possible to analyze the curve more carefully. The tension level reaches a high point in the sample preceding the last one taken during the work period. For the last reading tension has dropped and continues to do so during the succeeding rest period.

Davis has more evidemce to support his claim for an increasing trend throughout the work period in a later paper (1939) which we have partly examined in Part 1. It will be remembered that he recorded from both forearms and from the left calf while subjects worked at mental multiplication and memorizing nonsense syllables. He began taking records of work period activity after a lapse of 15 seconds. This was done "in order to omit any shock effect". However, it was possible to observe on the oscilloscope, although not to record in a permanent form, an initial burst of activity which subsided at the end of 15 seconds, so that the first reading taken then was often little greater than the rest period values.

It seems to the present writer that if such a shock effect is brought about by the presentation of a piece of work and the preparatory adjustments of the subject in beginning it, then any attempt to trace the course of muscular activity during mental work must necessarily <u>include</u> this period. Omitting it entirely is analagous to the study of reaction times accompanied by a dismissal of the fore-period from consideration.

After the lapse of 15 seconds Davis recorded for periods of three to five seconds at the end of every minute. Muscular activity appeared to increase during the work period, and to obtain a measure of this effect the tension level recorded during the <u>last</u> camera run in a work period was expressed as a percentage of the <u>first</u>. These percentage values are given in Table II.4. for the three loci where recordings were made.

Table II.4. Ratio of muscle potentials of last work reading to those of first work reading, in percentages. (Davis, 1939.)

	Left Leg	Left Arm	Right Arm
Arithmetic	155	153	133
Memorizing	114	121	158

Ignoring the different magnitudes in the different muscle groups which have been mentioned in the last part of this chapter, it can be seen that in all cases there is an increase over the tension recorded after the first 15 seconds. Sometimes the final level is half as much again.

Davis concludes from this that muscular tension increases progressively during work, but this is going beyond the published results which merely show that the tension levels during the last camera run of approximately three to five seconds in duration was higher than the tension level during the first run taken after the first 15 seconds of work. Indeed to be precise only three sample periods of 1/12th second each were measured during these camera runs and only the largest deflections within these periods. The measurement of 1/4 second's activity near the end of work and a similar measurement near the end of the work period and the computation of their ratio hardly justifies a statement to the effect that tension increases progressively. It would seem more correct to conclude that Davis found tension increased at the beginning of a task, remained high for about 15 seconds, then dropped, and probably rose agaim near the end of the work period.

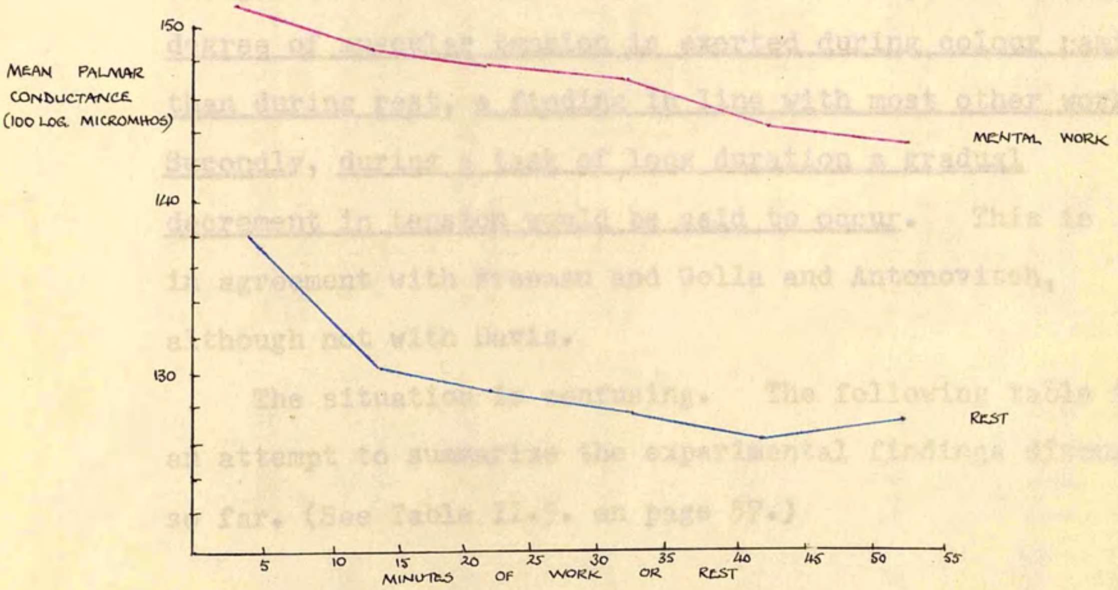
Telford and Swenson (1942) recorded tension during a mirror-drawing task by means of a pneumatic stylus. Twenty-five subjects took part, each subject attempting the task 100 times.

It was found that in the earlier runs tension was low at the beginning of a trial and increased irregularly but fairly constantly until it was highest at the end of the trial. As learning progressed initial tension increased until during the last trials there was little difference between the beginning and the end of a trial. Variability likewise decreased. From a typical sample record included in their paper one might also conclude that there was a sharp increment in tension at the beginning of the task.

Although apparently supporting Davis' views with regard to the increase in tension during work, this experiment does not appear to be directly comparable, as it is concerned with changes that occur in the muscles involved in a motor-learning task, which are probably very different from the changes that occur in similar muscle groups during so-called central processes.

A more recent study by Geldreich (1953) utilized palmar skin resistance and traced the trends occurring during long work periods of 55 minutes. The mental work consisted of a colour-naming task, the colours being presented serially by means of Bills' psychergometer. The mean conductance level was recorded for each 15 seconds of the work period and means were calculated for five-minute periods.

The graph below (Graph II.5.), modified from Geldreich, shows the course of skin resistance during the work period and during a control period of the same length when the subjects reclined in an easy chair. Ten subjects took part in the experiment.



Graph II.5. Palmar conductance during work and rest.
(Modified from Geldreich, 1953.)

The greatest reduction in conductance occurs during the first five minutes of control rest, after which the trend parallels the mental work curve. The difference between the first and second thirds of the control curve is significant at the .01 level, but between the second and third thirds does not reach significance.

During mental work a significant trend appears to have occurred. Both the decrement from the first to the second and from the second to the third third are reliable at the .05 level.

Finally, the average conductance level during mental work is significantly higher than during rest.

If palmar skin conductance is considered a valid though indirect measure of muscular tension, then <u>a greater degree of muscular tension is exerted during colour naming than during rest</u>, <u>a finding in line with most other work</u>. <u>Secondly</u>, <u>during a task of long duration a gradual decrement in tension would be said to occur</u>. This is in agreement with Freeman and Golla and Antonovitch, although not with Davis.

The situation is confusing. The following table is an attempt to summarize the experimental findings discussed so far. (See Table II.5. on page 57.)

Table II.5. Summary of experiments tracing the course of tension during mental work.

	Workers	Locus of recording	Nature of task	Length of task	Course of muscular tension during work.
(1929)	Golla and Antonovitch	Right (?) shin	Addition, reading, recitation.	Approx. 18 mins.	Initial increase (3 to 6 mins.), then decrease.
(1929)	Bills and Brown	Hand and forearm	Addition	Up to 10 mins.	Sharp initial increase (either 1/2 or 2 1/2 mins. depending on set) followed by plateau.
(1930)	Freeman	Right thigh	Addition, counting verbs & adjectives	9 mins.	Initial increase, (30sec?) then slow decline.
(1937)	Davis	Right forearm	(a) Memorizing (b) Addition (c) Multiplication	(a) 5' (b) 3'	In all tasks an increase throughout which reached a peak in the penultimate sample in (a) and (b).
(1939)	Davis	Right forearm & left calf	(a) Memorizing (b) Multiplication	(a) 5' 15"	Initial increase (15 secs.), drop to rest level, then increase by end of task.
(1942)	Telford & Swenson	Hand & forearm	Mirror-drawing	82 secs. average.	Increase throughout task on early trials.
(1953)	Geldreich	Palmar skin resce	Colour naming	55 mins.	Initial increase, slow decline throughout work period.

Any general conclusions to be drawn from this table will depend on a subjective estimation of which differences are important and which of no account. It is hardly to be expected that all these workers should concur on the shape of the tension curve, considering the variety of tasks of various lengths that have been employed and the many different loci from which recordings have been made. Nevertheless they all report a sharp increase in tension at the beginning of the task. This seems to occur in all the muscle groups measured and for different types of work. The length of this initial increase has been shown to depend partly on the set of the subjects induced by the anticipated length of the task (Bills and Brown), and may also depend on the length of the task, its nature, and the locus of measurement.

There is less agreement about the later course of tension. It has been found to increase, decrease, or to remain constant. Bills and Brown, who obtained the latter effect, used such an insensitive method of recording that they may not have been able to pick up the trend. The other experiments fall into two groups: (1) Golla and Antonovitch, Freeman, and Geldreich who found tension decreased until the end of the task; (2) Davis who found tension increased in two separate experiments. Telford and Swenson agree with Davis, but the relevance of their data is doubtful.

One striking difference between Davis and other workers lies in the length of his tasks which took no longer than about five minutes. Freeman's tasks were almost double this length, Golla and Antonovitch's three times as long, and Geldreich's lasted for 55 minutes. As Davis in his 1937 paper presents graphs which decline towards the end of the work period, it seems a likely extrapolation from these data to predict a continuous decrement if the task were to be continued. The difference then between Davis and the others may lie in the shorter tasks employed by the former. There is unfortunately no evidence from the other experimenters that tension rose to a high point after about five minutes; secondly, if the results of the 1939 paper are to be trusted, Davis has obtained an increase during the work period with no sign of a final drop.

It should be noted that Davis did not record from the same muscle groups as the other workers, and he employed discontinuous work. The counting and addition tasks used by the others were of a more cumulative and continuous nature.

We are probably justified in coming to the following conclusions:

At the beginning of mental work there is, in all muscle groups so far investigated, a marked rise in tension, the extent of the rise having been shown to depend partly on the set of the subjects.

There may then occur an increase in tension, to be succeeded by a slow decline until the end of the task, this latter trend being better documented.

The length and type of task, particularly its repetitive or cumulative nature, probably influences the form of the tension curve and the locale of maximum change.

Part (3) Individual Differences and the Association of Tension with Work Output.

In many of the experiments reviewed we have mentioned the common finding of variability in results. Several workers have attacked the problem of individual differences in muscular tension and sought to relate these differences to levels of performance.

White (1935) was probably the earliest to investigate this problem in a technically competent way, although he used an indirect indication of tension, namely skin resistance.

Twenty-seven subjects learned a series of paired equivalents which they then attempted to recall. Rank difference correlations were run between total amount recalled and mean resistance level. A correlation of -.16 was found between total recall and resistance during learning and tends to suggest that with many exceptions the superior learners may have been more tense than the poorer learners. More convincingly, the correlation between total recall and resistance during rest was +.50, which is significant at the 1% level and implies that the better learners relaxed more during the rest period which followed the attempt at recall.

The tendency for the better learners to be more tense is in agreement with Clites (1935, 1936) who recorded blink rate, skin resistance, and action potentials during problem solving. The results obtained by the three methods were similar, and those derived from the action potential method were reported in Part 1 of this chapter. An increase in tension during work was found only in the case of those subjects who solved the problem. These successful subjects are perhaps comparable to White's better learners.

Brown (1937) employed 18 subjects who learned a list of nonsense syllables presented serially while their G.S.R. was recorded.

Correlations were computed between average resistance levels at the beginning and the end of the task and efficiency of learning measured by the number of trials required for one successful reproduction of the list.

The results obtained are given in the following table:

Table II.6. Correlations between resistance levels and efficiency. (Brown, 1937.)

	Correlation
Resistance at beginning of task and efficiency	.25 ± .14
Resistance at end of task and efficiency	.57 ± .10
Average resistance at beginning and end of task and efficiency	.55 ± .10

From table II.6. it can be seen that the higher the resistance level, particularly at the end of the task, the fewer the trials required to learn the list. This implies that the better learners were less tense during learning and appears to contradict both Clites and White.

However, as Brown points out, the correlations must be interpreted with care as they are low, although the value of .55 is in fact almost significant at the .01 level. The inclusion of two hyperthyroid individuals in the sample was unfortunate as it would tend to raise the correlation.

The disagreement is heightened when Davis' results are included.

Davis (1937) recorded, it will be remembered, more localized tensions than Clites and used different tasks, i.e. memorizing, addition, and multiplication. Rank order correlations were computed between muscular activity in the various periods (initial rest, work, and final rest) and a measure of success in the task.

In the case of the memorizing task this was the number of words recalled. As Table II.7. indicates (see p. 65), there is a slight though not reliable tendency towards a positive relation between rest period activity and accomplishment, which suggests a more active state in the more successful subjects. More substantial coefficients are found during work where greater accomplishment seems to be associated with less increase in activity. This is clearer when the subjects are divided into three groups depending on their degree of comprehension of the material. The summaries of the passage which were most accurate were accompanied by the least increase in activity and vice versa.

For the addition task, as the subjects did not add aloud, it was possible to use only the final sum arrived at as a measure of success. The table on page 65 shows that the positive relation between rest period activity and accomplishment is more marked than before, and once again a negative relationship exists during the work period. It may be, as suggested earlier, that some individuals did not relax during the instructions and previous rest period, but rehearsed the rather complicated addition required of them (see p.37). This seems to have been the case, especially with the better performers, who worked during the fore-period and benefited by this ruse. The increase in action potentials mostly occurred not at the experimentally determined beginning of the task but at the very beginning of the session when the subjects first became aware of what was to be required of them.

In the third experiment subjects multiplied mentally a three-place by a two-place number. Two measures of accomplishment were used: the time spent on the work, and the number of correct digits in the product. The correlations are given in Table II.7. below and show a near significant and inverse relationship between output, by both measures, and increase in tension.

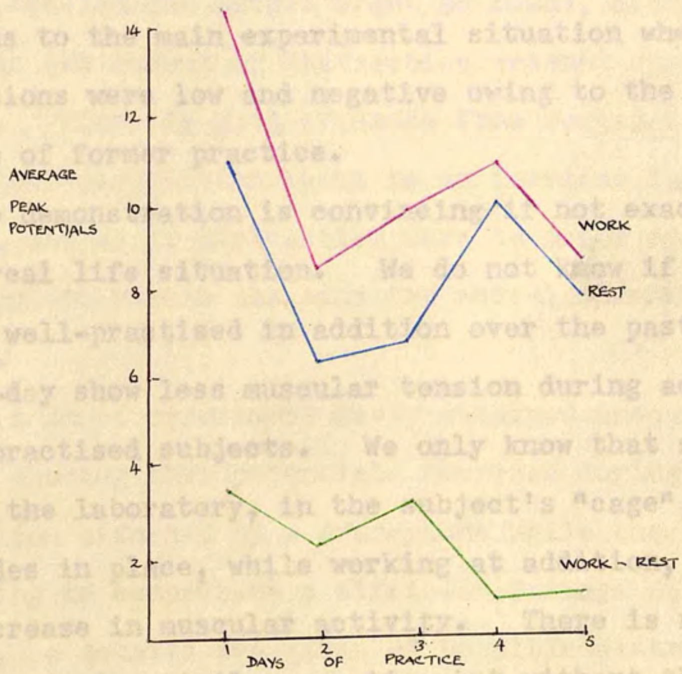
Table II.7. Correlations between muscular activity and work output. (Davis, 1937)

	Memorizing	Addition	Multiplication Time	Multiplication Correct digits
With activity in initial rest	.27	.43	.12	.11
With activity during work	-.25	-.10	-.06	-.09
With increase in activity during work over initial rest	-.34	-.35	-.25	-.24

All three sets of results agree that <u>a consistent correlation with accomplishment is found in the increase in activity in the work period over the resting level, the coefficient being negative and significant or near significant</u>.

In an attempt to elucidate these negative correlations Davis performed two further experiments. It is known from Freeman's work (1931) that muscular patterns change with practice in a given activity. Davis tried to show that practice also leads to a lessening of muscular tension.

Five subjects practised addition during five days while action potentials were recorded as before. The following graph (Graph II.6.) shows a tendency for activity to diminish as the series progresses. In fact the rest and work levels converge as practice proceeds; a finding in agreement with Freeman.



Graph II.6. The effect of practice on muscular activity. (Davis, 1937.)

Now, Davis argues, it can be supposed that subjects come to an experimental session with varying degrees of former practice. An imaginary situation can be envisaged in which the sittings of this practice group on their first day are taken with the sittings of the same five subjects on their last day as though they represented ten different subjects. The correlation in this hypothetical case between accomplishment and increase in tension would then be -.13 instead of +.40, the correlation obtained from the first day's results alone. Davis considers this analagous to the main experimental situation where the correlations were low and negative owing to the uncontrolled variable of former practice.

The demonstration is convincing if not exactly similar tb the real life situation. We do not know if subjects who are well-practised in addition over the past ten years will to-day show less muscular tension during addition than unpractised subjects. We only know that several days in the laboratory, in the subject's "cage", with electrodes in place, while working at addition, will lead to a decrease in muscular activity. There is no control group undergoing similar practice but without the presence of the potentially frightening laboratory set-up. The effect may be due to familiarity with the laboratory rather than practice at addition.

Furthermore it is strange that a correlation as high as +.40 should have been obtained from these subjects during the first session. After all they came to this first session with varying degrees of former practice and it is not obvious that the situation differs from the main experiment where the correlation was low and negative (-.35 between accomplishment and increase of tension). Davis' interpretation seems doubtful.

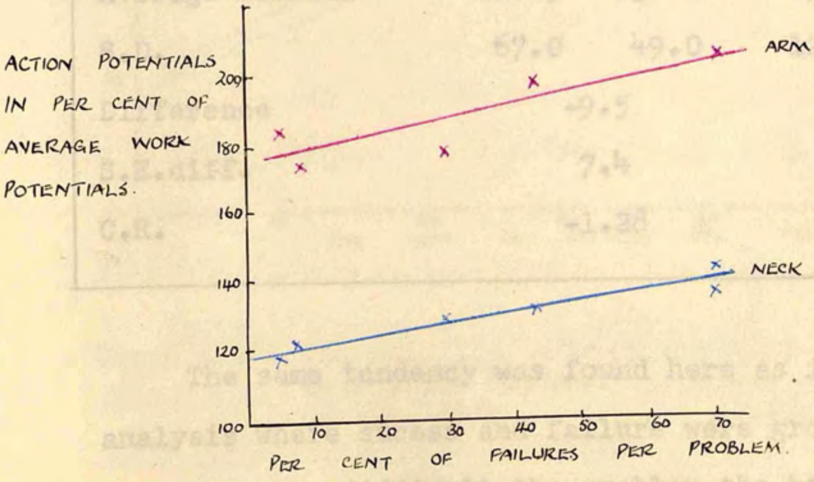
A further factor tending to decrease the correlation between tension and output might be found, according to Davis, in the amount of distraction present during work periods. There is good evidence from Morgan (1916) and others that distraction leads to an increase in muscular tension, and so if distraction were to occur during work and output to remain the same the correlation would be lowered.

In a short experiment Davis obtained unequivocal results showing that potentials increase during the distraction afforded by a gramophone while the subject is attempting to comprehend a difficult passage of prose. However, no details are given of possible distractions during the original work periods and these are unlikely to have been as intense as in this demonstration.

It is necessary to conclude that although Davis has shown that an inverse relationship exists between work output and the size of the increase in activity from rest to work, his attempts to specify reasons for this relationship are hard to accept.

In further contradiction to Clites, Davis (1938) found that the level of muscular activity of both successful and unsuccessful subjects was similar. He used a series of number problems and recorded electrically from the right forearm and neck.

A linear relationship was found between muscular activity in both these regions and the difficulty of the problems when percentage failure was used as an indicator of difficulty. Graph II.7. below is taken from Davis and shows the relationship clearly, and also that the amount of tension in the neck is considerably less than in the arm during work.



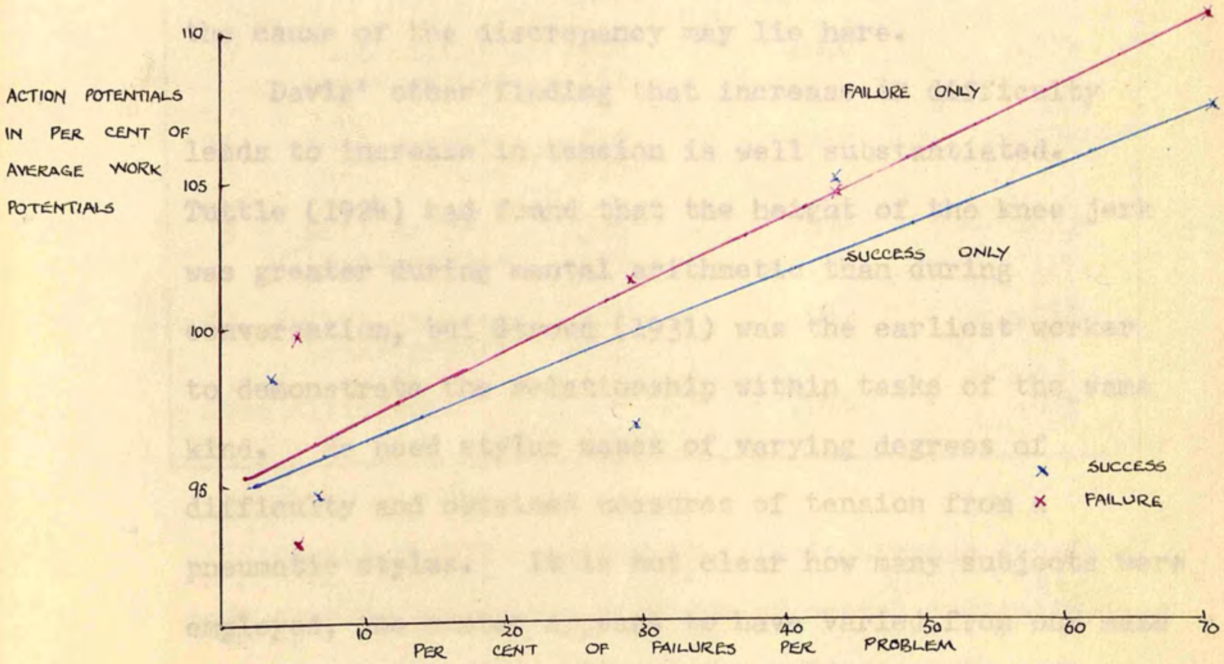
Graph II.7. The relation between muscular activity and difficulty. (Davis, 1938.)

Taking the analysis a little further it was found possible to differentiate between problems on which subjects reported failure and those on which they reported success. Comparisons of the average level of tension during "successful" solutions with the level during "failures" show no significant difference in either arm or neck, the slight differences being in opposite directions for these two loci. Table II.8. below gives the relevant values.

Table II.8. Average tension levels in neck and arm during successful and unsuccessful problem solving. (Davis, 1938.)

	Neck		Arm	
	Success	Failure	Success	Failure
Number of problems	124	60	136	63
Average tension	128.5	138.0	194.8	181.4
S.D.	67.0	49.0	129.0	99.0
Difference	-9.5		13.4	
S.E.diff.	7.4		13.3	
C.R.	-1.28		1.01	

The same tendency was found here as in the preceding analysis where sucess and failure were grouped together, i.e. the more difficult the problem the higher the activity level. Graph II.8. shows that more muscular tension appears to be involved in the solution of a difficult problem than in the solution of an easy one, and more activity is recorded for "giving up" a difficult problem than for "giving up" an easy one. (There is no actual difference between the two lines on the graph because of the wide scatter of points.)



Graph II.8. The relation between muscular activity on "failed" and "solved" problems and the difficulty of the task. (Davis, 1938.)

The disagreement with Clites may be due to the difference in recording technique; generalized tension as measured by Clites being an indicator of failure and frustration. An investigation is badly needed in which both localized tension in the arm and general tension in the bodily musculature, including the E.K.G., are recorded simultaneously during problem solving. On the other hand Clites employed a more objective measure of failure and the cause of the discrepancy may lie here.

Davis' other finding that increase in difficulty leads to increase in tension is well substantiated. Tuttle (1924) had found that the height of the knee jerk was greater during mental arithmetic than during conversation, but Stroud (1931) was the earliest worker to demonstrate the relationship within tasks of the same kind. He used stylus mazes of varying degrees of difficulty and obtained measures of tension from a pneumatic stylus. It is not clear how many subjects were employed, the number appears to have varied from one maze to another, and in one case to have been 12.

A consistent positive relation was found between tension and difficulty, tension being greatest on the trials with the largest number of errors. Table II.9. shows the consistent relationship which is not however statistically significant for individual cases. The high probable errors are due to the great variability in tension level from one subject to the next. When the mean difference is calculated a C.R. of 1.93 is obtained, which is also not quite significant.

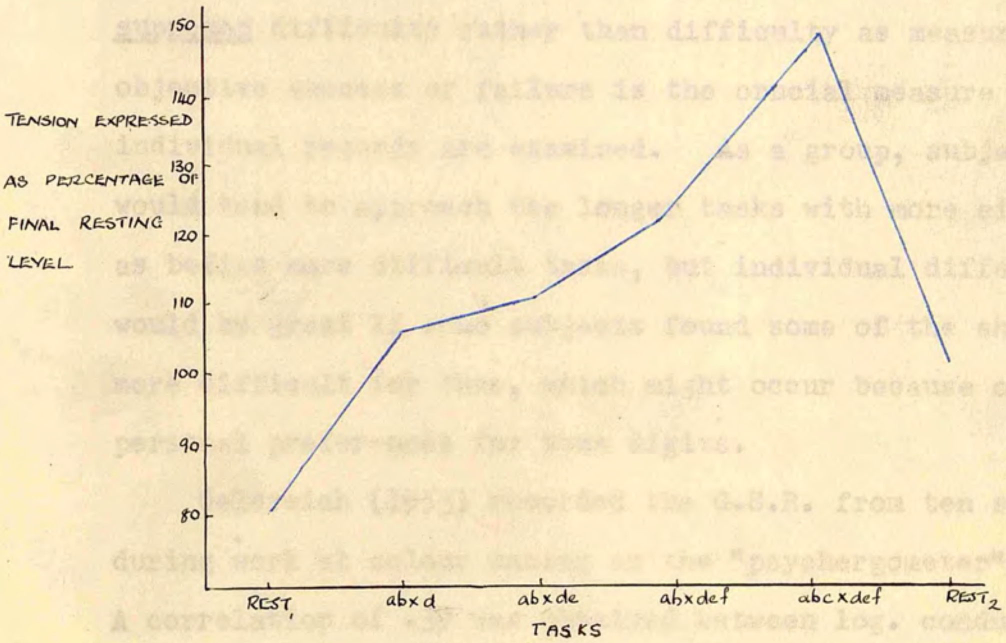
Table II.9. Average tension exerted on stylus during most and least successful maze runs. (Stroud, 1931.)

Maze	Category	Tension (ins.)	Difference in means	P.E.diff.
C3	Most errors	.208	.048	.014
	Least errors	.161		
C4	Most errors	.336	.038	.036
	Least errors	.298		
3	Most errors	.326	.038	.021
	Least errors	.298		
C2	Most errors	.275	.042	.038
	Least errors	.233		
Mean difference			.041	.015

Hadley (1941) recorded the electromyogram from the left forearm during the solution of mental multiplication sums of varying difficulty. Ten subjects took part in the experiment. The tasks were ordered in difficulty from 2X1 to 3X3 sums, the ordering agreeing with the percentage failure.

The average amplitude of the three highest waves occurring in each second was used as an indication of the amount of activity. This measurement technique resembles Davis' and is difficult to interpret.

Using this technique Hadley found that an increase in tension accompanied an increase in the difficulty of the task. Graph II.9. below shows the clear trend.



Explain.

Graph II.9. The relation between tension and degree of difficulty of the task. (Hadley, 1941.)

Hadley thought it likely that those subjects with the greatest percentage of failures would show the greatest increases in muscular activity, but upon examining individual records he found correlations which did not differ significantly from zero. In other words group trends do not apparently depict the true state of affairs for individual cases and prediction from group to individual is poor. Either that, or it may be that supposed difficulty rather than difficulty as measured by objective success or failure is the crucial measure when individual records are examined. As a group, subjects would tend to approach the longer tasks with more effort as befits more difficult tasks, but individual differences would be great if some subjects found some of the shorter sums more difficult for them, which might occur because of personal preferences for some digits.

Geldreich (1953) recorded the G.S.R. from ten subjects during work at colour naming on the "psychergometer". A correlation of .39 was obtained between log. conductance of the skin and rate of colour naming, which is significant at about the 3% level. The correlation between average skin conductance and the average number of blocks is -.60, which is significant beyond the 1% level. This implies that a decrease in general bodily tension is associated with a decrease in the rate of work and an increase in the rate of "blocking".

Once again it may help to clarify the situation if a summary of results is given in tabular form. On the next page the three experiments concerned with the relation between the difficulty of a task and the degree of tension exerted are listed, and on the following page, Table II.11. gives details of the findings of the six experiments which deal with the relation between work output and muscular tension.

Worker	Locus of recording	Nature of task	Findings
1. Stroud (1931)	Right forearm and hand	Stylus maze learning	More difficult problems associated with higher mean tension (not necessarily found in individual cases).
2. Davis (1938)	Right forearm and neck	Number problems	More difficult problems associated with higher mean tension (no details of individual cases).
3. Hadley (1941)	Left forearm	Multiplication	More difficult problems associated with higher mean tension (not necessarily found in individual cases).

Table II.10. Relation between difficulty of task and degree of tension.

Worker	Locus of recording	Nature of task	Findings
1. White (1935)	G.S.R.	Recall	Better learners were more tense during final rest period and possibly during work.
2. Clites (1935,6)	General body tension	Problem solving	Successful solvers showed larger tension increases from rest to work.
3. Brown (1937)	G.S.R.	Recall	Better learners were less tense, especially at end of task.
4. Davis (1937)	Right forearm	Memorizing, addition, multiplication	Greater work output associated with more tension in initial rest period and with smaller increase when work began. Practised performers were less tense.
5. Davis (1938)	Right forearm and neck	Number problems	Successful and unsuccessful subjects were equally tense.
6. Geldreich (1953)	G.S.R.	Colour naming	Greater work output (increase in speed and fewer blocks) associated with increased tension.

Table II.11. Relation between work output and degree of tension.

With regard to the first table it is possible to draw a common conclusion. More difficult problems give rise to higher tension levels in the forearm and neck musculature, but this appears only when records are pooled from many subjects and is not necessarily observable in individual records.

It might nevertheless be thought to follow from this that the better performers, who presumably find the task easier, should show lower tension levels during work. And in line with this, Davis (1937) found practised performers were possibly less tense. (See table II.11.) When it came to problem solving, however, he was not able to distinguish between the successful and unsuccessful,(Davis, 1938), unlike Clites who found the successful were more tense during the work period and during the period of report. The discrepancy between Davis and Clites is probably due to one of the differences already mentioned, either the difference in the loci of recording, or in the criteria of success.

Davis' earlier finding that practised performers were less tense is, as we have pointed out, capable of a different interpretation in terms of habituation or familiarity with the laboratory situation, but nevertheless it does accord with expectations. As Davis was the only worker besides Clites to employ the action potential method of recording, his results are probably more trustworthy than the three other investigators who disagree with him. They found a positive correlation between work output and tension during the task (apart from Brown who included abnormal subjects in his experiment), while Davis' only positive correlation was with tension level during preliminary rest. But this, as we have suggested, was probably due to his subjects working at the tasks before the work period proper began, especially as most of the correlation has its source in the addition task where the complicated instructions made this tendency most prevalent. White's finding that better learners were more tense during a final rest period is probably explicable in terms of a carry-over of tension from work.

It is not possible to come to any certain conclusions. If we regard Davis' finding of a lack of correlation between work output and tension during the task as springing from the active preparatory set of his subjects, we are left with an agreed conclusion to the effect that better performers are more tense during work, a conclusion derived, however, indirectly from the G.S.R. technique.

The next section of this review may help to clarify matters when the effects of inducing tension are taken into account.

Chapter 3.

The Effect of Induced Muscular Tension on Mental Work.

As long ago as 1899 Breese had discovered an increase in visual acuity occurred when subjects pressed their arms against their sides. But Bills (1927) appears to have been the first worker to have investigated the relationship between induced muscular tension and mental activity with the desire to obtain experimental evidence on the contraversial issue between the central and peripheral theorists. Were the muscular tensions accompanying mental effort a mere "overflow" phenomenon, as the central theory demanded, or were they, as Washburn thought, "an essential part of directed thought"?

Bills attacked four aspects of the problem:

(1) Would an increase in muscular tension beyond the normal level result in an increase in the efficiency of mental work? If so, the peripheral phenomena must have a direct influence on central processes.

(2) Would the effect of induced tension increase or decrease during continuous work? Would muscular fatigue affect mental fatigue?

(3) Would the effect of induced tension increase or decrease with practice?

(4) Would results depend on the criterion of efficiency employed?

Nine subjects took part in the first experiment. The task consisted of a series of nonsense syllables which were to be learned under either normal or tension conditions. Under tension conditions S squeezed a dynamometer continuously during work. Twenty lists of nine syllables each were learned, ten lists under tension and ten lists as a control.

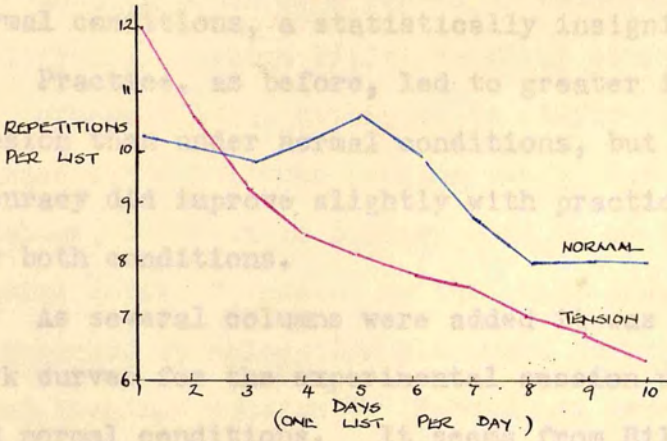
Three criteria of learning were employed and all showed a marked increase in efficiency had occurred under tension.

(a) Learning time decreased by 13% under tension,

(b) Recall score calculated by the savings method showed a 6% improvement under tension, and

(c) the absolute number of syllables recalled was 13% greater under tension.

The influence of practice on the relative efficiency of the two conditions was determined by plotting daily scores over a period of ten days. If learning time was taken as the criterion, tension had a decided effect in causing a more rapid increase in speed due to practice. For the other criteria, the initial difference in favour of the tension condition tended to disappear and the curves approached one another. Graph III.1. shows the results obtained with learning time. Very similar results were obtained with a different task, learning paired associates.



Graph III.1. The effect of practice on learning under normal and tension conditions. (Bills, 1927)

In another experiment continuous mental addition was used. Eleven subjects added twelve columns of 20 digits per column. Two measures were calculated: (a) the time taken to add the column, and (b) the accuracy of the reported sum. Once again work took place under both tension and normal conditions.

The average time taken to add the 20 digits under tension was 23.3 secs., and under normal conditions 25.7 secs. The difference is significant and there were no exceptions to the rule.

The average number of columns correctly added each session under tension was 5.4 compared with 5.1 under normal conditions, a statistically insignificant difference.

Practice, as before, led to greater improvement under tension than under normal conditions, but only in speed. Accuracy did improve slightly with practice, but equally for both conditions.

As several columns were added it was possible to obtain work curves for the experimental session under both tension and normal conditions. It seems from Bills' graph that the result of continuous work was to enhance the superiority of the tension conditions where speed was the criterion, but not where accuracy was concerned.

Bills concluded from these experiments:

(1) "That muscular tension, of the form and amount used by us, does facilitate the efficiency of mental work of the kinds tried.

(2) "That the increase in efficiency gained by tension is enhanced by practice, where speed is the criterion, but remains constant where other criteria or sets are used.

(3) "That the added efficiency gained by using tension tends to increase as S grows more fatigued, when speed is the criterion, but remains constant where other criteria are used."

(Bills, 1927. p.249.)

The evidence seems to support a peripheral theory of thought, although as Bills wisely pointed out, the tensions which normally accompany thought may not function in a similar way to those induced in this experiment.

This work has been reported in some detail as it formed the starting point of a series of researches which were to amplify and question Bills' original conclusions.

Freeman (1933) attempted to clarify the physiological changes occurring when tension was induced. Did the localized increase in tension lead to an increase in the general level of tension in the whole body, or was it accompanied by relaxation elsewhere so that the general level remained constant? Recordings were made from the quadriceps muscle while subjects held weights in their hands. A spread of tension always occurred which involved the quadriceps muscle. A similar spread of tension occurred when subjects maintained an erect sitting posture.

This evidence really affords no answer to the question. There may well have been relaxation elsewhere. It is not justifiable to conclude that so-called general bodily tension has increased from a recording made at one remote muscle group. The effect of erect posture on quadriceps tension is interesting and may be of some relevance in any comparison of experimental procedures.

Stauffacher (1937) took Bills' work a step further. In the light of Jacobson's finding that complete lack of tension inhibited all mental work, and Freeman's suggestion that the very tense were not as efficient as the less tense (Freeman, 1933), it appeared likely that there might be an optimum degree of tension for a task.

Stauffacher employed 40 students as subjects who learned series of nonsense syllables under four different conditions: (1) with no induced tension, (2) with one quarter of maximum pull, (3) with one half of maximum pull, and (4) with three-quarters of maximum pull. In order to obtain the maximum pull reading S pulled on a dynamometer handle for one minute. The reading at the end of the minute became the maximum pull figure for that subject. Weights were then made up into the various fractions required and suspended over a pulley. S had to pull the weights off the floor and keep them lifted during the work period.

It was found that all tension conditions were facilitative, the half maximum pull being clearly the best and the only one that differed significantly from the resting level.

Table III.1. Relationship between degree of induced tension and ability to memorize. (Stauffacher, 1937.)

Condition	Amount of induced tension	Number of syllables correctly anticipated (Means)
1	0	5.2 ± 0.23
2	1/4	5.6 ± 0.21
3	1/2	6.3 ± 0.23
4	3/4	5.4 ± 0.25

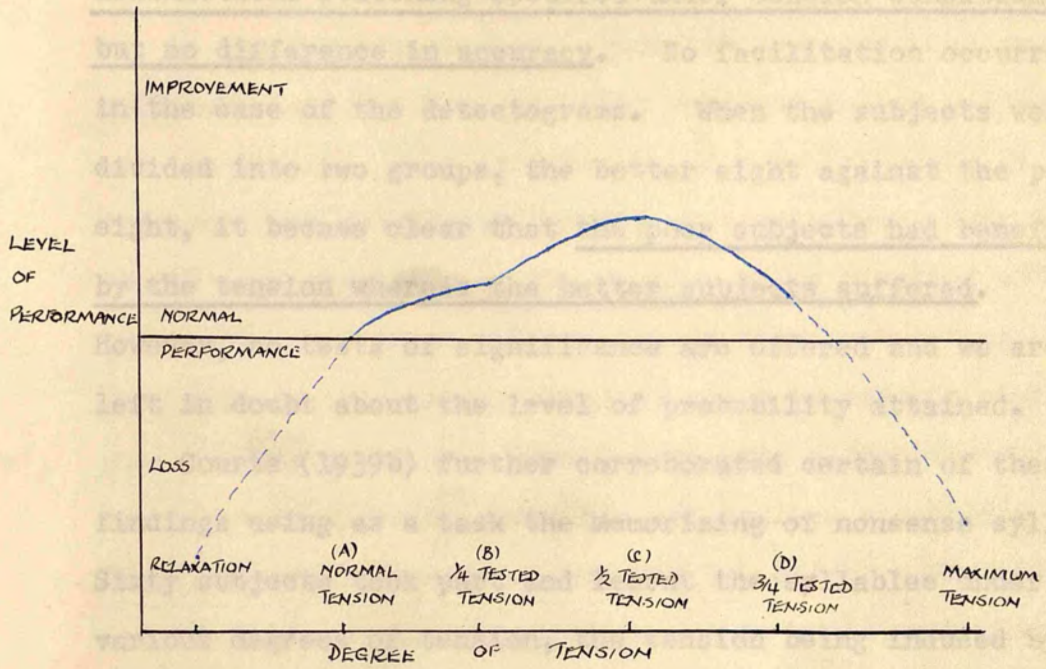
These averages tend to obscure the actual effects of tension. If subjects are divided into good, poor, and mediocre performers the following table is obtained:

Table III.2. The effect of induced tension (1/2 maximum pull) on the performance of subjects of different ability. (Stauffacher, 1937.)

	Number of trials required to learn lists.		
	Normal	Tension	Difference
Good performers (14)	19.5	20.9	-1.4
Poor performers (14)	40.5	32.6	7.9
Mediocre performers (12)	29.2	27.0	2.2

Only the poor performers appear to have benefited to any degree in their learning by the induction of tension, i.e. only 14 of the 40 subjects.

Stauffacher considered a possible explanation of this fact lay in the difference that might exist between good and poor performers in their normal levels of tension during work. Suppose the good performers have a higher level of tension than the poor performers before the induction of tension. The increment in tension will in the case of the former lead to an excess of tension over and above the facilitative amount, whereas in the case of the latter it will approach more closely to the optimum level. The following graph (Graph III.2.) depicts this hypothesis.



Graph III.2. Stauffacher's U-curve hypothesis. (Stauffacher, 1937.)

Bills and Stauffacher (1937) confirmed these results. They used more complex tasks, arithmetical reasoning and "detectograms". These were short detective stories of a page in length, full of irrelevant detail from which the essential clue had to be picked out. Tension was induced by lifting weights of 14 lbs.

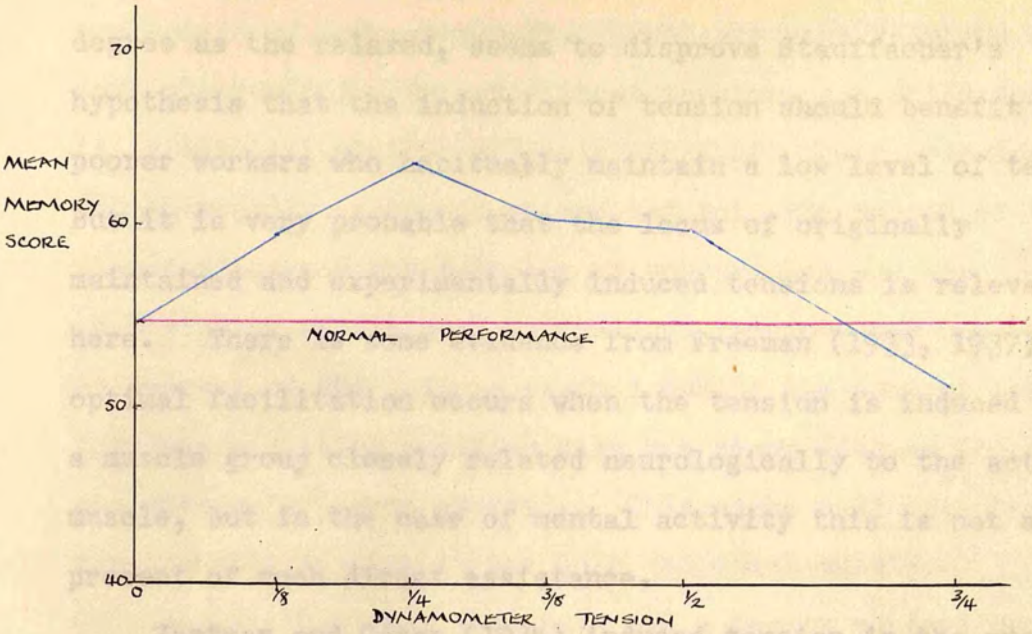
Statistically significant increases in speed of arithmetical reasoning occurred under tension conditions but no difference in accuracy. No facilitation occurred in the case of the detectograms. When the subjects were divided into two groups, the better eight against the poorer eight, it became clear that the poor subjects had benefited by the tension whereas the better subjects suffered. However, no tests of significance are offered and we are left in doubt about the level of probability attained.

Courts (1939b) further corroborated certain of these findings using as a task the memorizing of nonsense syllables. Sixty subjects took part and learnt the syllables under various degrees of tension, the tension being induced by squeezing a dynamometer. Meanwhile, the thickening of the quadriceps muscle in response to a regular tendon tap was taken as an index of tension.

It was found that the greatest facilitation occurred when an amount of tension equal to 1/4 of maximum effort was induced. If tension was increased beyond this figure, performance fell off until at 3/4 maximum tension memorization fell below the normal (no tension) condition. (See Graph III.3.)

Although the shape of the curve is similar to that obtained by Stauffacher the scale on the abscissa is different. Whereas Stauffacher found the 3/4 maximum tension condition facilitative, Courts obtained a memory score with this degree of tension that was lower than the control (no tension) condition. Tension was not induced in an exactly similar way in the two experiments. Courts' subjects squeezed a dynamometer, but Stauffacher's subjects pulled weights off the floor. What is probably of more relevance is the different way fractional amounts of tension were computed. Courts took fractions of the maximum value attained after 30 seconds continuous squeeze, while Stauffacher took fractions of the maximum attained after 60 seconds continual pull. This might mean that Courts used higher fractional tension values during work, his 1/4 maximum resembling Stauffacher's 1/2 maximum, and his 3/4 effort approaching Stauffacher's maximum condition. This would mean that there was considerable agreement between the two experiments, Courts having extended Stauffacher's work to confirm the hypothesized detrimental effect of high degrees of induced tension.

However, Courts observed no differential effect between good and poor performers. All subjects memorized most efficiently at the 1/4 maximum level, and the means of these optimal tensions did not differ significantly. When the subjects were divided into two further groups on the basis of their normal level of tension (high or low) during memorizing, it was found that the induction of tension affected both groups similarly and there was no significant difference in performance.



Graph III.3. The effect of variation in tension on performance. (Courts, 1939.)

Courts' groups of good and poor learners each contained 21 subjects, whereas Stauffacher's contained ten. Whether this means that those with more extreme scores were chosen in Stauffacher's experiment it is impossible to say, as the two experiments are not directly comparable although both tasks entailed memorizing. If it were the case, the fact that Courts' results are in the expected direction, without however reaching significance, would suggest that there may not be a true disagreement.

Courts' finding, to the effect that induced tension alters the performance of the tense subjects to the same degree as the relaxed, seems to disprove Stauffacher's hypothesis that the induction of tension should benefit the poorer workers who habitually maintain a low level of tension. But it is very probable that the locus of originally maintained and experimentally induced tensions is relevant here. There is some evidence from Freeman (1933, 1937) that optimal facilitation occurs when the tension is induced in a muscle group closely related neurologically to the active muscle, but in the case of mental activity this is not at present of much direct assistance.

Zartman and Cason (1934) induced tension in the muscles of the right leg while their subjects worked at a series of mathematical problems selected from various intelligence tests. A temsion of between 25 and 40 pounds was induced by means of a pedal mounted on springs which had to be pushed with the foot. The problems were timed and mistakes recorded. A correlation of $-.20 \pm .02$ was obtained between speed of solution and average pressure exerted during work.

The contradiction with earlier work might spring, as they suggest, from the greater complexity of the tasks they employed, which would agree with Bills and Stauffacher's findings from the detectograms. Or it might arise from the difference in the locus of induced tension. Bills (1937) in a critique of their experiment considers it likely that the control condition was one of residual tension owing to the design of the experiment. Subjects were required to work alternately with and without tension, and Bills thinks it is doubtful whether subjects can shift their muscular set so rapidly, although we are not told the length of time elapsing between the solution of one problem and the presentation of the next. Residual tensions may have existed on account of the posture assumed during the control periods. This was a sitting position with the right foot on the pedal but with no pressure exerted. This might well have led to considerable tension in the shin and thigh muscles.

Block (1936) may also have had a faulty control condition due to postural tensions. Subjects sat in a straight-backed chair and worked at analogy and syllogistic reasoning problems and continuous addition while tension was induced in the legs, or forearms, or both. Five degrees of tension were used (8, 15, 22, 48, and 56 lbs.) and in no case was an improvement seen over the control condition when group results were examined. But half the subjects found the 15 and 22 lbs. of tension facilitative when speed was the criterion, and two-thirds of them when accuracy was the criterion. AS the amounts of tension were identical for all subjects, and individual differences in strength were not taken into account, optimal values were unlikely to have been the same for all. Individual differences might well have cancelled one another out, and group trends would then become insignificant. It seems important to take into account these differences in strength as Stauffacher did.

Both Zartman and Cason's experiment and Block's seem to suffer from inadequate relaxation during the control condition and this may be the reason for their negative results. The greater complexity of their tasks may have played a part, although this does not appear to be generally the case. Courts (1942) has published a list of tasks which have been shown to be facilitated by induced tension and a further list of those which show no improvement or detrimental effects.

The following were facilitated: memorizing, pursuit learning, reaction time, latent time of blocking of the alpha rhythm, finger oscillation, addition of columns of digits, letter-naming, tapping, conditioned salivary response in dogs, maze learning, vibratory threshold, startle response, threshold for electric shock, and knee jerk. To these we can add perceptual span for digits (Shaw, 1956).

The following showed no effect: continuous addition, syllogistic reasoning and selection of analogies, affective judgements, and the eyelid reflex.

The following were impaired: mirror tracing, tossing tennis balls at a target, and postural steadiness. To these we can add arithmetical problem solving (Zartman and Cason, 1934).

It is difficult to abstract anything common to each group, and it certainly is not feasible to order the tasks in difficulty. Few of them are "mental" tasks, and the majority of these come in the first and second lists, i.e. those which were facilitated or showed no effect. As we have seen, Block's results are probably not trustworthy, but from the remainder of the work reviewed it seems safe to conclude that induced tensions facilitate most forms of mental work employed in the laboratory. The group of tasks in which the induction of tension shows a detrimental effect seems to be largely made up of motor skills, apart from Zartman and Cason's experiment the results of which are possibly also suspect.

It is perhaps going beyond this evidence to conclude that although induced tension facilitates "mental" work, it interferes with the acquisition of motor skills. There are insufficient data at present. In any case it is doubtful if it is useful or indeed possible to distinguish sharply between "mental" and "motor" tasks.

Returning now to the results summarized in Part 2 of Chapter 3, it may be possible to come to some general conclusions.

The bulk of evidence, derived from indirect methods, suggests that better performers are more tense during work, and the evidence from induced tension experiments supports this observation. The induction of tension appears to facilitate mental work, at any rate of the simpler kind, although group effects are misleading as individual differences may cancel one another out. This is due to the fact that the better performers, who are more tense during work, do not improve their performance when additional tension is supplied, whereas the poorer performers appear to be brought to their optimum (the U-curve hypothesis).

The problem is undoubtedly much more complex than this statement implies, as the time, locus, and amount of induced tension must interact in some way with the time, locus, and amount of tension "naturally" present during mental work to produce continually-changing patterns of afferent kinaesthetic feed-back to which justice cannot be done with the inadequate measuring instruments available to-day.

Several writers have put forward hypotheses about the ways in which induced tension brings about its effects; these suggestions can best be considered in the theoretical discussion in Chapter 7 of this thesis.

Chapter 4.

The Analysis of Mental Work Output.

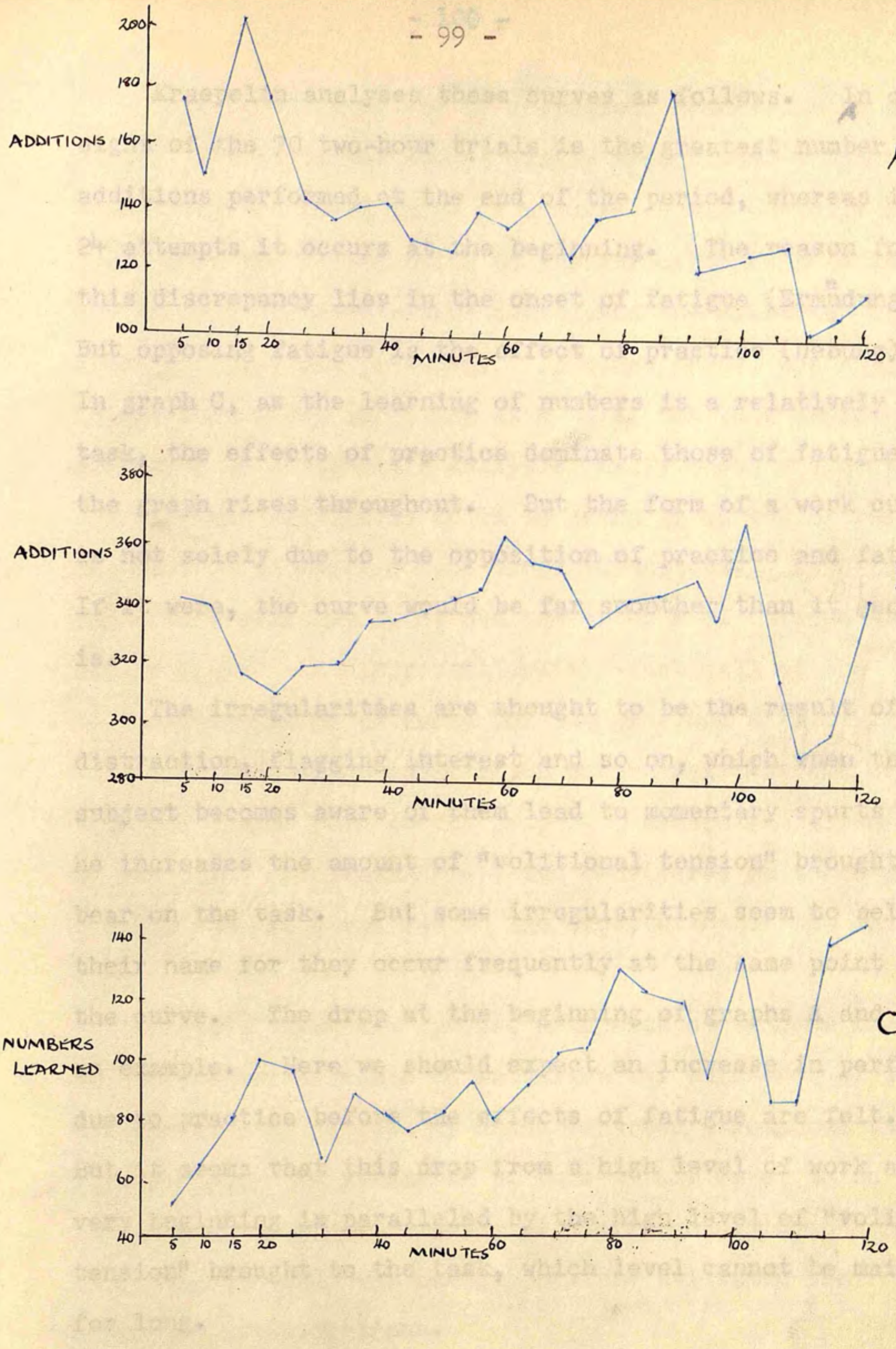
On reading the foregoing accounts of attempts to clarify the relationship between muscular tension and mental performance one is struck by the scant justice paid to the complexity of work curve analysis. For example, the fluctuations in tension which occur during the process of work might be thought to be related to similar fluctuations in work efficiency, but little attempt has been made to relate the two. It would seem apposite to consider here rather briefly what is known about the variations in mental performance during a work period, before describing the present experimental attack on its association with muscular tension.

Kraepelin was the first psychologist to study mental work experimentally. In the several volumes of the "Psychologische Arbeiten" he and his co-workers reported many investigations into the psychological aspects of work both in the laboratory and in the field.

Laboratory tasks included learning lists of nonsense syllables and numbers besides the more frequently used addition sums. The additions were carried out in a particular way, the numbers being added in pairs. The work sheet consisted of as many as 2000 numbers arranged in 40 columns of 50 numbers each. Subjects added the columns vertically, a pair at a time. The sum of the two digits was occasionally spoken but more often written down. Every integer was used twice, the second addend of the first problem being taken as the first addend of the next pair. The object of this procedure was to obtain uniformity over long periods of work.

The duration of tasks varied from 30 minutes to two hours, usually occupying an hour. In order to follow the course of work, subjects drew a line every time a signal was given, generally every three minutes. This enabled the experimenter to plot "work curves" which showed the fluctuations in output during the work period.

Three typical work curves taken from Kraepelin's "Die Arbeitscurve" (1902) are shown in the graphs on the next page. A and B are from an experiment by Oehrn in which two subjects performed Kraepelinian addition for two hours; C is from an experiment by Ebbinghaus in which numbers were learnt, also over a period of two hours.



Graph IV.1. Typical work curves. (Kraepelin, 1902.)

Kraepelin analyses these curves as follows. In only eight of the 70 two-hour trials is the greatest number of additions performed at the end of the period, whereas in 24 attempts it occurs at the beginning. The reason for this discrepancy lies in the onset of fatigue (Ermüdung). But opposing fatigue is the effect of practice (Uebung). In graph C, as the learning of numbers is a relatively strange task, the effects of practice dominate those of fatigue and the graph rises throughout. But the form of a work curve is not solely due to the opposition of practice and fatigue. If it were, the curve would be far smoother than it generally is.

The irregularities are thought to be the result of distraction, flagging interest and so on, which when the subject becomes aware of them lead to momentary spurts as he increases the amount of "volitional tension" brought to bear on the task. But some irregularities seem to belie their name for they occur frequently at the same point of the curve. The drop at the beginning of graphs A and B is an example. Here we should expect an increase in performance due to practice before the effects of fatigue are felt. But it seems that this drop from a high level of work at the very beginning is paralleled by the high level of "volitional tension" brought to the task, which level cannot be maintained for long.

This spurt (Antrieb) is a frequent occurrence in work curves, but it is not always easily recognized. Kraepelin considered the first value of a curve should normally be lower than the second owing to the influence of practice, and if this difference were diminished the existence of a starting spurt was presumed. In other words, the subject can be apparently improving at a task, but this improvement according to Kraepelin's analysis really masks a slowing down.

Another difficulty is to be found in curves of very tiring work in which output drops throughout. Here the signs of a starting spurt and the effects of fatigue are intermingled. A disproportionately fast fall at the beginning would be evidence for the presence of a spurt here.

A second marked spurt often occurs near the end of a task and can be seen in the graphs. Kraepelin called this an end spurt (Schlussantrieb) and considered on introspective grounds that this was due to the expectation of the end of work.

Besides these two spurts, Kraepelin considered there was sufficient evidence to establish the existence of a regular wave in efficiency which occurred throughout the work period. He attempted to relate this wave, which Voss (1899) claimed had a duration of 2.6 seconds, to conscious feelings, but this was hardly possible utilizing the subjects' retrospections.

Other factors affecting the course of work are even more hypothetical and we shall not be concerned with them here. In order to help his analysis, Kraepelin also used experimentally induced rest pauses, and in a series of careful experimental studies he and his pupils analysed the factors which determined the efficacy of the rest pause. This work was continued in a more practical setting by the early English industrial psychologists (H.M.Vernon, 1924; S.Wyatt; 1927).

Kraepelin's work has come in for just criticism. To begin with, the terms he used to describe the shape of the work curve may be understood in two ways. Either they refer to the objective observable results, or to the consciously felt "causes" of these changes. It is risking confusion to use the objective and subjective meanings synomymously. For one thing it is extremely doubtful whether certain subjective feelings are the unvarying concomitants of the corresponding objective fluctuations. There is a great deal of evidence, summarized by Bartley and Chute (1946), to suggest that they generally are not. For example, Poffenberger's work (1928) demonstrated that a rise in output could be accompanied by a drop in feeling tone. The difficulty in defining "fatigue" is witness to the fact that one can either employ subjective or objective criteria, but not both together. Kraepelin seems to use both objective and subjective criteria interchangeably. More frequently, perhaps, terms like starting and end spurt were defined subjectively as spurts in "volitional tension" which caused changes in work output. Reliance was placed on introspective evidence throughout the "Arbeitscurve", and yet work was never interrupted to record introspections, or prompt retrospections; they were inevitably retrospections after a lapse of as much as two hours.

Furthermore the number of subjects used was too small to admit much in the way of generalization. This criticism applies to nearly all the early work, where often indeed the experimenter himself acted as the sole subject, possibly on account of the tedious nature of the task. Studies with small numbers can be most useful in taking account of individual differences, but the traditional Wundtian approach hoped to demonstrate uniformities in response and individual differences were ignored by Kraepelin and his students.

In criticising the experimental conditions it must not be forgotten that Kraepelin and the other early workers in this field were careful and skilled experimentalists. Their results are valid under the stated conditions, and although their theoretical analysis may appear dated, these results and the discrepancies occasionally found between them and later investigators still need to be taken into account.

Kraepelin's pupils extended and verified much of his work. As none of this work is directly relevant to our purpose we will pass on to Thorndike's contribution.

Thorndike (1913) believed that the initial spurt was "certainly not characteristic of work curves in general", (p.48), and in support of this claim published results obtained with addition and multiplication tasks. Five subjects worked at addition for one and a half or two hours and recorded the time at the completion of each row of 16 examples. Twenty-one different rows were used. Time scores were corrected for errors by the addition of five seconds for each error.

The following table is modified from Thorndike and shows the time taken in seconds to add the first four rows by each of the five subjects.

Table IV.1. Corrected time scores for five subjects working at addition. (Modified from Thorndike, 1913.)

	Subjects.					
Row	A	B	C	D	E	Means
1	100	284	164	186	149	177
2	200	311	146	183	142	176
3	104	318	143	206	155	184
4	100	301	'138	186	158	180

It can be seen that only one subject, subject B, has apparently produced a starting spurt, although Thorndike claims that exactly opposite trends can be observed in the same individual on other occasions.

With regard to the end spurt not one subject of the five "showed a consistent tendency to increase his efficiency by even five per cent during the last five or ten minutes".(p.60).

Thorndike finally concludes,

> "Fluctuations of considerable amount occur in any one work period for any one subject, but except for a rise in achievement of approximately four per cent near the end when the date of the end is known, no regularity in them has been proved for any one of them for any one subject in any one sort of work, much less for any one subject in all sorts of work, or for all subjects in any one sort of work. The supposed law that the very first few minutes (is a period of) specially high efficiency (is) not supported by the facts. -------- The most important fact about the curve of efficiency of a function under two hours or less continuous maximal exercise is that it is, when freed of daily eccentricities, so near a straight line and so near a horizontal line. The work grows much less satisfying or much more unbearable, but not less effective." (p.69)

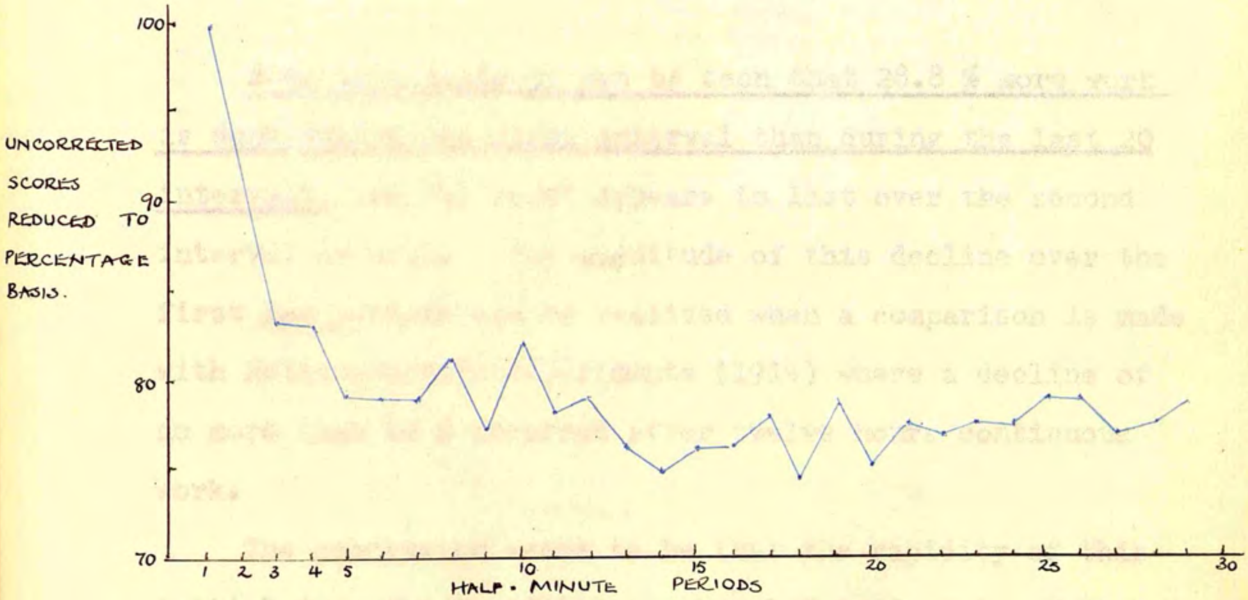
Thorndike is in accord with the psychological practice of his day in restricting the use of the words "starting" and "end spurt" to observable fluctuations in efficiency. We do not have to suffer the confusions due to the double reference of Kraepelin's terms.

The discrepancy in objective results between Thorndike and the Kraepelin school is not easily resolved. The bulk of the later evidence is for the reality of the starting and end spurts especially over short time periods. This does not explain the different results obtained by Thorndike and Kraepelin as they both used rather large units. Thorndike's were approximately two minutes and Kraepelin's three minutes in duration.) The difference may be explicable in terms of the number of subjects used, the mechanics of the adding operation required, and motivational differences. But this is conjecture. It is probable that Thorndike obscured some points of interest by the use of an arbitrary weighted score instead of presenting accuracy and speed scores separately. Faster speed combined with greater inaccuracy would not be revealed at all. These scores are best examined separately.

Chapman and Nolan (1916) considered the weakness of previous experiments on the starting spurt lay in the use of intervals of time too long to reveal the rapid decline in efficiency which takes place. They employed thirty-second intervals for recording the amount of work done at an addition task. Addition blanks similar to those used by Thorndike were employed and 20 female subjects worked continuously at these for 16 minutes once a day for seven days. At each thirty-second interval the word "Check" was called by the experimenter and subjects made a mark showing the place reached in their work. Subjects were not allowed to see the work before the starting signal, nor did they know the purpose of the experiment.

As the addition sheets consisted of 48 columns of ten one-place numbers, it was decided to award ten points for each column correctly added and to subtract ten points for each column with an error. However, this is such an arbitrary procedure that it seems safer to place reliance on the scores uncorrected in this way, although in this instance both methods of scoring show similar trends.

The following graph is modified from Chapman and Nolan and gives a good indication of the marked trend obtained.



Graph IV.2. Output at addition over 15 minutes. (Modified from Chapman and Nolan, 1916.)

If we compare the scores in each interval with the average score of the last 20 intervals the following table is obtained:

Table IV.2. Comparison of scores obtained in the first ten intervals with the average for the last twenty. (Chapman and Nolan, 1916.)

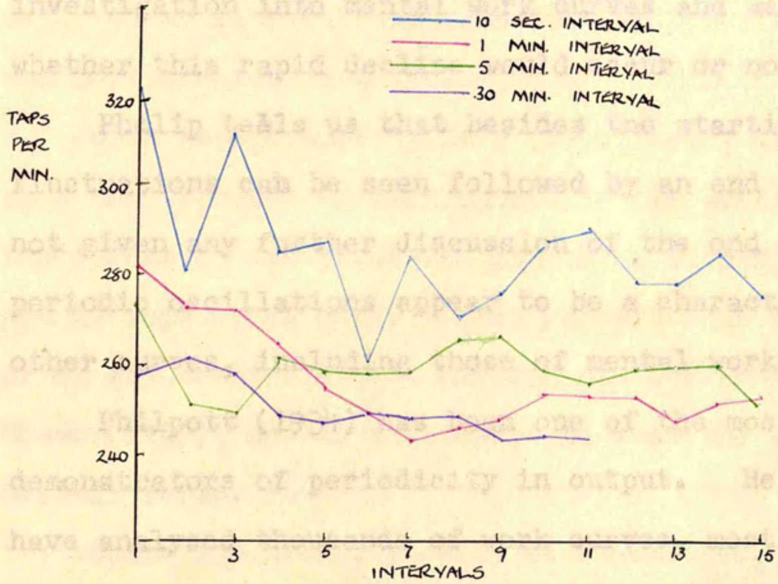
Interval	1	2	3	4	5	6	7	8	9	10
% by which each interval exceeds av. for last 20.	28.8	13.1	6.3	6.3	1.4	2.3	1.4	4.5	-1.4	5.9

From this table it can be seen that 28.8 % more work is done during the first interval than during the last 20 intervals, and the spurt appears to last over the second interval as well. The magnitude of this decline over the first few periods can be realised when a comparison is made with Hollingworth's experiments (1914) where a decline of no more than 10 % occurred after twelve hours continuous work.

The conclusion seems to be that the rapidity of this initial decrease in efficiency has led to denials of its existence, but that it is very pronounced when output is mesured more finely over half-minute periods.

Philip (1939) was able to employ recording intervals as short as ten seconds in his studies of high speed continuous work. The task was not a mental one; it consisted of tapping alternately on two metal plates with a stylus at maximum speed. The rate of tapping was recorded by counters. Twelve subjects took part in the experiments and were required to work at the task until they were too exhausted to continue.

Graph IV.3. below shows the work output for all subjects over the first 15 intervals. Various size intervals were used: 10 sec., 1 min., 5 min., and 30 min.



Gra ph IV.3. Work output at a tapping task. (Philip, 1939.)

It can be seen that the curves are similar no matter what the size of the intervals. All curves show an early slump followed by a subsequent rise, except the curve for the 30 minute interval which is too long to show a starting spurt.

The conclusion seems to be that in a task of this nature there is a steep decrement from the very beginning of the task even when intervals as short as ten seconds are employed.

Unfortunately there seems to have been no comparable investigation into mental work curves and we do not know whether this rapid decline would occur or not.

Philip tells us that besides the starting spurt periodic fluctuations can be seen followed by an end spurt. We are not given any further discussion of the end spurt, but the periodic oscillations appear to be a characteristic of many other curves, including those of mental work.

Philpott (1934) has been one of the most persistent demonstrators of periodicity in output. He and his pupils have analysed thousands of work curves, mostly of mental addition, and appear to have demonstrated that the periodic fluctuations progress geometrically, and so occur at ever widening distances from one another. Any given work curve is supposed to be composed of several different component periodicities which it is possible to analyse out mathematically. These basic periodicities are supposedly related to certain organic or rather sub-atomic constants.

It seems futile to follow such mathematical elaboration. The experimental work is too coarse to justify any attempt to find physical constants of this nature. It is possible to find periodicities in any work curve if small enough periods are chosen. And when gross methods of timing are used, the variability inherent in the work process itself and the fluctuations in the motivational state of the subject must combine to render supposed periodicities of cortical cell action mathematical artefacts with neither psychological nor physiological meaning.

Some recent work by Katz (1946, 1948, 1951) has opened up a new approach to work output in its consideration of the effect of the perceived length of a task on the rate and efficiency of work. This research can best be regarded as an elaboration of the experiments performed by Bills and Brown (1929), and as an attempt to view the results in Gestalt terms.

Bills and Brown, it will be remembered, required their subjects to add pairs of digits either over various periods of time or until certain amounts of work had been accomplished. Four periods of time were employed, 2, 4, 8, and 16 minutes in length, and four amount units, 135, 270, 540, and 1,080 pairs of digits.

They found with the "amount set" that the initial rate of work was directly proportional to the amount to be worked, but this was not found to hold in the case of the "time set".

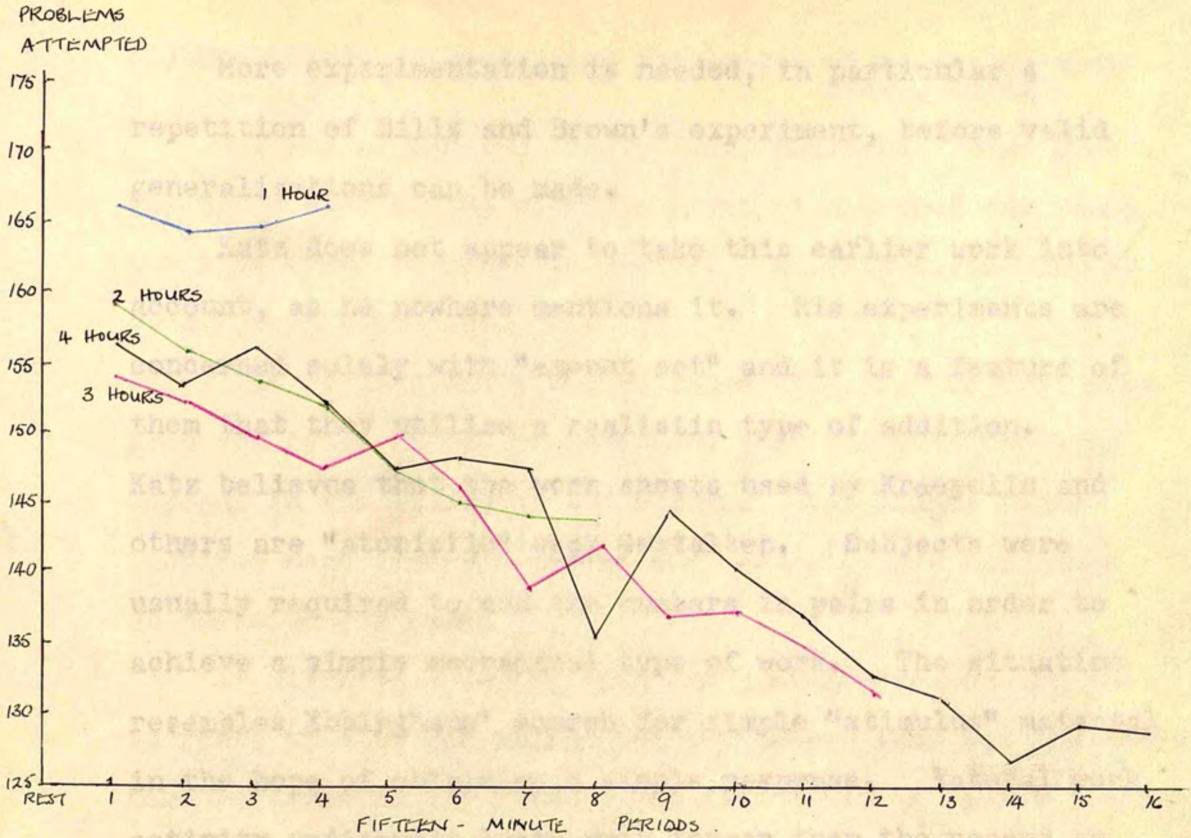
Krueger (1937) repeated the experiment with 36 subjects but employed larger units than Bills and Brown. Time units were 5, 25, and 50 minutes, and amount units were 500, 2000 , and 4000 pairs of digits.

Under these conditions it was found that the highest initial rates of work occurred in the two shortest periods of each type. So the two sets produced a similar effect.

Barmack (1939) investigated the "time set" for even longer work periods. Twenty-three subjects added pairs of six-place numbers for 4, 8, 12, and 16 fifteen-minute periods.

It was found that the rate of work for the shortest period was faster than any of the others. The initial rate (that is, over the first hour) for the two-hour period was faster than for the three-hour but not significantly greater than for the four-hour. Barmack suggests that this may be due to the extremely challenging nature of the longest period, presumably because it is the longest period. Subjects prepared themselves for this particular period in a more determined manner.

The following graph (Graph IV.4.) is taken from Barmack and gives a good comparative picture of work output.



Graph IV.4. Work output with different time sets.
(Barmack, 1939.)

The results agree with Krueger but not with Bills and Brown. Barmack suggests that the discrepancy may be due to the shorter tasks employed by the latter workers, or to the fact that they were only concerned with the output during the first quarter minute of the task, whereas Barmack measured the first hour's output.

More experimentation is needed, in particular a repetition of Bills and Brown's experiment, before valid generalizations can be made.

Katz does not appear to take this earlier work into account, as he nowhere mentions it. His experiments are concerned solely with "amount set" and it is a feature of them that they utilize a realistic type of addition. Katz believes that the work sheets used by Kraepelin and others are "atomistic" weak Gestalten. Subjects were usually required to add the numbers in pairs in order to achieve a simple mechanical type of work. The situation resembles Ebbinghaus' search for simple "stimulus" material in the hope of obtaiming a simple response. Natural work activity ordinarily lasts much longer than the second or so required by Kraepelin's subjects to add a pair of digits. That is to say, work on a Kraepelinian sheet consists of thousands of discrete work units, tied together by nothing more than "Und-Verbindungen" and not structured in any way. Results obtained from this sort of material, "a borderline case of intellectual work" (Katz, 1951. p.104.), cannot according to Katz be said to be typical of mental work in general.

In accordance with this view Katz used addition sums of one, two, or three columns and varied the length of the columns. We shall report only two of his experiments here, those most relevant to our argument.

(1) The effect of increasing the length of a single column. (Katz, 1946.)

Columns of various lengths were employed. The work was timed with a stop watch to 1/5th of a second excluding the time taken to write an answer. An unspecified number of subjects took part.

The results are given in Table IV.3. on the next page. From the table it can be concluded that the addition time depends on the length of the column. The longer tasks required more time per addend and more mistakes were made on these longer sums.

It might be objected that the probable reason for the increase in time per addend for the longer sums was the longer time required to say them. But Katz tells us that a similar increase is observed when pairs addition is employed and in that case the numbers do not increase in size as the addition proceeds.

Results then appear to be in line with the previous work. Subjects attack a piece of work at a speed dependent on the perceived length of the task. When the subject is not aware of the length of the task confronting him, as in a variation of this experiment, he attacks the problem cautiously and the starting spurt is weakened or eliminated. The situation is comparable to that of a runner confronted with a race of indeterminate distance, He is unlikely to sprint from the starting pistol in case the race proves to be a marathon.

Table IV.3. The effect of column length on adding efficiency. (Katz, 1946.)

No. of digits in col.	10	15	20	25	30	35	40	45	50	55	60
Average adding time (secs.)	4.2	10.4	17.4	24.2	33.4	37.2	46.7	63.9	69.2	74.6	80.2
Time per addend (secs.)	.42	.69	.87	.96	1.1	1.05	1.16	1.4	1.38	1.35	1.34
Mistakes (%)	8	9	13	9	11	12	18	17	15	18	21

Two specific criticisms can be mentioned here. It is difficult to see how Katz can deduce anything about a starting spurt occurring within a column from a measure of the total time taken over the whole column. Secondly, as pairs addition gives similar results, Katz has hardly proved his point about the use of continuous work Gestalten.

(2) The effect of employing addition sums of several columns. (Katz, 1951.)

Columns of 20 digits were arranged into sums of one, two, or three columns. Subjects were requested to add these sums in the ordinary way and to carry from one column to the next. In order to compensate for thisfigure introduced into the tens and hundreds columns, an extra figure was printed at the top of the units column. The addition of each column was timed.

Table IV.4. presents Katz's results obtained from ten subjects.

Table IV.4. Time required to add columns of one-digit, two-digit, and three-digit numbers. (Katz, 1951.)

	Units	Units	Tens	Units	Tens	Hundreds
Addition time in secs.	15.2	16.3	17.1	16.7	18.1	19.0
% errors.	22.8	14.2	16.5	7.4	14.8	24.0

It can be seen in the above table that (1) the time for the units column increases from the one-digit problems to the three-digit problems, (2) the hundreds column takes slightly longer to add than the tens column which in turn takes considerably longer than the units column, (3) the percentage error for the units column decreases from the one-digit to the three-digit problems, and (4) the number of errors increases from the units to the tens and from the tens to the hundreds column.

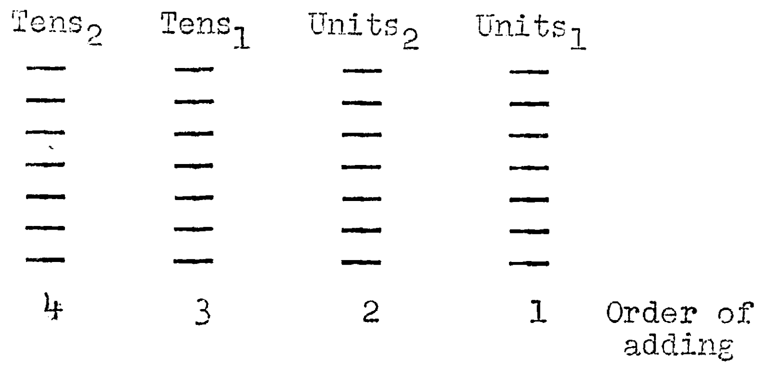
Katz interprets these results as follows: as the task becomes longer, the burden of expected work impairs performance on the units column. The subject works more slowly. But he also works more accurately, revealed by the fewer errors in the units column of the longer sums.

An error here, near the beginning, will lead to an error in the final result no matter how well the remaining columns are added. Finally, the tens and hundreds columns are added more slowly than the units column because they are tens and hundreds. That is, the nature of the digit, its "worth", will affect the ease with which it is handled.

Summing this up under one comprehensive rule Katz would say the progress and reliability of a piece of work are determined by the whole task of which it is a part. This rule resembles the most general Gestalt law of perception and so Katz calls it the primary Gestalt law of mental work.

The increased productivity during the first time unit (i.e. the units column) is of course understandable in terms of the starting spurt. Katz does not believe such an explanation is tenable, but thinks the difference in the "worth" of the digits is a sufficient cause. One experiment is offered to support this view and this is an inadequate one.

One subject added ten four-column sums. The work was printed in differently coloured inks as two two-column sums. These two sums were intermingled in such a way that the second column, instead of being the normal tens column, was to be considered as the units column of the second sum. The diagram on the next page shows the way the sums were printed; the columns were the normal distance apart. The arrows represent the way in which remainders were carried.



Under these conditions the following addition times were recorded:

(Col.1) Units$_1$ 11.2 secs. (Col.2) Units$_2$ 11.9 secs.
(Col.3) Tens$_1$ 15.0 secs. (Col.4) Tens$_2$ 14.8 secs.

For comparison, addition times for four columns added normally were:

(Col.1) Units 21.5 secs. (Col.2) Tens 26.1 secs.
(Col.3) Hundreds 26.5 secs. (Col.4) Thousands 25.7 secs.

Under these control conditions we find the tens column taking longer to add than the units. (The longer times in this table are not explained. Twenty-one figure columns were used in both the control and experimental investigations and the large differences must reflect subject variation.)

In the experimental investigation on the other hand, although the second column is added directly after the first, no decrement in performance occurs as one would expect if a starting spurt had been responsible for the usual decrement. It does not seem to be the order in which the work is performed which is important, but the nature of the digits concerned. If a column is considered to be made up of units rather than tens it will be added more quickly.

These results were not confirmed in an experiment by the present writer. Ten subjects were employed and each worked three trials. Adding was carried out in the same way as in Katz's experimental condition. The following means were obtained:

(Col.1)	$Units_1$	20.0 secs.	(Col.2)	$Units_2$	20.8 secs.
(Col.3)	$Tens_1$	21.8 secs.	(Col.4)	$Tens_2$	19.5 secs.

It can be seen that carrying in this unusual way does not disturb the normal course of events. The first column is added faster than the second, and the decrement appears to follow the familiar starting spurt.

Katz's work seems to suffer generally from the use of a poor method of timing and a complete lack of statistical treatment, leading to the overemphasis on results obtained from a very small number of subjects.

Although much of his work needs repetition it has value in its suggestion that we need to take into account the length of a task in any future investigation of the speed and efficiency of mental work.

There appears to have been no continuation of Katz's work by his students (Katz, 1952). There has been a confirmatory finding by Norrie Ward (1950) in quite a different field.

From the representative experiments reviewed here it seems possible to conclude:

(1) Mental work at simple tasks appears to be characterized by starting and end spurts which, certainly in the case of the former, occur over short intervals of time.

(2) There may also occur periodical fluctuations in efficiency, but the coarseness of the timing methods employed at present renders an analysis of this phenomenon difficult.

(3) The length of a task appears to determine the speed and accuracy of attack and therefore presumably influences the nature of the starting spurt.

Chapter 5.

Description of the Apparatus and Procedure. Design of the Experiment.

In the last chapter we attempted to establish the reliability of certain fluctuations in the curve of mental performance. It will be recalled that in an earlier chapter we similarly found evidence for fluctuations in muscular tension during mental work. There would appear to be a need to establish whether a relationship holds between these two variations. As Hadley (1941) has said,

> "Before the electromyograph can be used with any assurance as an index of psychological activity it must be shown that its variability from moment to moment is definitely correlated with variation in psychological process." (p.61)

This will require, as we have seen, the recording of mental output and the concomitant recording of muscular tension over short time intervals. It is strange that this aspect of electromyographic recording has attracted little attention. Here we have an extremely fast time-base, as we are dealing with molecular events proceeding rapidly, and yet records are generally treated in an imprecise manner, either sampled or summed. Part of the difficulty lies in the complexity of the trace obtained over periods as short as one second. A sampling procedure is a necessity, but as "fine" a sample as possible should be used.

The mental performance should be finely recorded too. This necessitates some sort of muscular response on the part of the subject. Normal speech is probably the simplest and most accustomed response to employ, as the moment of speaking can be timed by a voice-key and the content also recorded.

The task should be preferably one of a simple repetitive kind. Although it may not be possible to generalize from the results to more usual work it seems necessary in the present state of psychological knowledge to accumulate data and to repeat experiments on a simple level before attempting explanations of greater complexity.

Addition was chosen as the mental task in the present experiment as (1) it fulfils the above criterion, as (2) something is known of the locus of maximum tension during work of this kind, and as (3) it can be made a realistic and meaningful task to the subject.

It was necessary to employ various length sums in view of Katz's work, and as both speed and accuracy measures were needed over short time periods a tape recorder was used as well as an E.M.G. By asking subjects to add aloud it was possible to record the complete work process on the tape and thus to check later the accuracy of the work. One channel of the E.M.G. was employed as a voice-key, the muscular movements in the region of the tongue being recorded on the trace. The other channel picked up activity in the right forearm, the locus of maximum activity during work of this kind according to Davis (1939) and Voas (1952), and recorded the electromyogram on the same trace as the voice. We were able in this manner to measure the muscular activity at any moment during work and to attempt a correlation with mental efficiency.

It was then decided to attempt to disturb any such relationship. This could probably have been achieved through the alteration of the muscular processes by the administration of a drug such as curare which would affect the neuro-muscular transmission, or more simply by asking the subject to tense the relevant groups while he worked. This latter procedure was adopted. On the other hand alterations in the attitude to the work might also affect any correlation between output and tension; for example, if the subject were urged to add as quickly as possible in contrast to the normal conditions where he added at a self-regulated speed. This second method was also adopted. This means that recordings were taken from subjects working under three conditions: (1) Normal, (2) Induced muscular tension, and (3) Induced mental "tension".

The experimental technique and procedure are described more fully in the pages which follow.

Description of the Apparatus.

(1) Electrodes: As careful examination of the shape of the muscle potential spike is not required in the present experiment, surface electrodes are quite satisfactory. The non-muscular tissues and skin which intervene between the potential source and the recording surface will lead to distortion of the high-frequency component of the electromyogram, but since no pen recorder can follow these higher frequencies the loss is not important. Empirically it has been found that the electromyogram obtained in this way is a very useful one, its height, as we have seen, being a reliable indicator of the intensity of the muscular contraction.

Several factors affect the placement of surface electrodes: (a) Anatomical considerations, and (b) the orientation and separation of electrodes.

(a) The size and depth of a muscle are important. Large muscles will give a large strong electrical field, small muscles a small weak one. There will be considerable attenuation of signals from deep muscles.

(b) Although a pair of electrodes placed in any position over a muscle group will pick up some activity, the direction of the largest signals is usually parallel with the muscle fibres themselves. The separation of the electrodes is also relevant: narrowly spaced electrodes yield lower potentials than more widely spaced ones, probably because information from deeper layers becomes available. Too wide a spacing on the other hand will lead to interference and the inclusion of the electrocardiogram.

In the present experiment electrodes were placed on the dorsal surface of the right forearm, a site which has been found in previous studies to be the locus of considerable activity during mental arithmetic. The spacing and direction of the electrodes were in accordance with the requirements already mentioned. The first electrode was placed over a point approximately one third of the distance from the lateral humeral epicondyle to the styloid process of the ulna. The centre of the second electrode was placed two inches along this same line in a distal direction. In such a position the electrodes were over the belly of the superficial extensor muscles of the forearm and would be expected to pick up maximum activity from this region during extension of the wrist or fingers.

A second pair of electrodes was used to indicate the moment of speaking. There was less need for accurate placement here and a process of trial and error ensued until a clearly defined outburst of activity occurred when S spoke. Generally it was best to site one electrode above and one below the point of the chin in the midline. The lower electrode is roughly over the digastric and genioglossus muscles of the tongue.

The electrodes were made from cubes of natural sponge soaked in saline. These are recommended by Travis and Kennedy (1947) and Davis (1953). A half-inch cube was cut from a sponge and a bared wire "tinned" with solder, forced through a hole in the sponge and then brought back through a second hole and twisted on itself to form a loop. By being soaked in saline the sponge is made to form a good conductor and has the advantage over more conventional methods of being light and having low resistance. The resistance between a pair of electrodes of this type varied between 3 and 25 kilohms. A high resistance does not appear to affect the fidelity of the recording, but makes it more susceptible to 50 cycle pick-up. Too low a resistance on the other hand usually means a conducting bridge of saline has formed between the electrodes, and E.M.G. potentials will be distorted and considerably attenuated.

To hold the electrodes in place over the muscle group concerned, strips of zinc plaster, half an inch wide, were used. These seemed fairly satisfactory in that they held the electrodes firmly against the skin, were not extensive enough to cause vasoconstriction, and did not interfere with the mechanical action of the muscles. However, any extensive contraction of the forearm musculature or stretching of the skin could have pulled on the plaster and have led to movement of the electrode cubes with the inclusion of artefacts in the recording. It is unlikely that this occurred as S was instructed to lie quite still during recording. "Lastonet" (nylon-covered rubber thread woven into a network) appears to be a much more satisfactory method of holding electrodes in place, but the writer became aware of its advantages too late for use in this investigation.

The surface of the skin beneath the electrodes has to be cleaned to remove the oil. Methylated spirit was found suitable for this purpose. A good contact seemed to be achieved without rubbing off the outer dead layers of skin or massaging a conducting jelly into the skin.

An earth electrode consisting of a zinc plate about 6" X 4" was strapped to S's right upper arm over the biceps muscle. This effectively earthed the subject as the lead was taken to the earth point on the E.M.G. chassis.

The leads from the recording electrodes to the E.M.G. were eight feet long and supplied with an attahhment clipped to S's clothing which relieved the drag from the weight of the cable. This length was considered the minimum to avoid pick-up from the mains lead to the instruments.

(2) Electromyograph: The two-channel E.M.G. was of private design and consisted of an R-C coupled amplifier, the output of which could be monitored on a built-in cathode-ray tube and also taken either to a special photographic C.R.T. or

to an external pen recorder. An integrator unit completed the apparatus, but this was not employed as such in the present experiment as it was desired to follow momentary variations in potential rather than to sum the total amount of activity occurring over a specified time.

A calibrator was fitted to the E.M.G. enabling the operator to feed a 50 or 1000 cycle sine wave on to the monitoring tube face or on to the recording paper. These calibration pips could be altered in intensity and served as a convenient check on the performance of the amplifiers and the speed of the tracing.

The gain controls have nine settings, and were usually run at their next to highest setting for the forearm recording to obtain maximum amplification without excessive "grass". This was not necessary in the case of the potentials from the chin.

(3) Pen recorder: The output of both channels of the E.M.G. was taken to a Kelvin-Hughes high-speed pen recorder. The choice of this instrument rather than a photographic method was made on account of the following considerations:

(a) No delay need occur between recording and examining the records. It is important to be able to adjust the position of the electrodes and to modify the machine controls before a run; an impossible procedure with photographic methods.

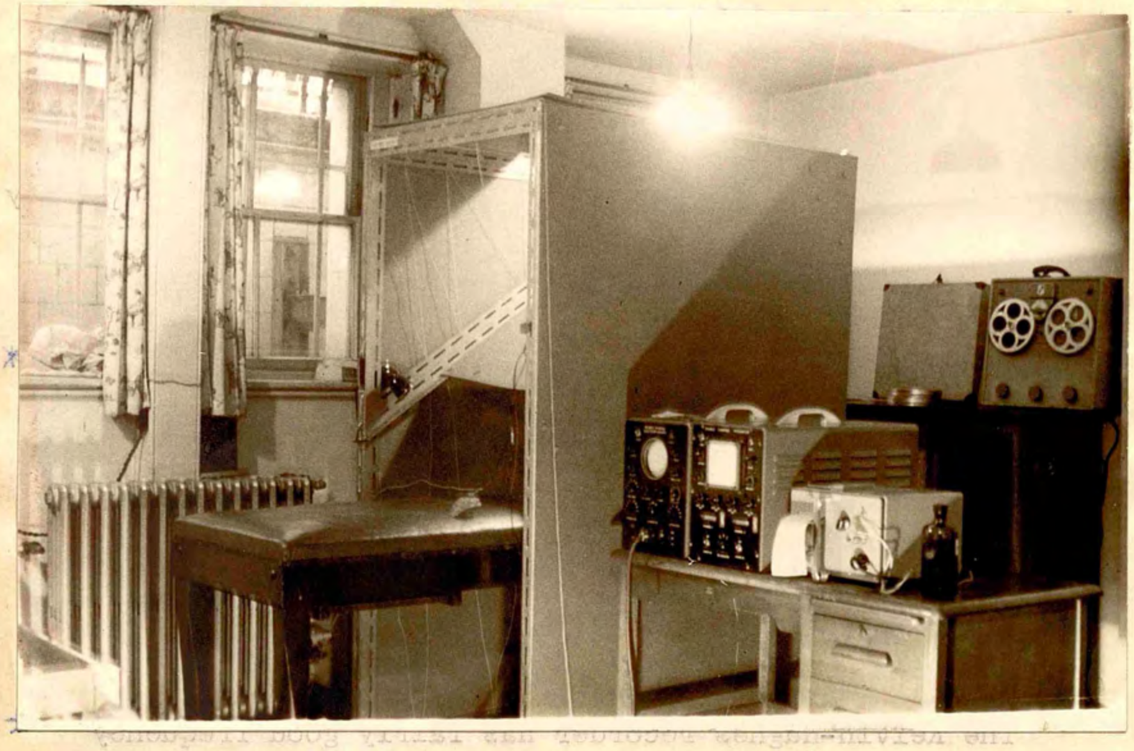
(b) Photographic methods are extremely expensive and it is necessary to use a sampling technique if records are to be taken over long periods.

(c) Distortions may occur in the film during processing.

(d) Although a pen, on account of its relatively great inertia, cannot follow high-frequency wave forms as faithfully as a cathode ray, this is not a decisive drawback when surface electrodes are employed.

However, the orthodox ink-writers used in E.E.G. work are not ideally suited to E.M.G. investigations. Typical E.E.G. frequencies range between 0.5 and 80 cycles per second which is lower than E.M.G. fluctuations (10 to perhaps 400 c.p.s.). Secondly, the ink-writing pens tend to drag on the surface of the paper. *

The Kelvin-Hughes recorder has fairly good frequency characteristics, probably being the best available pen recorder in this respect. The response is linear up to about 100 c.p.s. and then drops off to about 150 c.p.s. The "pens" write on Teledeltos dry recording paper, by passing a current through the paper from the stylus point to the frame. This current leads to the electrolytic reduction of chemical compounds in the top layer of the paper and causes a fine black line to appear when the paper is drawn past the stylus point. The paper can be driven at either 5 or 15 cms/second. The slower speed was used throughout the present experiment. *



Arrangement of the Apparatus.

The room in which the experiment took place was a basement room and almost ideal from the point of view of privacy. Recordings were made in the late afternoon when there was little noise from an adjoining workshop. Fluctuations in supply voltage were also at a minimum at this time. The room was fitted with radiators which kept the room warm and served as a convenient earth.

The experimental set-up is shown in the photograph opposite. S reclined on a couch inside a cabin built of Dexion covered with hardboard with a network of copper wire over the inside surface. This screening wire was taken to the earth point on the E.M.G. and this point in turn wired to the radiator. Thus the subject, the cabin, and the electromyograph were all earthed to the same point. This is an important precaution, as if several paths to earth exist, so-called "earth-loops", there is a likelihood of significant voltage drops along the wire and the possibility of "inductive" pick-up.

The cabin contained a board about 15 inches above S's eyes on which the sums could be placed face downward over a square hole cut in the board. This hole was then covered with a card so arranged that when E pulled on a piece of string attached to the edge of the card the work was exposed to S's gaze. The board and sums were illuminated strongly by a lamp placed behind S's head.

In the extreme front of the cabin a microphone was arranged to pick up S's verbalizations which were recorded on a tape recorder in the far corner of the room.

A spring-balance was suspended on the right-hand side of the cabin in such a position that S could insert the fingers of her right hand and pull down on the balance while E could observe the reading on the scale.

(It will be noted that the muscle group from which the recording was made was not the muscle directly involved in the induced tension procedure. S had to <u>press down</u> on the spring-balance; a movement brought about primarily by the muscles of the ventral surface of the forearm, the triceps and the latissimus dorsi. The muscles on the dorsal surface of the arm are antagonistic to this movement. That they would certainly be active in this movement seems to follow from the work of Levine and Kabat (1953) who say,

> "In unrestricted voluntary movement, there is no doubt but that the antagonist is inactive while the agonist is in contraction, but as resistance to agonist contraction is applied, the antagonist begins to respond in co-contraction. The contraction of the agonist is far greater in degree than that of the antagonist, but co-contraction does occur.") (p.116.))

Design of the Experiment.

The mental work consisted of addition sums typed in the conventional way on white postcards. Sums of three lengths were used: 6, 11, and 21 figures in a single column. Six sums of each length were made up from the random numbers in Fisher and Yates' (1938) tables of random numbers. Copies of the sums used will be found in Appendix I.

The work was performed under three conditions:

(1) "Mental tension" conditions when S was required to add as quickly as possible. (Type M).

(2) "Normal" conditions when S was asked to add at an easy speed which could be maintained for ten minutes at a stretch. (Type N).

(3) "Physical tension" conditions when S was told to add at an easy speed, but had to press down on the spring-balance during work. (Type P).

As a practice effect was thought likely, it was decided to randomize the order in which the three conditions were worked. The ideal design would have been one where sums of each type were intermixed with those of the other types so that a block of sums all of the same type would rarely occur. Unfortunately this was impossible on psychological grounds. The M type required S to make a determined effort to work as quickly as possible, and it did not seem feasible to intersperse these with the P and N conditions where S was working at her own speed, as the attempts to change set so rapidly would probably have led to a considerable carry-over from one condition to the next. On the other hand, it seemed likely that the P and N conditions could be worked immediately after one another as S would only have to pull on the spring-balance during a P trial and relax during an N trial and no change in mental set need occur. We are presuming then that a change in postural set can occur more quickly than a change in mental set.

The following design was therefore used: The P and N trials were intermixed and preceded or followed the M trials which were worked in a block. It can be seen from Table V.1. on page 136 that Ss 3, 6, 8, 9, and 10 worked at the M type first.

Whenever a practice effect is thought likely the design in which different conditions occur in blocks entails the assumption that the different conditions will lead to an equal amount of practice. There seemed to be no evidence that such an assumption was inappropriate here.

Ten subjects took part in the experiment. They were all females between the ages of 18 and 22, undergraduates at Bedford College. Four of them were studying psychology and six sociology. They were all known to E and had volunteered for the experiment. It was decided to give only three sums of each length under each condition as working the whole six sums would have meant doubling the length of the session and would have made the analysis a very lengthy task. In order to randomize the order of presentation of the sums the following procedure was adopted.

The sums were numbered from 1 - 6 and called A, B, or C depending on their length; A was the 6-figure, B the 11-figure, and C the 21-figure sums. These code numbers were written on pieces of paper and picked at random until three of each length had been chosen, a total of nine.

The order of choice gave the order in which the first subject was to attack the nine M type sums. These chosen numbers were now put back and the procedure repeated for the N and then the P type sums. As these two conditions were to be worked together it was now necessary to mix the N amd P type sums thoroughly and to select them again to determine the order in which they would be worked.

A repetition of this procedure determined the order of work for each of the other nine subjects. Table V.1. on the next page shows the order in which the sums were added.

Table V.1. Order of presentation of sums.

S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1A	6A	5B	2C	P3A	5A	P1A	4B	5A	5B
4A	5A	3C	P1A	3C	4A	3B	5B	2B	6C
2A	1A	2A	P2A	4B	4C	P3C	5C	2A	4B
P3C	4C	3B	P6C	3B	2B	4A	3B	2C	3C
P2A	P3C	6A	6B	6C	6C	6C	6C	4B	3A
P4C	P2B	2B	2B	P4B	6A	P3A	2A	6B	6A
2C	5B	1C	P1B	P1C	5C	4B	1A	1C	4A
P6B	3B	4A	6A	P3C	3B	5A	6A	6A	4C
P4A	6B	6C	1C	2A	1B	P4C	2C	3C	3B
2B	P3A	---	4C	P4A	---	P2B	---	---	---
5B	3C	P6C	P4B	P2B	P3C	5C	P3B	5A	2C
P5B	P2A	1A	P3C	1B	3B	2C	6A	3C	6A
4C	2C	6C	P1C	P3B	P4A	5B	P2B	P3A	P1C
P2B	P5A	P2B	P6A	P5A	4A	P5C	5C	3B	3B
P2C	P1C	4C	3A	4A	5A	3A	2B	P6A	6C
P3A	P4C	P2A	P3B	1C	P6A	P2A	5B	4A	P1B
6C	P6B	4B	1B	P4C	6A	P4B	4A	1C	4C
4B	P1B	5C	4A	6A	P1B	P6B	P4A	P4A	P6B
--	---	2A	---	---	2B	---	P3A	P6B	1A
4A	6C	6B	6A	6B	P4C	5A	3B	P4C	P3C
5A	6A	P4A	2C	6C	2C	1A	2C	5C	P4A
6C	2B	P1C	5A	4C	P4B	2B	P1B	P4B	P4B
1A	6B	P3C	4C	6A	1C	3B	P1C	P3B	P2C
5C	4B	6A	5B	5C	P1A	4A	6C	P6C	2A
4B	2A	P3B	4B	2B	P1C	6C	P6C	3A	4B
3C	5A	P6A	1C	5B	P2B	5B	P2A	P1C	P2A
6B	1C	5B	3A	5A	6C	4C	P4C	1B	P1A
3B	3C	P4B	3B	2A	6B	5C	3A	4B	5B

P = P type

—— = M type

Procedure.

The experimental session began with an explanation to the subject of the purpose of the experiment. She was told that the tension in her forearm muscles would be recorded while she performed addition sums, and that two further electrodes attached to her chin would give an indication of the moment of speaking. In order to prevent electrical interference she was going to be asked to lie down inside a shielded cabin. She was asked whether she disliked the idea of being in a small enclosed space. (No S reported such a fear.) She was then told that full instructions would follow later, but if she had any preliminary queries they could be answered.

She was now asked to sit on the couch outside the cabin while her right arm and chin were prepared for the electrodes. The arm was cleaned with methylated spirit and the bipolar electrodes attached with the zinc plaster. The electrical resistance between the electrodes was checked, and a trial recording made, partly to see that the machine was functioning and partly to reassure S. During the electrode placement E carried on a conversation with S and reassured her that there was no possibility of an electrical shock.

The second pair of electrodes were then attached and S lay down on the couch. She was asked to count slowly and a recording was taken. It was unusual for the placement of this pair of electrodes to be correct the first time, and they were adjusted until a burst of activity could be clearly observed on the record whenever S spoke. S was again reassured and told the reason for this trial-and-error. Most subjects appeared more concerned about these electrodes than the pair on the forearm, presumably because of their proximity to the brain.

The headrest of the couch was now adjusted and S was made as comfortable as possible. The couch was then slid into the cabin and the interior light switched on. If S felt comfortable, the apparatus for exposing the sums was shown to her and its operation explained. A practice sum was then put in place and she was asked if she could see it easily. She was asked to count aloud and the tape recorder was switched on and the volume adjusted.

S now put her hand on the spring-balance and pressed down as hard as possible. She was told to keep up a steady pressure for half a minute. At the end of 30 seconds E noted the reading on the balance in kilograms.

S was now asked to relax for ten minutes and to ignore the various noises from the switching gear which would occur from time to time. During this time E observed the oscilloscope until the level of activity dropped below 4 microvolts. To simplify this observation two strips of Sellotape were gummed on the tube face 1.5 mm. apart. When peak voltages did not exceed this height the recorded potentials were of 4 microvolts or less in intensity. All subjects were able to achieve this degree of relaxation, and most of them within a few minutes. Those who remained tense or who kept moving were urged to get really comfortable and then to relax completely. Most subjects sounded sleepy when spoken to after the ten-minute period and one S apparently fell asleep.

During this time the calibration signal was switched on and a short tracing taken.

The following instructions were then given:

> "You will be asked to add up a column of figures under various conditions. The columns will be of various lengths and I want you to add them successively, that is, one figure after another from the top to the bottom, not missing out a figure or combining two figures to make, say, a ten. Is that clear? But instead of adding the present column in the normal way - (E added the sum normally) - you are to take no notice of the tens but only add units. Instead of saying 8 and 6 make 14, you'd say 8 and 6 make 4, and then carry on with, say, and 3 make 7, and 5 make 2, and 9 make 1. To show you this more clearly listen while I add this column the new way - (E added the sum in the required manner). Now try this one." - (Another practice sum was put into position for S to add).

The reason for this procedure was to ensure uniformity of response throughout the sum. If normal addition had been employed the later additions would take longer to say because they are polysyllabic numerals. This might have led to a slowing down. Another factor complicating the issue seems to have arisen from Katz's work (1951) when he found subjects took longer to add tens or hundreds possibly because of the "value" of these digits, although the mechanical operations were identical with those required in the addition of units. If then we were to employ ordinary addition and were to find a work decrement in the present experiment it could be due to either or both of these factors. It was decided to refine the process and to accept further artificiality rather than confused realism.

Subjects appeared to find the task a simple one and soon grasped the mechanics of the procedure. No obvious practice effect occurred. (See Appendix III.)

Instructions now differed depending on the order in which S was given the three types of work. For the M type, instructions were as follows:

> "I want you to add these sums as quickly as you possibly can. Try to be accurate, as everything you say will be recorded and checked later. But the main emphasis is on speed; go as fast as possible. I will time you over each sum. Now if you make a mistake carry straight on. Don't go back to correct it. Is that clear?"

For the N type, instructions were:

> "I want you to add these sums at an easy speed. That is, disregard how long the sum is, just add at a speed which you could keep up for ten minutes at a stretch. I want you to be accurate, as everything you say will be recorded and checked later. There is no rush and no emphasis on speed. Just add at an easy pleasant rate. If you make a mistake, please carry on. Don't go back to correct it. Is that clear?"

For the P type, instructions were identical with those for the N type, but were preceded by the following:

"Before beginning a sum you will be asked to pull on the spring-balance and to keep up a steady pull throughout the addition until I tell you to relax. You need not worry about the steadiness of your pull. I shall be watching the pointer on the spring-balance and will stop you if your pull begins to fluctuate. I will show you how much to pull at the beginning and then you just keep that up."

The N type instructions then followed.

These detailed accounts of procedure were only given before the first sum of that type was added. For later sums in the series abbreviated instructions were given, such as, "Once again as quickly as you can," if an M type was to be added.

After the instructions had been understood the card was put into place, the recording apparatus started, a "get-ready" signal given, and the work exposed to view. As soon as the sum was completed, the calibration signal was switched on for a few seconds, then the recorder was stopped, a new sum put into place and covered, and S told once again to relax. About two minutes elapsed while E tore off the recording and labelled it. The next addition followed as soon as possible after a calibration signal had been recorded on the new tracing. Occasionally a delay as long as ten minutes occurred, as <u>in no case was S allowed to start a new sum until the residual tensions from the previous sum had reached the control value again</u>.

After the block of M sums, or after the P and N sums if these were given first, the couch was pulled out of the cabin and S allowed ten minutes' rest. During this time she was reassured and congratulated in general terms on her performance. Three Ss requested a drink of water at this time, and five Ss mentioned the heat from the lamp in the cabin. One S, S8, complained of a headache but readily agreed to continue. (It is of interest that this S found most difficulty in relaxing and remained very tense throughout the work period.)

Other pauses occurred when it became necessary to change the tape on the tape recorder, when people began talking in the corridor, and when noises came from the workshop nearby. Only once did an extraneous noise occur <u>during</u> the actual work period, which was continued in spite of this.

The whole session lasted approximately two and a half hours. During this time each subject added three sums of each of three lengths (6, 11, and 21 figures in a column) under three conditions (physical tension, "mental" tension, and normal conditions). Each subject then was required to add 27 sums in all.

After the session subjects generally asked to see the recordings and these were discussed. As the tape recorder was run all the time, all comments were recorded.

Chapter 6.

Treatment of the Results.

Measurement of the records.

Initially we are confronted with many yards of record with two parallel tracings, the E.M.G. from the forearm and the voice record. Any quantifying procedure is somewhat arbitrary, but certain criteria such as repsesentativeness and meaningfulness need to be fulfilled.

The following procedure was finally adopted:

(1) The first obvious spike (of more than two millimetres in height) of a cluster of spikes was taken as the moment of verbalization. A line was drawn at right angles through this point to cut the tracing of the E.M.G. of the forearm. This was done for each verbalization on the record, and resulted in the E.M.G. tracing being divided into five intervals in the case of the six-figure sums, ten intervals in the case of the eleven-figure sums, and twenty intervals in the case of the twenty-one-figure sums.

(2) A pair of dividers set to 2.5 mm was used to step off small divisions of this size working from the beginning of the interval to the line drawn to mark the next verbalization. As the trace moved at 5 cm. per sec. this represented 1/20th of a second. These 1/20th sec. divisions were numbered. If the end point of the interval occurred less than half-way

through a division, that division was counted in that interval, but in measuring the divisions in the following interval we once again began at the very beginning; in other words, in this case these two divisions overlapped.

(3) These 1/20th sec. divisions were now sampled. Although ideally all divisions should have been measured this would have been a marathon task, and instead it was decided to choose one quarter of the divisions for measurement. In order to do this in a random way, Fisher and Yates' (1938) tables of random numbers were used. If there were 20 divisions in an interval between one verbalization and the next, the numbers in the table would be divided by 20 and the first five (i.e. one quarter of 20) chosen. The numbered divisions corresponding with these five numbers would now be singled out for measurement.

(4) All spikes were measured within these chosen divisions to the nearest 1/2 mm. This was done with a transparent ruler under ammagnifying glass in the light of a powerful reading lamp. The left-hand edge of a spike was always chosen for measurement at right angles to the base line and so the ruler was always placed vertically and the measurement made either above or below the base line to the peak of the spike.

(5) The mean of these measurements was calculated for each division and the mean of the several division means gave a

figure representative of the interval as a whole. This value was converted into microvolts. (0.34 mm. = 1 mm.V.)

Several assumptions are made in dealing with the records in this way.

(1) It is assumed that the tracing moves at a constant speed.

(2) It is assumed that there are no errors in amplitude measurement due to the characteristics of the pen recorder.

(3) It is assumed that the experimenter is capable of valid and reliable measurement with the ruler.

With regard to (1), the calibration voltage which was recorded at the beginning and end of each tracing represents a 50-cycle fluctuation; it thus serves as a convenient time-marker. In no case was a measureable difference found between the first and second calibration signals, nor did the speed of the trace vary perceptibly from the stated speed. It seems that the first assumption is justified.

In the second case we need to know if the pen responds linearly. According to the maker's handbook the amplitude error is in fact negligible and only amounts to 0.2% at 7.5 mm. amplitude.

With regard to the accuracy of the measurement technique we have no means of knowing the "true" microvoltage other than through the measurements of an observer. This does not mean the technique is a very subjective one, any more than the reading of any physical scale. However, by having another person repeat the measurements, we obtain an indication of the accuracy of the experimenter. This was done for three records chosen at random with the restlts shown in Appendix II. There is no difference between the two sets of means calculated from the measurements.

The question of reliability does not really arise as a problem separate from one of sampling. It is necessary initially to decide on the size of the sample to be taken; the larger the sample, the greater the accuracy. We are able to estimate the population mean and scatter from the sample mean and scatter within certain degrees of accuracy and, of course, by enlarging the sample we increase our confidence in its resemblance to the whole population. Such statistical inference renders the taking of further samples and the computation of their correlation with the original samples a completely unnecessary and indeed pointless procedure peculiar to psychological studies and possibly a carry-over from mental testing. Many workers in the electromyographic field have thought that it was necessary (a) for another person to repeat all the original measurements, and (b) to repeat the sampling procedure in search of validity and reliability, but this would seem partially to stem from a need to bolster up the data for reasons of scientific insecurity.

This particular technique for quantifying results is extremely laborious and would become impossible if the tasks were made any longer or the number of subjects increased. It was though desirable to make an intensive study of a few subjects with a measurement technique more exact than that usually employed in studies of this kind. As it was, more than 30,000 measurements were necessary beside the labour of ruling and randomizing the divisions.

The complete results (i.e. the means representative of each interval and the time taken) for all sums for all subjects are included in Appendix V.

Statistical treatment of the results.

Several problems are posed by the raw data and by means of statistical techniques we can summarize these data and calculate probabilities of association and difference.

The first question that arises concerns the different experimental procedures. What differences were brought about by the induction of muscular and mental tension, by the use of tasks of three different lengths, and by the employment of ten different subjects? In Part 1 we shall attempt to answer these questions.

In Part 2 the evidence for the association between muscular tension and work output is discussed.

In Part 3 the work curves are examined to see if there is any evidence for starting and end spurts in mental output, and any concomitant changes in the electromyogram.

Finally, in Part 4 the differences between individuals in their response to the experimental variables are examined in greater detail.

PART 1.

In the first place we wish to discover if our "mental tension" instructions were effective in leading the subjects to adopt a more vigorous approach to the work and to add more quickly than under the N conditions, and whether there were changes in muscular tension accompanying this difference.

Secondly we want to know whether the subjects really became more tense in the relevant muscle group when they pulled on the spring-balance, and, if so, whether this induced tension affected their work output.

In other words we wish to know whether there were real differences between the three conditions of work in both time and tension levels and in the number of errors made in line with the instructions and with expectations based on earlier experimental work.

A series of analyses of variance should give the required information. It will be remembered that owing to psychological considerations it was necessary to design the experiment in such a way that the M type sums occurred together and were worked in a block either before or after the P and N types which were intermixed. This is unfortunate from the point of view of analysis as a comparison of the M type with either of the other types is rendered less precise. In the N v P analysis the within-types variance can be used as the error term against which to evaluate both the main effects (types and subjects) and the types-X-subjects interaction. But in the M v N and M v P analyses, where random assignment of sums had not proved possible, the types-X-subjects variance must itself be used as the error term.

The short, medium, and long sums were treated separately. The values from which the variance tables were calculated will be found in Appendix V. The following table gives the mean values for the different conditions.

Table VI.1. Mean values of time and tension under different conditions.

		Short	Medium	Long	Means
	P	12.0	14.1	15.6	13.9
Tension	N	7.2	8.7	9.2	8.4
	M	10.6	13.0	13.9	12.5
	Means	9.9	11.9	12.9	11.6
	P	40.0	52.3	54.8	49.0
Time	N	46.9	64.9	63.1	58.3
	M	39.1	53.2	55.2	49.2
	Means	42.0	56.8	57.7	52.2

N.B. Throughout this chapter time values will not be given in fractions of a second but in millimetres of trace. (50 mm. = 1 sec.)

M type v. N type.

Table VI.2. Analysis of variance. Comparison of time taken over M and N type additions.

		SHORT SUMS	MEDIUM SUMS	LONG SUMS
Source	df	Mean Square	Mean Square	Mean Square
Types	1	303.42+	687.96+++	319.2
Between Ss	9	181.25+	278.65++	245.3
Types X Ss	9	53.33	32.0	78.75

+ = p=.05
++ = p=.01
+++ = p=.001

In the comparison of the time taken over the sums added under M or N conditions it can be seen from Table VI.2. that all the F ratios are significant except in the long sums. With regard to the type difference, examination of the original means reveals that in most cases the longer time was taken over the N type sums. Some subjects did not add faster when urged to do so, but on the whole Ss obeyed instructions, except in the case of the longer sums where the difference has dwindled and could be due to chance with a probability of 10%.

The variance attributable to subjects is significant in the short and medium length sums and almost reaches the 5% level in the long sums. Differences between subjects then in their speed of addition are large and unlikely to be chance fluctuations. The medium length sums appear to discriminate between types and between Ss better than other lengths.

Table VI.3. Analysis of variance. Comparison of tension recorded during M and N type additions.

		SHORT SUMS	MEDIUM SUMS	LONG SUMS
Source	df	Mean Square	Mean Square	Mean Square
Types	1	55.11++	91.59++	111.86++
Between Ss	9	11.88+	18.66+	14.6++
Types X Ss	9	2.73	4.6	1.83

Significance levels in the case of tension are surprisingly more consistent than in the case of speed. All differences in Table VI.3. are significant and most of them highly so.

With regard to the type difference, from the original means it can be seen that the M type sums have a consistently higher tension level than the N type, and this difference is likely to have occurred by chance less than once in 100 times for all length sums. One S (S4) does not show the effect during medium length addition, but for other Ss the change is substantial; S10, for example, has three times as large a microvolt reading during M type addition.

Generally differences between Ss are well marked, some Ss are more tense than others whichever length sum they are working at. In the long sums the differences are very reliable although this is not due so much to comparatively greater variation between Ss as to a small interaction residual.

M type v. P type.

Table VI.4. Analysis of variance. Comparison of time taken over M and P type additions.

		SHORT SUMS	MEDIUM SUMS	LONG SUMS
Source	df	Mean Square	Mean Square	Mean Square
Types	1	4.32	4.05	0.68
Between Ss	9	207.35++	282.3++	172.5
Types X Ss	9	31.7	45.59	67.0

A very different state of affairs is found in the M v. P analysis. Table VI.4. shows that in no case is the difference between the P and M types significant, and the direction of the effect is not consistent. Although the instructions preceding the P type made no reference to speed, Ss apparently added as fast as when they were told to add quickly. These results appear to confirm the common finding that induced tension facilitates mental work.

Subjects differed very much between themselves. As in the former comparison the difference is less marked in the longer sums and could occur by chance 10% of the time.

Table VI.5. Analysis of variance. Comparison of tension recorded during M and P type additions.

		SHORT SUMS	MEDIUM SUMS	LONG SUMS
Source	df	Mean Squares	Mean Squares	Mean Squares
Types	1	10.51^{+}	6.27	13.61^{+}
Between Ss	9	19.28^{+++}	50.48^{+++}	20.38^{+++}
Types X Ss	9	1.54	3.53	1.98

The effects are fairly consistent in the case of tension too. In Table VI.5. although the type effect has disappeared in the medium length sums, it is significant at the 5% level in the short and long varieties. A non-parametric test gives much higher significance levels in these cases, as the mean tensions of subjects working at the P type are consistently higher than the tensions recorded during the M type except in the medium length sums where four of the ten subjects show the reverse effect.

In sums of all lengths the subject differences are clearly significant, the tension level from some Ss being as much as twice that of others.

P type v. N type.

Table VI.6. Analysis of variance. Comparison of time taken over P and N type additions.

		SHORT SUMS	MEDIUM SUMS	LONG SUMS
Source	**df**	**Mean Square**	**Mean Square**	**Mean Square**
Types	1	4100.0^{+++}	2386.4	993.9
Between Ss	9	405.9^{+++}	762.2	312.5
Types X Ss	9	123.7	190.2^{+++}	291.5^{+++}
Error	40	72.9	43.3	46.1

In the analysis of the P v. N types we must first test the interaction term, as if it is significant our ability to conclude anything about the direction of the main effects may be modified.

Table VI.6. shows that in the short sums the interaction is only significant at the 10% level, and the variance from this source is completely swamped by the main effects, both of which are significant at the 0.1% level.

Looking at the means we see that the P type sums are added more quickly than the N type and that this effect is consistent for all subjects.

In the medium ~~and long~~ sums the interaction terms are highly significant at the 0.1% level. If now the main effects are compared with the interaction effect we find they are significantly larger, the type effect at the 1% level, and the subject effect at the 5% level.

(The F ratios are computed in this way with the interaction effect rather than the within-types residual as the denominator, as otherwise we would be in no position to generalize from the results of this experiment to other human beings. That is, we consider our ten subjects as a random sample from a population of subjects in which the variable is normally distibuted. If on the other hand the residual were used in the calculation of the F ratios, we would be assuming that the subjects resembled the types, i.e. in being"fixed", and no generalizations to people other than those resembling the present subjects in certain unspecified ways would be justified.)

It seems safe to conclude that the main effects are so large that it is unlikely that the type effect is variable from one S to another. The totals for each S show the P type sums are always added more quickly than the N type, and only in the case of S7 does the difference shrink to a small value.

In the case of the ~~long~~ sums although the type and subject effects are significant at the 0.1% level when compared with the error variance, compared with the interaction variance neither effect reaches the 10% level. The suggestion is strong that subjects behave differently with regard to the two conditions. An examination of the totals for each S shows in fact that S2 works more slowly at the P type than the N type, that in the case of S4 the difference between the types has disappeared, and that all the other Ss work more quickly at the P type. The reversal of the effect then only occurs with one S, and if we examine the matter more closely and look at the means for each sum instead of the total for each S, we find that in 24 out of 30 sums the P type conditions lead to faster work.

It is of interest to see if the interaction effect is significant when S2 is omitted from consideration. The variance from the other nine subjects is only 162.0 and the F ratio 3.5 which is not significant. It seems fair to conclude that most of the interaction springs from S2's behaviour, and that if we leave her out of account we can interpret the main effects directly.

Table VI.7. Analysis of variance. Comparison of tension recorded during P and N type additions.

		SHORT SUMS	MEDIUM SUMS	LONG SUMS
Source	df	Mean Square	Mean Square	Mean Square
Types	1	340.8	437.9	606.7
Between Ss	9	51.1	65.9	49.6
Types X Ss	9	8.6+++	19.2+++	13.1+++
Error	40	0.7	2.3	1.6

When the tension variance is analysed in the P v. N type comparison, the interactions are found to be highly significant at the 0.1% level in all cases. Once again it seems more appropriate to compare the main effects with the interaction term rather than with the error. In the short sums the type effect is significant at the 0.1% level and the subject effect at the 1% level. In the medium sums also the type effect reaches significance at the 0.1% level although the subject effect is not so certain (5% confidence). In the long sums the significance levels are the same, types at 0.1% and Ss at 5%.

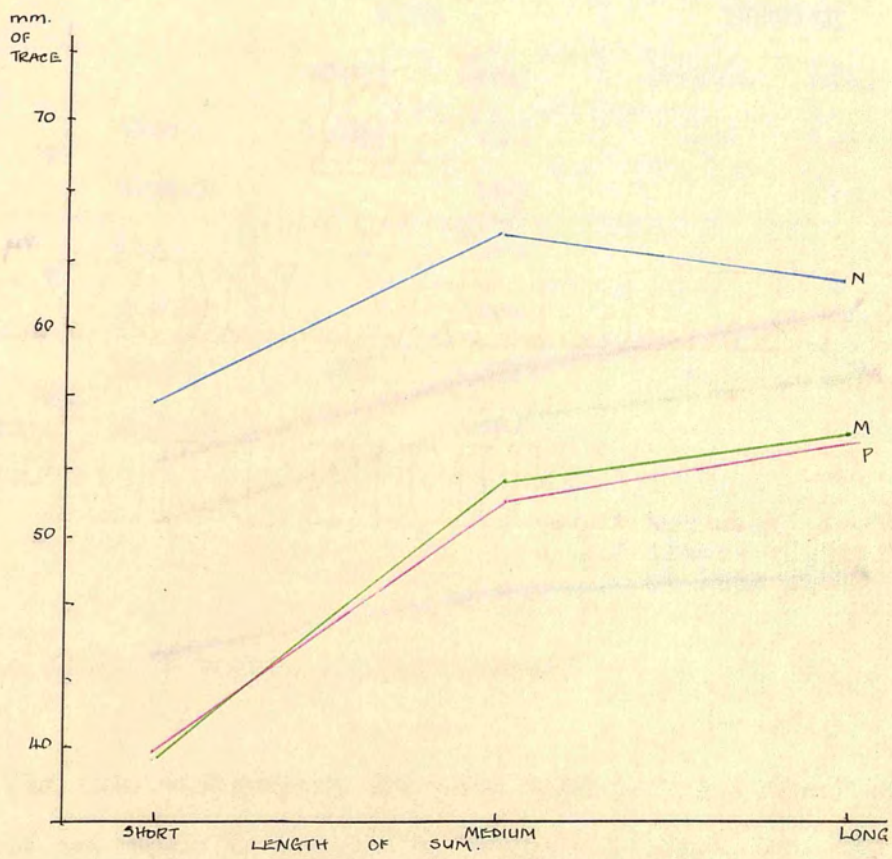
Examining the short sum means we find that in all cases the P type sums gave rise to a higher average tension level than the corresponding N type, and so all Ss showed the effect in the same direction.

In the medium length sums four out of the thirty possible comparisons of sum means showed a reversal of the expected effect, three of these sums being added by S4 who is the only S to show a reversal. The other nine subjects became more tense during the P type additions as expected. However, S4 contributes very little to the interaction variance and if omitted makes no difference to the significance of the effect. Unlike the earlier instance where one subject could be held responsible, in this case several subjects appear to react in differing amounts to the change in experimental conditions. S4 stands out as she shows a reversal of the effect, but other Ss, such as S8, contribute much more to the total interaction variance.

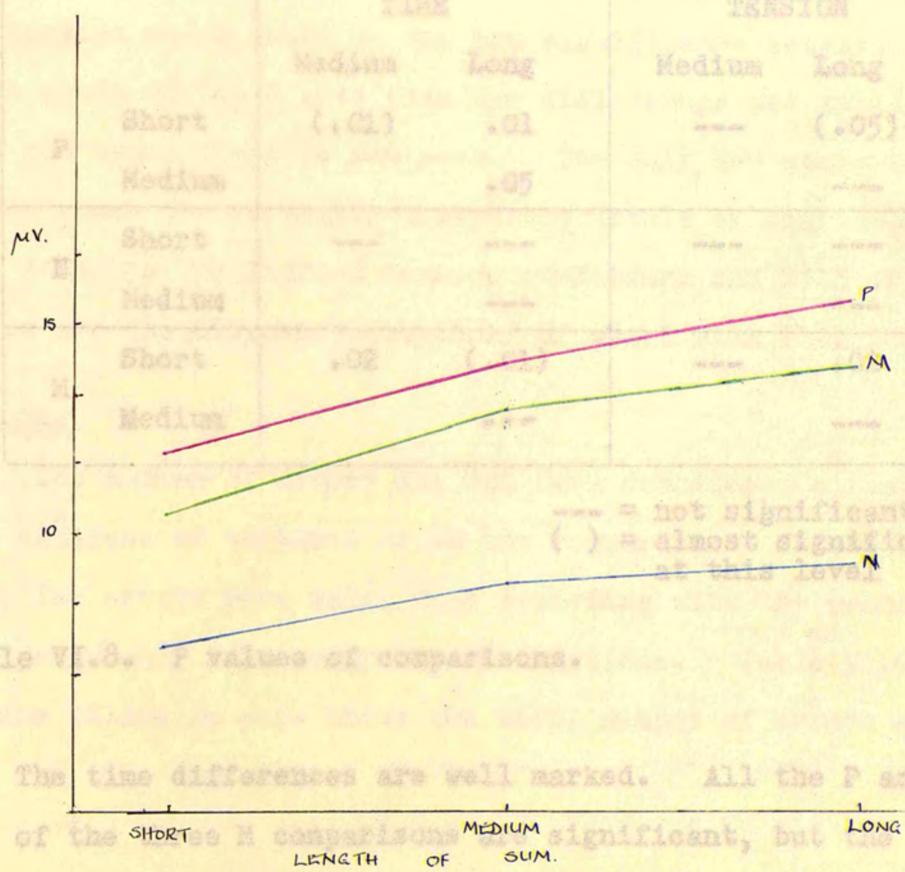
On the average there was more physical tension during the P type additions in the long sums, and out of thirty comparisons there was only one in the other direction.

We can conclude that generally speaking the P condition has the expected effect in leading to greater physical tension whatever the length of the sum, although subjects differ a great deal among themselves in their average tension levels and in the way they react to the P condition, S4, however, being alone in showing a drop in tension rather than an increase.

The analyses of variance have treated the different length sums separately and no direct comparison of lengths has yet been made. It seemed to be of considerable interest in the light of Katz's work to compare the mean time and tension levels for the different length sums. The relevant figures were given in Table VI.1. on page 150 and these values are plotted on the following two pages.



Graph VI.1. Mean times taken over each addition of the three different type sums at the three lengths.



Graph VI.2. Mean tension levels during the three different type additions at the three lengths.

From inspection the values cah be seen to increase with the length of the sum; that is, the long sums are added more slowly and with more tension. Testing these differences statistically we obtain the following table of comparisons:

		TIME		TENSION	
		Medium	Long	Medium	Long
P	Short	(.01)	.01	---	(.05)
	Medium		.05		---
N	Short	---	---	---	---
	Medium		---		---
M	Short	.02	(.01)	---	.02
	Medium		---		---

--- = not significant
( ) = almost significant at this level

Table VI.8. P values of comparisons.

The time differences are well marked. All the P and two of the three M comparisons are significant, but the differences in the case of the N type are all too small.

These results appear to support Katz's thesis that the time taken over each addition increases with the length of the sum, but the effect appears to be limited to the induced tension conditions. The instructions to add at a "comfortable" speed (N type) seem to have been effective in causing S to add sums of all lengths at approximately equal speed.

There seems a tendency for the time differences to be accompanied by tension differences as the trend is in the same direction, but there is much more individual variation in tension which leads to the low significance levels. Once again in the N type sums the differences are smaller and the usual trend is not seen. The only two comparisons which reach the generally acceptable levels of confidence are found in the induced tension conditions and both of these are the extreme comparisons of short with long sums.

Errors.

The number of errors has not been considered either in the analyses of variance or in the comparisons of lengths. Very few errors were made, this according with the accuracy set presumably induced by the instructions. Table VI.9. on the following page shows the total number of errors made.

Table VI.9. Total numbersof errors made.

		S	M	L			S	M	L
	P	1	-	1		P	1	-	2
S1	N	-	-	1	S6	N	-	-	-
	M	-	-	2		M	-	-	3
	P	-	-	-		P	-	-	1
S2	N	-	-	-	S7	N	-	-	-
	M	-	-	-		M	-	2	-
	P	-	2	-		P	-	-	-
S3	N	1	-	1	S8	N	-	-	2
	M	-	-	3		M	-	-	1
	P	-	1	-		P	-	-	2
S4	N	-	-	-	S9	N	-	-	-
	M	1	1	1		M	-	-	1
	P	-	-	-		P	-	-	-
S5	N	-	-	-	S10	N	-	-	-
	M	-	-	-		M	-	-	-

On the hypothesis that an equal number of errors is to be expected for each type of addition the following contingency table was formed:

Table VI.10. Total errors obtained in each type of addition.

	P	N	M
Total errors obtained	11	5	15
Total errors expected	10	10	10

The X^2 value calculated from Table VI.10. is 5.1 with 2 degrees of freedom which is not significant.

A comparison of the total number of errors made in the different length sums gives the following table:

Table VI.11. Total errors obtained in each length addition.

	S	M	L
Total errors obtained	4	6	21
Total errors expected	4.4	8.8	17.6

In Table VI.11. the expected frequencies were calculated by taking respectively 5/35ths, 10/35ths, and 20/35ths of the total number of errors made (31). The X^2 value of 3.13 with 2 degrees of freedom is not significant.

We can conclude that there is no change in accuracy with increase in sum length and from the former analysis it can be seen that the different methods of addition employed did not affect the number of errors made.

These results do not agree with Katz's, but a strict comparison is not possible for several reasons: Katz's sums did not entail pairs addition; he used as many as 60 digits in a column whereas the present experiment did not include tasks longer than 21 figures; he recorded errors only in the final totals whereas we recorded errors in addition throughout a column. It seems likely that Katz's long sums showed an increase in percentage errors because of the value of the digits concerned; that is, it was not the increase in length per se which was responsible for the lack of accuracy.

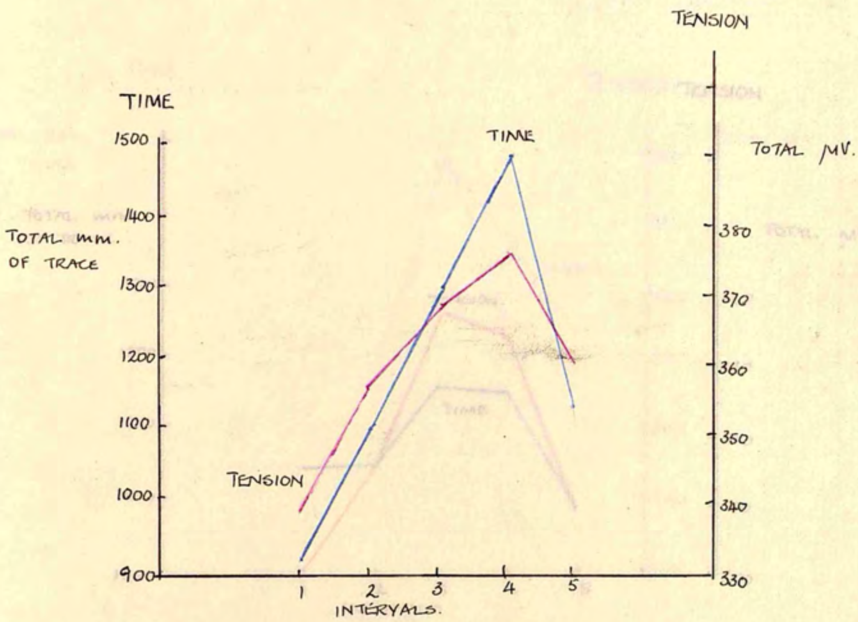
Subject differences in accuracy were to be expected but are not very marked. There seems to be no tendency for the more rapid workers to make the greater number of errors.

PART 2.

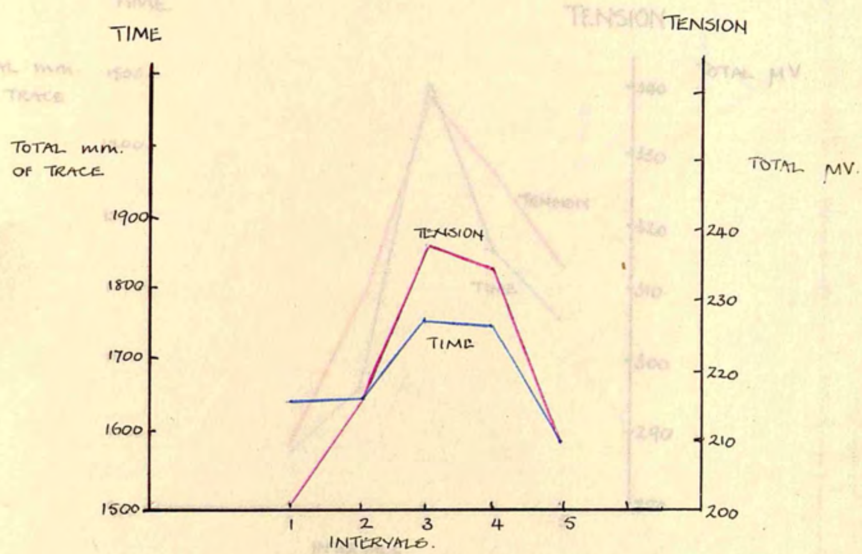
In Part 1 it was found that high tension tended to be associated with the greater work output found in the M type sums, and similarly work was performed more efficiently when tension was indueed as in the P type sums. This being so, we should expect time and tension to vary together during work, and an analysis of this relationship has now to be attempted.

The total time and total tension recorded for all subjects for each adding operation of the sums have been graphed on the following pages in order to give a picture of the variation in speed and tension during a task.

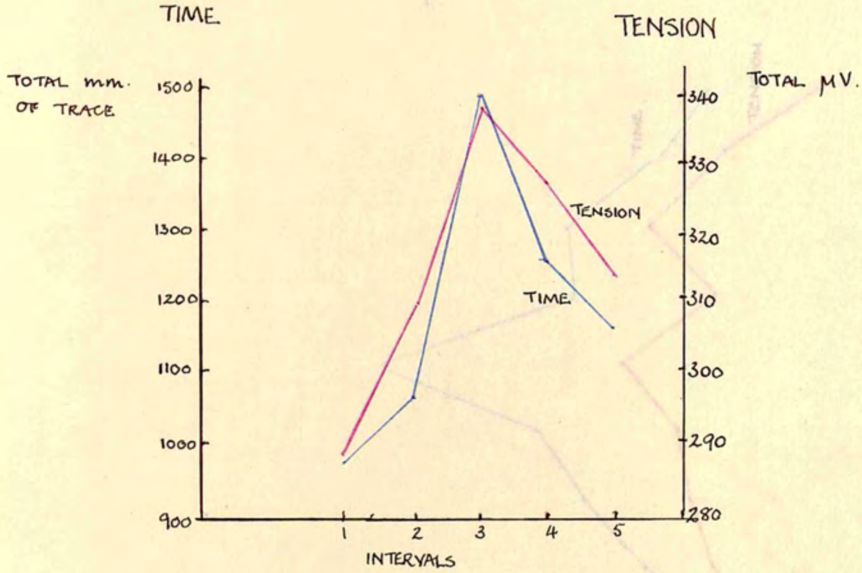
(N.B. The scale on these graphs is similar, but the origin of both time and tension scales is never zero.)



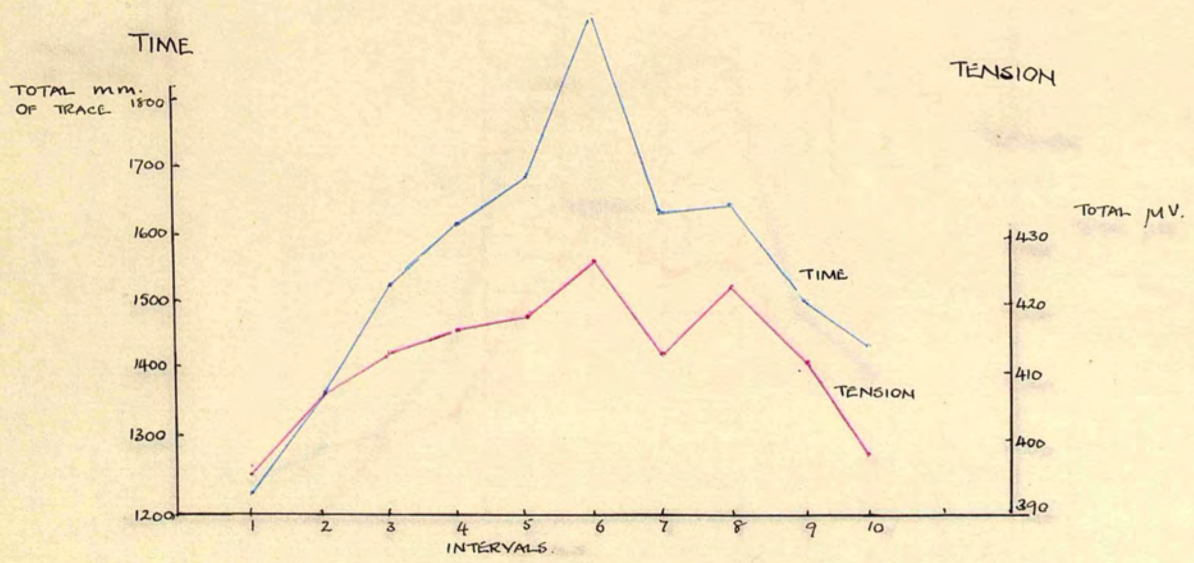
Graph VI.3. P type addition. Short sums. Variation in time and tension during work.



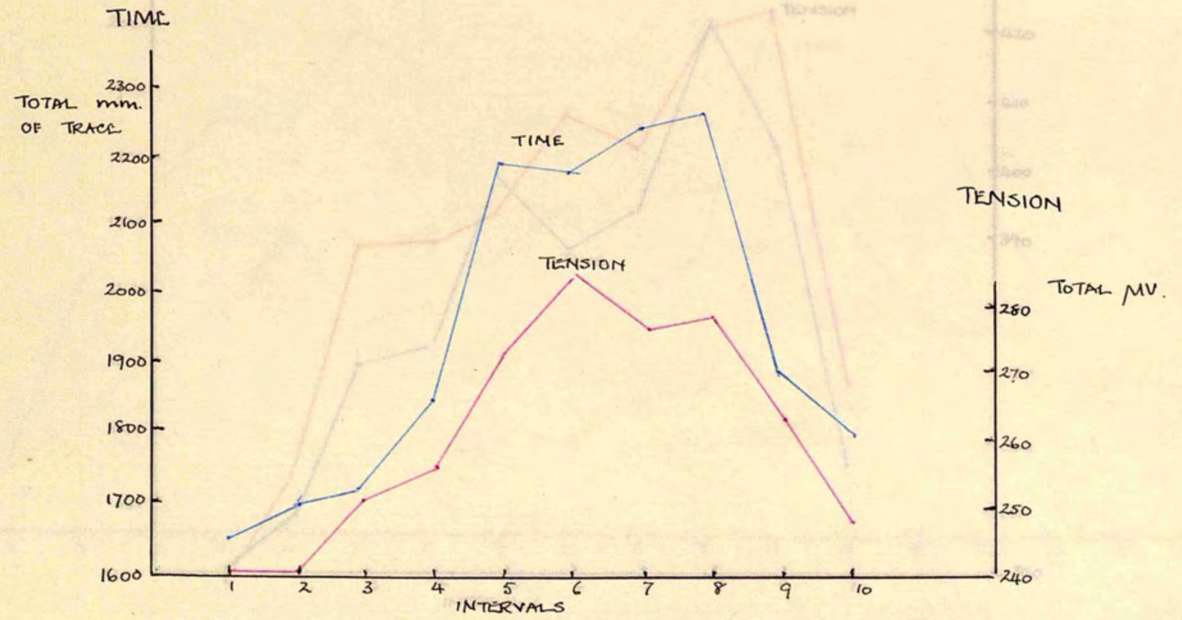
Graph VI.4. <u>N type addition</u>. <u>Short sums</u>. Variation in time and tension during work.



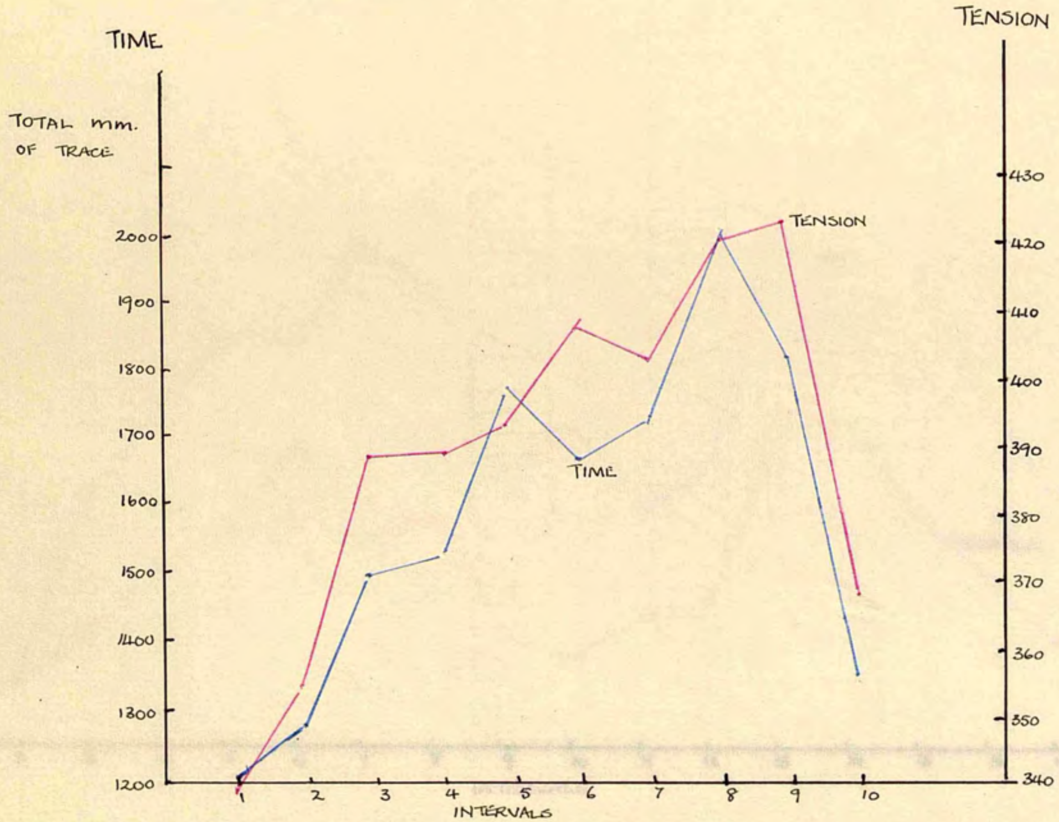
Graph VI.5. M type addition. Short sums. Variation in time and tension during work.



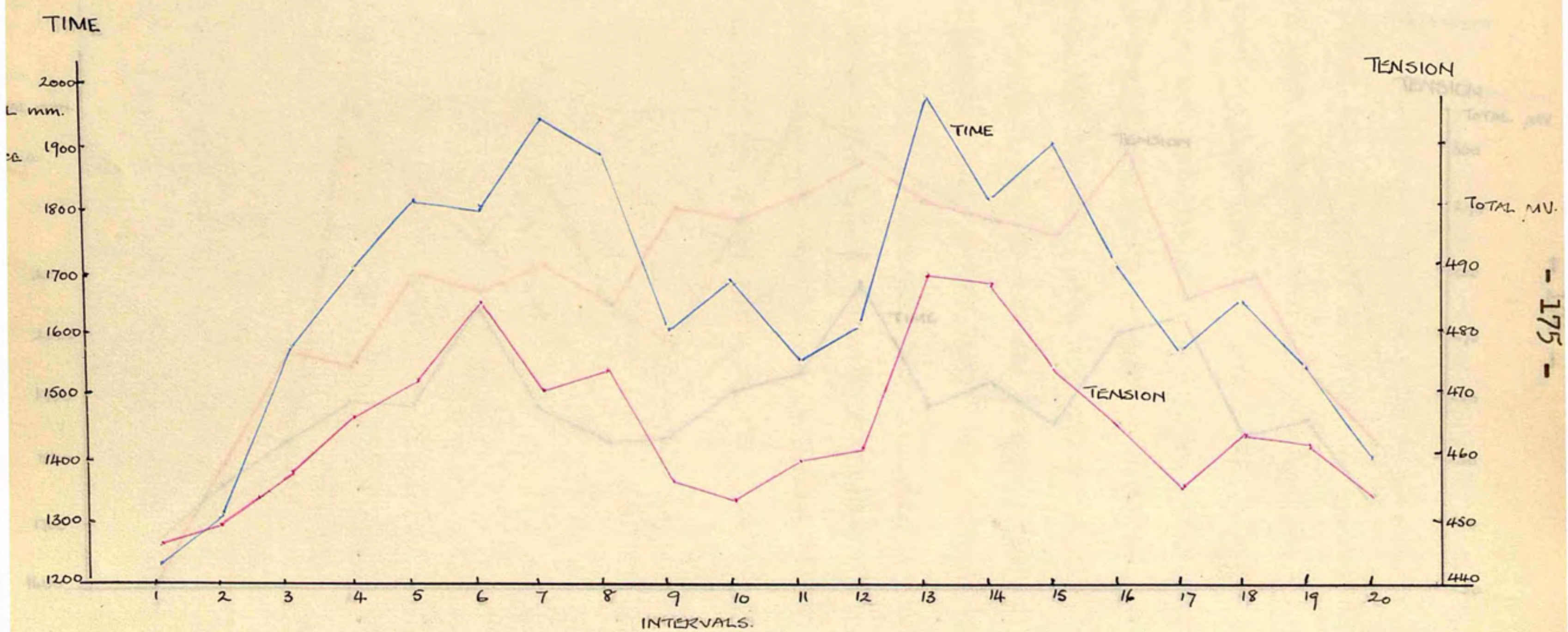
Graph VI.6. P type addition. Medium length sums. Variation in time and tension during work.



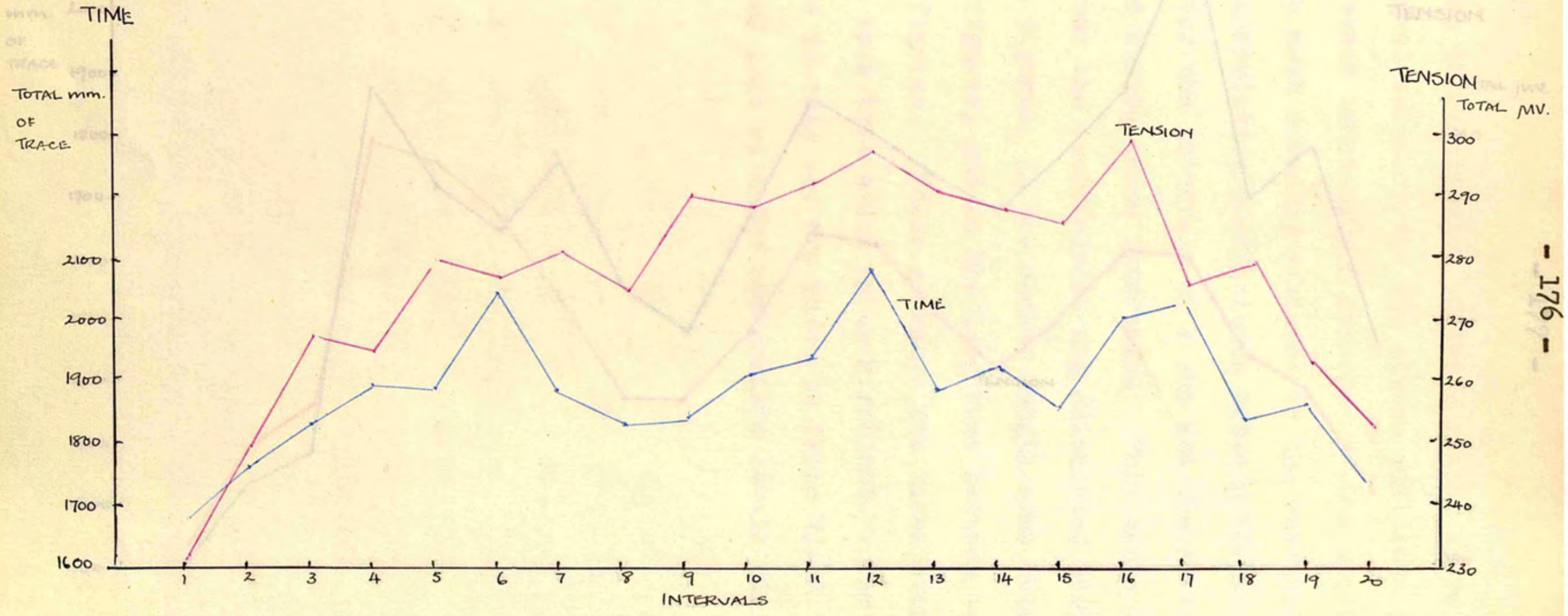
Graph VI.7. N type addition. Medium length sums. Variation in time and tension during work.



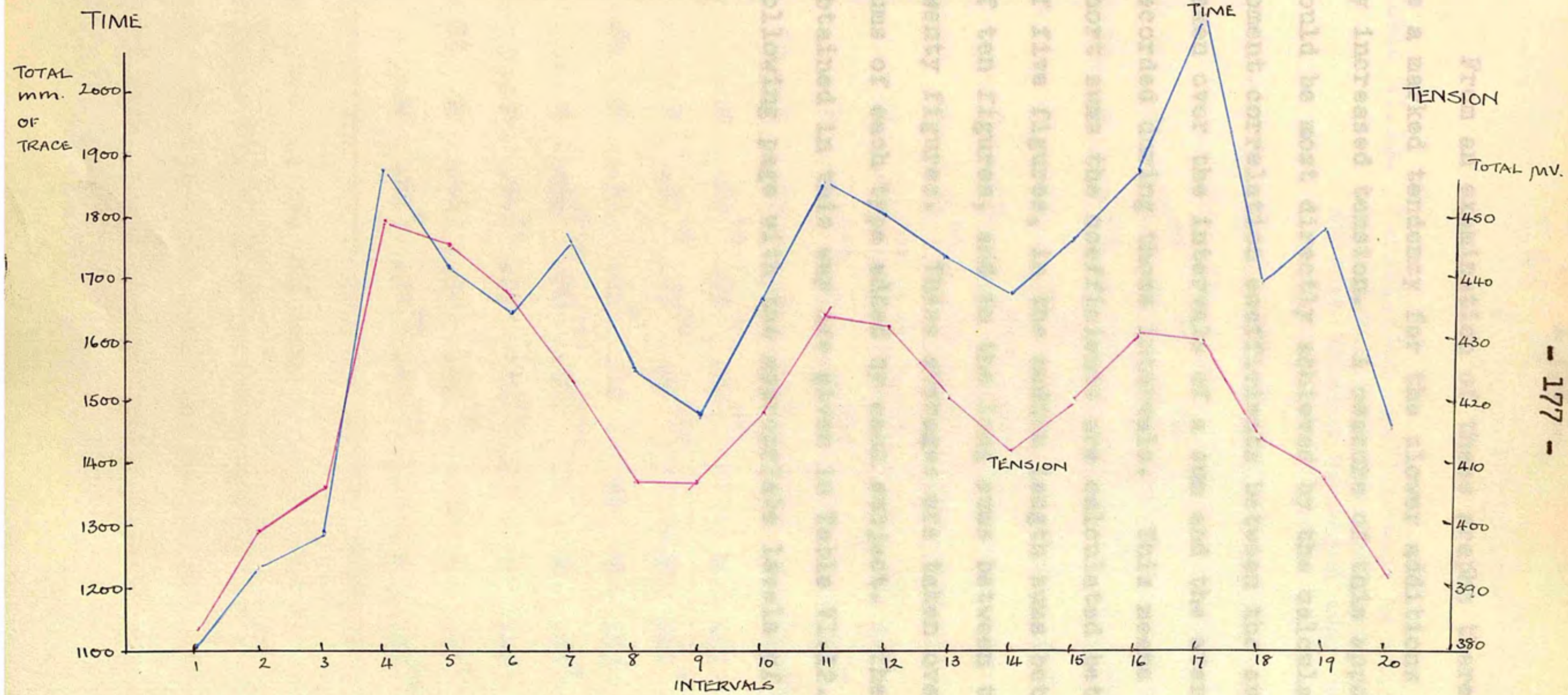
Graph VI.8. M type addition. Medium length sums. Variation in time and tension during work.



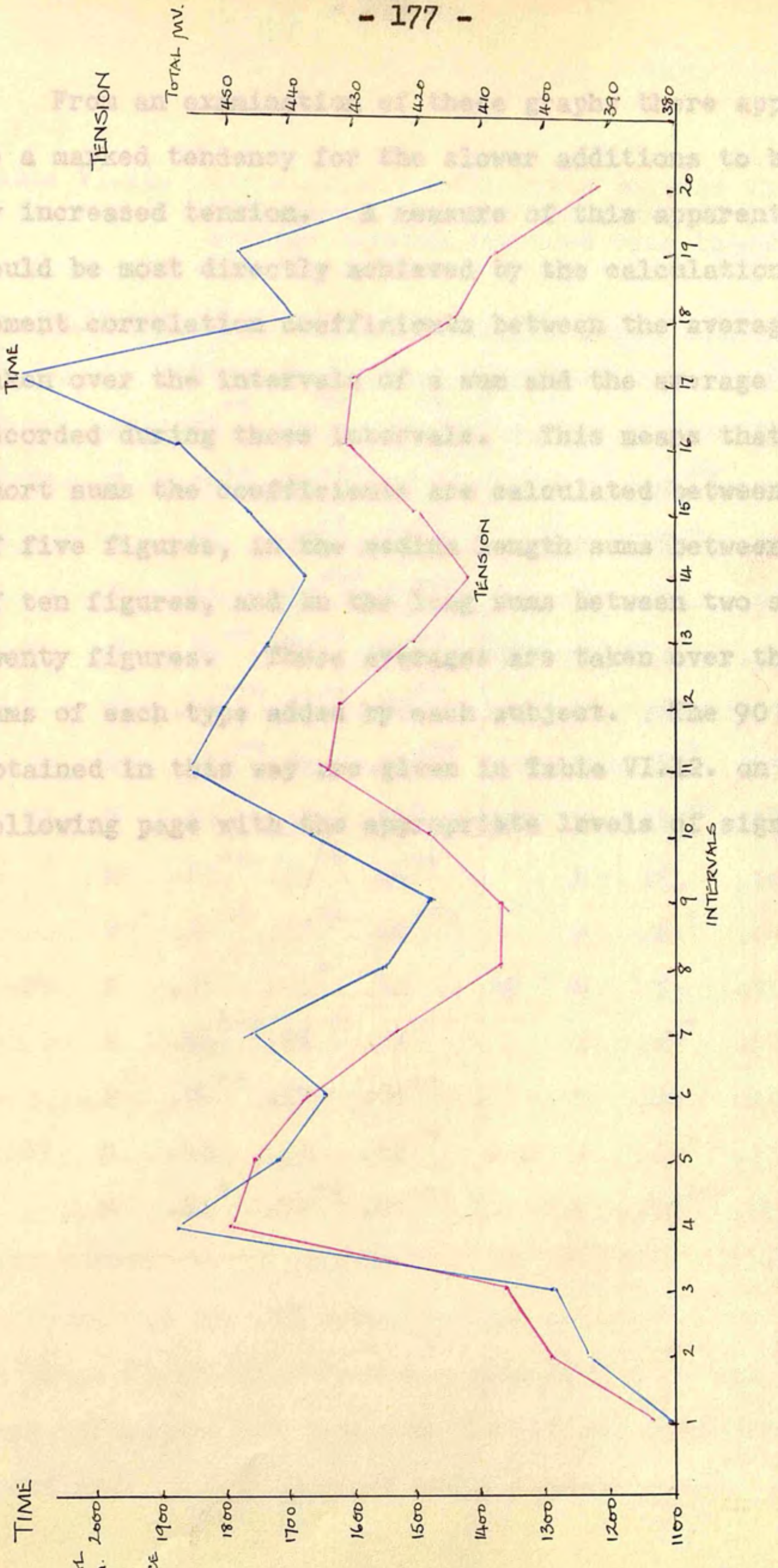
Graph VI.9. **P type addition.** **Long sums.** Variation in time and tension during work.



Graph VI.10. N type addition. Long sums. Variation in time and tension during work.



Graph VI.11. <u>M type addition</u>. <u>Long sums</u>. Variation in time and tension during work.



Graph VI.11. M type addition. Long sums. Variation in time and tension during work.

From an examination of these graphs there appears to be a marked tendency for the slower additions to be accompanied by increased tension. A measure of this apparent relationship could be most directly achieved by the calculation of product-moment correlation coefficients between the average times taken over the intervals of a sum and the average tensions recorded during those intervals. This means that in the short sums the coefficients are calculated between two sets of five figures, in the medium length sums between two sets of ten figures, and in the long sums between two sets of twenty figures. These averages are taken over the three sums of each type added by each subject. The 90 correlations obtained in this way are given in Table VI.12. on the following page with the appropriate levels of significance.

Table VI.12. Correlation coefficients between the average time taken over the intervals of a sum and the average tension recorded over those intervals.

		S	M	L			S	M	L
	P	$.91^{++}$	$.72^{++}$	$.75^{++}$		P	.09	.34	$.62^{++}$
S1	N	$.95^{++}$	$.81^{++}$	.20	S6	N	$.95^{++}$	.32	$.68^{+++}$
	M	.69	$.78^{++}$	$.62^{++}$		M	$.85^{+}$	$.86^{+++}$	$.61^{++}$
	P	.66	$.91^{+++}$	$.70^{+++}$		P	.45	$.92^{+++}$	.14
S2	N	$.84^{++}$	$.79^{++}$	$.58^{++}$	S7	N	.11	$.77^{++}$	$.69^{+++}$
	M	$.98^{+++}$	$.71^{++}$	$.61^{++}$		M	.62	$.77^{++}$	$.75^{+++}$
	P	$.96^{+++}$	.29	$.74^{+++}$		P	$.83^{+}$	.25	.38
S3	N	.71	.37	$.44^{+}$	S8	N	$.87^{++}$	$.78^{++}$	$.60^{++}$
	M	$.87^{++}$	$.79^{++}$	$.64^{++}$		M	.61	$.76^{++}$	$.53^{+}$
	P	$.87^{++}$	$.77^{++}$	$.69^{+++}$		P	$.81^{+}$	$.67^{+}$	$.75^{+++}$
S4	N	.51	$.65^{+}$	.42	S9	N	.53	.54	$.64^{++}$
	M	$.96^{+++}$	$.86^{+++}$	$.81^{+++}$		M	$.85^{+}$	$.78^{++}$	$.80^{+++}$
	P	$.94^{++}$	.17	$.61^{++}$		P	.25	.45	−.21
S5	N	.46	.34	$.62^{++}$	S10	N	$.83^{+}$	$.67^{+}$	$.77^{+++}$
	M	$.81^{+}$	$.72^{++}$	$.67^{+++}$		M	$.98^{+++}$	$.80^{++}$	$.56^{+}$

It is not possible to take the significance levels in Table VI.12. literally as the coefficients were calculated from sets of figures that were not independent of one another. That is, the time or tension at one point of a sum is likely to influence the time or tension at a later point. However, the coefficients obtained are extremely high. Sixty four of the ninety values are significant at the 5% level or higher, and it can be seen at a glance that these cluster in the long sums. These facts seem worthy of attention because of the extent of the agreement, and so, in order to obtain a more precise indication of subject, type, and length differences, an analysis of variance of the table of coefficients was carried out. This was not possible as it stands, because of the nature of the correlation coefficient which is (a) "bounded", i.e. it can only vary between +1 and -1, and (b) non-normally distributed. To overcome these difficulties it can be transformed into "z" scores. This course was adopted and an analysis of variance carried out, the results of which are presented in Table VI.13. on the following page.

Only two sources of variance are significant in this table, that due to lengths (at the .01 level) and that due to types (at the .05 level). The mean "z" scores are given in Table VI.14. also on the next page and it can be seen that the medium and long sums are alike and differ from the short sums, the difference being significant at the .01 level.

Similarly the P and N conditions resemble one another but differ from the M type, this difference again being significant at the .01 level.

Table VI.13. Analysis of variance of "z" scores.

Source	df	Mean Square
Lengths	2	1.4583++
Types	2	.8696+
Lengths X Types	4	.0469
Groups	8	
Subjects	9	.1197
Subjects X Lengths	18	.1722
Subjects X Types	18	.2705
Subjects X Types X Lengths	36	.2099
Interaation	72	.216
Total	89	

Table VI.14. Mean "z" scores.

	Short	Medium	Long	Average	
P type	1.049	= .743	.620	.804	.806 (P and N)
N type	1.007	.753	.666	.809	
M type	1.358	1.133	.813	1.101	
Average	1.138	.876	.700	.905	
		.788 (Medium and Long)			

We can conclude that the relationship between time and tension is most marked in the short sums and in those of the M type, and this relationship seems to be independent of subject differences. The correlation between speed, or rather lack of speed, and degree of tension is extremely high. The average coefficient over all sums is 0.72 as can be seen from Table VI.15. This table of average correlations has been obtained from the table of average "z" scores which have been transformed back into correlation coefficients.

Table VI.15. Average correlation coefficients.

	Short	Medium	Long	Average
P type	.78	.63	.55	.66
N type	.77	.64	.58	.67
M type	.88	.81	.67	.80
Average	.81	.71	.60	.72

So far the relationship between time and tension within a sum has been discussed but no attention has been paid to the relationship between the total time taken over a sum and the total tension exerted. It is conceivable that the tendency for slower additions to be accompanied by higher tension levels is an intra-sum phenomenon, and that a different type of relationship may exist when totals are compared. Two levels of analysis are possible: (1) the total time and total tension values <u>within</u> a subject can be correlated, and (2) the total time and total tension <u>between</u> subjects can be correlated.

With regard to the first possibility, if the individual records in Appendix V are examined it can be seen that the association varies enormously from one subject to the next. However, the correlations of these totals for each subject were computed for the short length sums of the three types, and are given in Appendix IV. They vary from +1.0 to -1.0, and approximately half the subjects show a positive and half a negative correlation.

When the association between time and tension is examined between subjects a more consistent picture is obtained. Table VI.16. reveals a <u>tendency</u> for time and tension to be positively correlated; that is, those subjects who have added slowly tend to be more tense. This association is not nearly as marked as that of the earlier analysis when the moment-to-moment variation within a sum was examined.

	Short	Medium	Long	Average
P type	.39	.15	.06	.21
N type	.45	.71	.32	.52
M type	.12	.26	.22	.20
Average	.33	.38	.21	.32

Table VI.16. Correlations between total time and total tension.

To recapitulate. An analysis of the relationship between performance and tension has been attempted at three levels: (1) within a sum, (2) between totals within each subject, and (3) between totals and between subjects.

It was found in the case of (1) that a high correlation existed between time and tension, i.e. slow additions were accompanied by high tension. In the case of (2) no consistent relationship was apparent, and in (3) a low but consistent relationship (i.e. a low positive correlation) was found. In other words although high tension is closely associated with slow performance during work it is not possible to compare tension levels from one sum with those from another. Each subject behaves differently. Some subjects show a higher average tension level during their faster sums, whereas other subjects show lower average tension levels during their faster sums. It is as though a random level of tension is achieved at the beginning of a sum, on the longer sums this will be higher than on shorter sums, and in the case of the poorer subjects the level will tend to be higher than for the better subjects, but for sums of the same length it will vary in an unpredictable manner from one subject to the next. When once work begins the fluctuations in performance and in tension become closely associated.

Some difficulties arise when the general rôle of tension is considered in its relation to efficiency. For, as we have seen in Part 1 of this chapter, induced physical tension leads to more efficient work, and higher tension levels are to be found in the efficient M type work. And yet, in apparent contradiction, when the association between efficiency and what might be called "endogenous" tension is examined in this section of the chapter, a marked inverse relationship is found within a sum, and a slight inverse relationship between subjects. This apparent discrepancy can best be discussed later in Chapter 7.

PART 3.

From the review of the literature the conclusion was reached that a starting spurt is frequently to be found in mental work. The discrepancies between investigators seem partly to have arisen from differences in definition of the term and partly from differences in recording techniques. Only by an exaggerated conception of the original Kraepelinian starting spurt could Thorndike conclude that it was a rare event. His statement to the effect that a starting spurt implied that the subject worked at greater efficiency at the beginning of a task than ever again was a distortion of Kraepelin's view of the spurt as a temporarily-sustained flux of "will-tension" which generally led to an objectively discernible decrement in the work curve soon after the beginning of the task, although later fluctuations might produce peaks of more efficient performance.

Secondly, the spurt appears to be a phenomenon which occurs over a short interval of time and unless a suitable method of recording can be devised it may well be overlooked.

It would seem to be in accord with the earlier view if a trend in the direction of greater efficiency from the beginning of work were taken as the criterion of an initial spurt. A similar trend towards the end of the work curve could then serve as an indication of an end spurt. Our definition is not as extreme as Thorndike's although equally objective, for the problem becomes one of defining a trend in terms of its steepness and its extent.

It was thought most meaningful to take the highest peak of a work curve (i.e. the interval over which the longest time was taken) as the end point of the period over which a spurt may or may not occur. In the long sums it was decided to confine the examination to the first half of the sum, as otherwise the phenomenon could hardly justify its name. In a similar manner the tension curves were examined and the highest peak of tension taken as the end point of any trend that might accompany the spurt in the work curve.

The end spurt was defined as any improvement which occurs in the work curve from this same high peak to the end of the task. In the case of the long sums the highest peak occurring after the half-way point was taken as the beginning of the spurt. This is perhaps an unorthodox conception of the end spurt which is commonly thought to occur nearer the end of the task, but as we are dealing with very short tasks it does not seem inappropriate.

The following tables (Table VI.17 - VI.20.) show the intervals in which the peak occurred. Each figure refers to the mean values over three sums for each subject.

Table VI.17. Intervals in which peaks occur (i.e. slowest performance and highest tension). Short sums.

STARTING SPURT

	Time				Tension			
	P	N	M	Total	P	N	M	Total
S1	4	3	3	10	4	4	3	11
S2	3	2	3	8	3	4	3	10
S3	3	3	4	10	3	3	4	10
S4	4	5	4	13	4	5	5	14
S5	4	4	3	11	4	4	5	13
S6	5	2	3	10	3	2	3	8
S7	3	4	4	11	3	3	4	10
S8	4	3	3	10	4	3	3	10
S9	4	3	1	8	4	4	1	9
S10	4	4	3	11	3	4	3	10
Means	3.8	3.3	3.1	10.2	3.5	3.6	3.4	10.5

Table VI.18. Intervals in which peaks occur (i.e. slowest performance and highest tension). Medium sums.

STARTING SPURT

	Time				Tension			
	P	N	M	Total	P	N	M	Total
S1	6	8	5	19	6	7	6	17
S2	8	5	7	20	4	4	7	15
S3	6	10	9	25	5	6	4	15
S4	6	6	7	19	6	8	7	21
S5	2	8	8	18	6	8	9	23
S6	6	5	8	19	3	1	8	12
S7	6	7	8	21	6	7	8	21
S8	8	5	4	17	8	7	4	19
S9	8	6	9	23	8	6	9	23
S10	9	7	8	24	6	8	8	22
Means	6.5	6.7	7.3	20.5	5.8	6.2	7.0	19.0

Table VI.19. Intervals before half-way point in which peaks occur (i.e. slowest performance and highest tension). Long sums.

STARTING SPURT

	Time				Tension			
	P	N	M	Total	P	N	M	Total
S1	8	7	4	19	8	9	8	25
S2	8	10	4	22	9	4	4	17
S3	9	8	10	27	9	3	7	19
S4	7	6	4	17	6	3	6	15
S5	7	5	5	17	2	5	6	13
S6	6	6	5	17	6	6	5	17
S7	10	10	4	24	2	10	5	17
S8	10	6	6	22	6	6	3	15
S9	5	2	10	17	5	10	10	25
S10	3	10	5	18	7	8	3	18
Means	7.3	7.0	5.7	20.0	6.0	6.4	5.7	18.1

Table VI.20. Intervals after half-way point in which peaks occur (i.e. slowest performance and highest tension). Long sums.

END SPURT

	Time				Tension			
	P	N	M	Total	P	N	M	Total
S1	13	17	17	47	14	14	17	45
S2	18	18	14	50	13	11	17	41
S3	15	11	15	41	15	16	15	46
S4	13	17	17	47	15	12	20	47
S5	15	14	12	41	13	14	12	39
S6	13	12	11	36	13	12	12	37
S7	14	11	12	37	13	11	12	36
S8	16	14	13	43	11	16	16	43
S9	15	12	16	43	16	12	11	39
S10	16	16	13	45	12	16	13	41
Means	14.8	14.2	14.0	43.0	13.5	13.4	14.5	41.4

In none of these tables is there a significant difference between types. The conditions of the task do not appear to influence the extent of the starting or end spurts.

With regard to the effect of sum length, it is not possible to compare the short and medium length sums as only five intervals occurred in the short sums, but a comparison of the medium and long sums seems feasible, since by definition we restricted the length of the spurt to not more than half of the long sums.

A series of "t" tests were applied but none of the differences were found to be significant.

The time and tension curves appear to reach a peak simultaneously in many cases. The total number of times the two high points coincide is recorded in Tables VI.21. and VI.22. on page 194. The problem now resolves itself into one of the probability of coincidence of these two points. In the short sums there are five possible positions for each peak and so the probability of coincidence of the time with the tension high point is 1/5. In the case of the medium and long sums the probability will be 1/10. From Fisher and Yates' tables it can be found that six (eight) coincidences are needed in the short, and four (five) in the medium and long sums to reach the .025 (.005) level of significance. Those values which exceed chance expectation at this level are starred in Tables VI.21. and VI.22.

Besides these measures of the extent of the spurt in both curves it is necessary to obtain some indication of the slope of the graph up to that point. The occurrence of a peak at a particular place in the work curve is of itself no evidence that the curve mounts steadily to that point rather than fluctuating at random beforehand.

The criterion for a trend can be simply the number of increments, from one interval to the next, that occurs before the high point. The probability of any one interval having a larger value than the preceding interval is 1/2. Therefore, by chance, we should expect half the total number of intervals before the high point to be increments and half to be decrements. The number of increments occurring before the high point is given in Table VI.21. and is expressed as a percentage of the total number of intervals concerned. This was done for both time and tension curves.

In a similar way the trend of an end spurt can be estimated by counting the percentage of decrements after the high point. Again both time and tension curves were examined in this way, and these percentages are given in Table VI.22.

Table VI.21. Evidence for starting spurt in time and tension curves.

	Short			Medium			Long		
	P	N	M	P	N	M	P	N	M
Percentage of +s before high point in time curve	89^{++}	70^{+}	95^{+}	80^{++}	68^{++}	71^{++}	74^{++}	63^{+}	80^{++}
Percentage of +s before high point in tension curve	96^{++}	96^{++}	100^{++}	73^{++}	70^{++}	75^{++}	72^{++}	79^{++}	79^{++}
Total number of times time and tension peaks coincide	8^{++}	6^{+}	8^{++}	5^{++}	3	7^{++}	2	4^{+}	2

Table VI.22. Evidence for end spurt in time and tension curves.

	Short			Medium			Long		
	P	N	M	P	N	M	P	N	M
Percentage of -s after high point in time curve	100^{++}	82^{++}	84^{++}	74^{++}	73^{++}	81^{++}	73^{++}	63^{+}	65^{+}
Percentage of -s after high point in tension curve	100^{++}	100^{++}	92^{++}	75^{++}	73^{++}	86^{++}	65^{+}	65^{+}	73^{++}
Total number of times time and tension peaks coincide	8^{++}	6^{+}	8^{++}	5^{++}	3	7^{++}	2	5^{++}	5^{++}

With regard to the coincidence of time and tension peaks, an examination of Tables VI.21. and VI.22. shows that in most cases they occur together. In the case of the starting spurt the number of coincidences drops below the .025 level of significance only in the medium length sums of the N type and the long sums of the P and M types. The peaks that occur in the second half of the long sums and mark the beginning of the end spurt likewise tend to occur together in the N and M types, but do not reach significance in the P type. However, the type of addition and the length of the sum do not appear to affect the issue unduly.

The trends up to and down from these peaks are very marked. In all cases the percentage number of increments (or decrements) differs significantly from the 50% expected by chance, and in 29 out of the 36 cases this is significant at the .01 level. It can be concluded that there is a consistent increase at the beginning of work up to the high point in both time and tension curves, The tendency is to slow down and to become more tense. Towards the end of the task subjects begin to work more quickly and to become less tense.

Part 4.

The discussion of results has so far largely been limited to group trends, although large differences have been noted between individuals in both their speed of work and level of muscular tension in response to the experimental variables.

The variance in time and tension attributable to subjects was generally significant in the original analyses of variance and perhaps the most interesting aspect of these subject differences lies in the tendency towards consistency. Some subjects appear to be more tense than others irrespective of the type or length of sum, and similarly some subjects are more efficient than others at addition under all conditions.

A comparative index of consistency can be obtained by drawing graphs of each subject's performance and tension levels throughout work, and by then recording which individual graphs remain above or below the graph of the mean values. This is expressed in tabular form in Table VI.23. on the next page. (In this table + means that the individual graph is consistently above the mean graph throughout the sum; - means that the individual graph is consistently below the mean; 0 means that the individual graph crosses the mean graph and is neither consistently above or below the mean.)

This table should be read in conjunction with the table of individual means which follows it. (Table VI.24. on page 198.)

Table VI.23. Comparison of individual tension graphs with the graph of mean tension.

	Short			Medium			Long			Total number of signs		
	P	N	M	P	N	M	P	N	M	+	0	-
S1	+	+	+	+	+	+	+	+	+	9	-	-
S2	+	0	0	+	0	0	0	0	-	2	6	1
S3	0	-	+	+	-	0	+	0	0	3	4	2
S4	-	-	-	-	0	-	-	-	0	-	2	7
S5	+	+	+	+	+	+	0	+	+	8	1	-
S6	0	-	0	-	-	-	-	0	-	-	3	6
S7	-	-	-	-	-	-	0	-	0	-	2	7
S8	+	+	+	+	+	+	+	+	+	9	-	-
S9	-	0	-	-	-	-	-	0	-	-	2	7
S10	-	-	-	0	-	+	0	-	0	1	3	5

Table VI.24. Mean tension levels per addend for each subject.

	Short			Medium			Long			
	P	N	M	P	N	M	P	N	M	Averages
S1	14.5	11.9	14.1	17.5	14.6	17.5	17.8	13.3	17.9	15.5
S2	12.9	7.4	10.3	14.6	9.1	11.6	14.2	7.9	11.0	11.0
S3	11.9	4.9	10.3	15.0	5.8	12.8	17.5	7.6	14.6	11.4
S4	6.9	5.5	6.9	6.4	7.8	7.7	10.1	7.8	13.1	8.0
S5	13.7	9.2	11.2	16.0	11.6	17.6	17.1	13.2	16.0	14.0
S6	11.9	5.7	9.9	12.4	6.9	11.4	14.1	8.9	12.0	10.4
S7	8.3	6.3	7.9	8.4	6.6	9.4	15.0	7.5	12.4	9.1
S8	19.7	11.1	14.9	21.4	12.0	17.0	23.1	12.5	19.2	16.8
S9	9.6	6.3	6.8	15.3	7.7	9.4	11.3	7.6	9.8	9.3
S10	10.7	4.1	11.1	13.7	4.6	15.1	15.7	5.8	13.4	10.5
							Overall Average			11.6

It can be seen that three subjects (Ss 1, 5, and 8) remain consistently more tense than other subjects, while Ss 4, 7, and 9 generally give tension levels below the mean. This is admittedly a crude measure of consistency, but it seems pointless to seek further refinement in view of the lack of other data about the subjects. A few qualitative observations of personality differences may not be out of place in this connection.

We have already mentioned S8's complaint of a headache after work in the confined space of the cabin. This subject found it most difficult to relax to the required level before work began. Under the N conditions she always gave a high level of tension, but with induced tension of either kind her tension level far exceeded that of other subjects especially at the beginning of the task.

It might be presumed that the situation appeared threatening to her. She asked several times, "How am I doing?" and appeared to be "ego-involved" in the task. The headache could be considered a sympton of over-anxiety.

The following table (Table VI.25.) expresses individual differences in performance compared with the mean, and Table VI.26. on the next page gives the mean times taken per addend.

Table VI.25. Comparison of individual performance graphs with the graph of mean performance.

	Short			Medium			Long			Total number of signs		
	P	N	M	P	N	M	P	N	M	+	0	-
S1	0	0	0	+	0	0	0	0	0	1	8	-
S2	0	-	-	0	0	0	0	-	-	-	5	4
S3	-	-	0	-	-	-	0	-	-	-	2	7
S4	0	0	0	0	0	0	0	0	0	-	9	-
S5	0	+	+	0	0	0	0	0	0	2	7	-
S6	-	0	-	0	-	0	0	0	0	-	6	3
S7	0	-	-	0	0	0	0	0	0	-	7	2
S8	+	+	+	0	0	0	0	0	0	3	6	-
S9	+	+	0	-	0	0	0	+	0	3	5	1
S10	+	0	+	-	-	0	0	0	0	2	5	2

Although there is much more variability in Table VI.25. than in Table VI.23. it can be seen that S8 is a poor performer. S1 and S5, the other two tense subjects, also tend to work poorly. This is not clear from Table VI.25. although it is apparent in the following table of means.

Table VI.26. Mean times taken per addend for each subject.

				Medium			Long			
	P	N	M	P	N	M	P	N	M	Averages
S1	45.2	56.5	46.4	81.2	84.0	83.2	57.6	64.4	67.4	65.1
S2	37.0	49.1	23.4	45.6	61.0	45.7	55.7	45.0	36.9	44.4
S3	22.2	50.5	30.3	34.9	42.7	37.2	42.8	47.4	36.0	38.2
S4	40.7	57.9	47.3	53.1	71.4	53.9	60.0	60.4	83.5	58.7
S5	40.3	63.8	43.2	52.6	69.6	59.8	57.0	70.8	60.6	57.5
S6	24.7	58.3	30.6	49.3	60.5	54.1	50.4	62.1	49.7	48.9
S7	34.0	45.1	23.9	59.8	60.3	50.6	63.9	65.1	55.0	50.9
S8	58.1	66.5	46.8	59.9	67.8	42.0	60.2	70.8	56.5	58.7
S9	51.1	65.2	49.5	39.4	79.2	57.8	51.6	83.1	58.7	59.5
S10	46.3	52.1	49.2	46.7	52.3	47.2	48.6	60.1	47.2	50.0
							Overall average			53.2

The relaxed subjects (S4, S7, and S9) did not appear particularly at their ease during the experimental sessions, except for S7 who seemed interested in the procedure and discussed the experiment afterwards. This subject was an efficient worker, relaxed quickly in the fore-period and generally gave the impression of poise and confidence. S4 and S9 on the other hand were both slow workers.

The most efficient subject (S3) is interesting as she had considerable mathematical ability compared with the other subjects. She worked quickly and efficiently, but disliked the electrodes and appeared anxious to escape from the situation. Her nervous giggle meant several false starts had to be made, but when once work began she seemed to become more confident about her performance. Although outstanding from the point of view of performance this subject did not give an unusual muscular tension record. Under normal conditions her level was a little less than the mean and a little higher under tension.

These observations were only incidental and their significance is doubtful. There is need for research into the personalities of both the muscularly tense and the extremely relaxed, and into their response to stress conditions even of this mild kind.

Earlier work (Bills and Stauffacher, 1937; Stauffacher, 1937) suggests that better workers are generally more tense and that induced tension does not facilitate the work of these better subjects. Although as we have seen in Part 2 of this chapter there appeared a slight tendency for the better workers in the present experiment to be <u>less</u> tense, it should, nevertheless, be of interest to separate the better from the poorer subjects on the M type sums where they were urged to work at maximum speed, and then to examine the effect of induced physical tension on these two groups of subjects.

Table VI.27. shows the mean time values for each S on sums of the three different types.

Table VI.27. Mean time values under different conditions for each subject.

	P	N	M		P	N	M
S1	61.3	69.0	65.7	S6	41.5	49.1	44.8
S2	46.1	51.7	35.3	S7	52.6	53.1	43.2
S3	33.3	46.9	34.5	S8	58.3	65.6	48.4
S4	51.3	63.2	61.6	S9	47.4	71.1	55.3
S5	50.0	60.2	54.5	S10	47.2	52.9	47.9

The three most efficient subjects under "mental tension" conditions are S3, S2, and S7, and the three weakest subjects are S9, S4, and S1.

If the performance of these extreme subjects on the P type task is now examined we find that there has been the following improvement over their working level for the N type sums (See Table VI.28. on the next page).

Table VI.28. Total improvement of best and worst subjects under physical tension conditions.

		Improvement			Improvement
Best Group	S3	13.6	Worst Group	S9	23.7
	S2	5.6		S4	11.9
	S7	0.5		S1	7.7
	Total	19.7		Total	43.3

This apparent tendency for the poorer subjects to improve more than the better subjects is not however significant. It seems necessary to take into account the original working level when dealing with an increment of this sort. If these figures are expressed as percentage improvement over the original N type performance the better subjects are seen to have improved 17.4% compared with 23.7% in the case of the poorer subjects. This difference is also non-significant.

These findings cannot be interpreted as a contradiction of Stauffacher's U-curve hypothesis. In Stauffacher's experiment the relative improvements calculated as percentages appear to be 7.2% and 19.5% respectively. But in that case the effects of induced tension were examined on subjects who were working at their maximum speed. In the present experiment the comparison is between subjects working at an easy pace (N type) and at a similar pace with induced physical tension (P type). The difference between the two conditions (see the variance analysis in Part 1) may be due to the independent experimental variable, induced tension, but it may equally well be due to a change in set, since it may have proved impossible to maintain an easy pace while the spring-balance was pulled. Such an indirect effect, as we shall see, may also be offered as an explanation in Stauffacher's experiment, although it seems more plausible in the present case. In view of the dissimilar conditions, and particularly the tendency for our better subjects to be more relaxed, it is not surprising that there was no differential effect with induced tension.

Chapter 7.

Interpretation of the Results and Theoretical Discussion.

The central problem of this investigation has been to study the relation of muscular tension to efficiency. This entailed (1) tracing performance carefully during work to see whether an analysis in terms of starting and end spurts was justifiable, and (2) tracing the moment-to-moment variations in tension during work. The question was: were these variations in performance and tension closely related and, if so, would it prove possible to heighten any such relationship by the induction of "mental" or physical tension?

The effects of the different conditions (P, M, and N) under which work was performed were on the whole clear-cut. Under "mental tension" subjects added more quickly and became more tense. Thus more efficient work was accompanied by greater tension. Indeed the tension differences between the M and N type sums were more significant than the time differences.

The increase in the length of tasks under tension conditions led to an increase in the mean time taken over each adding operation. This finding is in complete accord with previous work (Bills and Brown, 1929; Katz, 1946), but no increase in errors with the longer tasks was found. The discrepancy here is probably due to the non-cumulative nature of the present task, which entailed pairs addition. There is also a tendency for higher tension levels to accompany the longer tasks under induced tension, but the large amount of subject variation prevents a clear-cut difference. It is as though subjects approached the longer tasks in this way in order to overcome the more difficult task before them, a task which would require a greater expenditure of energy.

The effects of induced tension.

Under physical tension conditions all except one subject became more physically tense in the muscle group studied, but there was a considerable amount of variation between subjects. We cannot conclude, therefore, that we have induced the same amount of general tension in each subject for all the sums, in spite of our attempt to use a standard pull on the spring-balance. All subjects worked more quickly under these conditions and approximated to the speed shown under M conditions. At first glance this finding would seem to be in agreement with earlier work. Induced physical tension of the same amount as in the present investigation has been found to facilitate mental work of the simpler kind, although it will be remembered this was generally only true of the poorer workers. When the three best and three worst performers are separated out in the present experiment no such differential effect can be observed. What is more, contrary to Stauffacher's U-curve hypothesis, the three better workers do not tend to be more tense than the three poorer workers. It is not surprising, therefore, that the differential effects expected from induced tension do not arise.

We have mentioned in the previous chapter that a strict comparison with the work of Stauffacher and others is not possible. In other work the effects of tension have been superimposed on maximal mental effort. In the present experiment tension has been induced in subjects who were working at an easy steady rate. The changes in the speed of work may be due to either (1) a direct physiological effect of induced tension, or (2) an indirect effect due to failure to retain the set to work slowly. This failure might be due to a misunderstanding of the instructions, especially in the shortened form in which they were given after the first trial of the P type, or to a real difficulty in working slowly while tensing the forearm.

Unfortunately no opinions were offered by the subjects about the number of different types of task they considered they had been given, and it did not seem necessary to ask for this information at the time. This might have shed light on whether subjects realized that succeeding sums were to be added in the same manner as the first ones.

If the second alternative is true and a change of set occurred, we can fairly conclude that induced tension facilitates mental work in this experiment although not perhaps in the manner supposed by earlier workers. The replies of two subjects when questioned some time afterwards support this idea. Both said it was difficult to add slowly when tense and that they had to keep reminding themselves not to go too fast.

Robinson (1934) suggested three possible ways in which induced tension might lead to improved performance.

(1) The induced tension might lead to a more constant proprioceptive feedback and this more stable afferent input should prove beneficial to the performance of a complex skilled task which is by its very nature easily disturbed by environmental variation.

(2) The increased proprioceptive input might raise the general level of excitement in the cortex and this might lead to a more efficient approach to mental work.

(3) The induction of tension in one muscle group might lead to fairly widespread increases in tension and therefore a greater readiness to react in other muscle groups. Since even the "purest" mental work demands some form of muscular response before it can be measured this readiness to respond might be the basis of the facilitative effect.

The first possibility does not appear to have been put to experimental test. Robinson suggests that the facilitative effects of music on mental work (e.g. Diserens, 1926) may be brought about in a similar way. The evidence from the present experiment suggests that fluctuations in tension occur equally readily when tension has been induced in antagonistic muscles, and this makes the hypothesis slightly less tenable.

Freeman has attempted an elaboration of the second theory. He thinks the proprioceptive feedback lowers the thresholds of excitability for both cortical and lower levels of the nervous system. This is essentially a theory of "vigilance" as a function of peripherally supported excitation. It is far too simple an "explanation" in view of the complexity of the probable neurophysiology. If an interpretation is to be sought on this level, criticisms such as those of Meyer (1953) must be given their due. There is very little evidence for the widespread effects mentioned by Freeman. Proprioceptive feedback is only one kind of input and although it must certainly alter the level and distribution of excitation within the motor system it is unlikely to have wider effects. Meyer believes it is possible to combine the classical concept of spatial summation with modern knowledge of the organization which occurs within the motor system. The convergence of impulses is thought to take place on the _motor pathways_, and the theory entails the belief that tension can only facilitate performance by an alteration in either the magnitude or latency of a _response_, and in this respect bears resemblance to Robinson's third hypothesis.

Meyer's theory must encompass the detrimental effects of very high levels of induced tension. He believes these results can be accounted for by the postulate that irrelevant responses are facilitated by gross amounts of tension induction. In other words there must be some differentiation of the input to favour the selected response. One can think of a pool of activated neurons, surrounded by a fringe which is brought to firing point by the induction of small amounts of tension. If further excitation is supplied by the induction of more tension, more remote neurons will fire, and these may be irrelevant and indeed detrimental to the required performance.

In line with this theory are the results obtained from the induction of tension at various stages of practice. Bills (1927), Freeman (1938), and Courts (1942) all found the greatest amount of facilitation occurred early in practice. As performance becomes more efficient and an optimal selection of motor neurons takes place, the recruitment of further neurons to the pool will no longer facilitate performance, but, in so far as they are inappropriate neurons, they will tend to give rise to irrelevant responses. None of the experimental work has reported an actual reversal after practice of the usual differential effect in favour of induced tension, but perhaps practice has not been continued until a well-marked plateau has been reached.

The differential effect in favour of the poor performers could presumably be brought within the same explanatory framework. Increments of tension only succeed in recruiting inappropriate neurons in the case of the efficient worker with his optimal motor organization, whereas there is facilitation of appropriate responses in the case of the poorer worker.

The theory insists on the facilitation of speed alone with no change or a deterioration in accuracy. The facilitative effects are indeed more marked when speed is used as the criterion in simple mental tasks. In fact if performance is thought of in terms of quantity alone results are most impressive, whereas if accuracy or quality is taken as the criterion Bills (1927) is almost alone in supplying supporting evidence, and a repetition of his experiment by Bourne (1955) does not offer any confirmation of his results. Russell (1932), Freeman (1933), Bills and Stauffacher (1937), and Klein (1952) are among those who find a detrimental effect on accuracy. In the present experiment twice as many errors occurred in the P type additions as in the N type additions which seems to be in agreement with the bulk of previous evidence. This distinction between speed and accuracy is a useful one as it helps to clarify the conclusions reached in Chapter 3.

A different type of explanatory hypothesis on a psychological level was put forward by Block (1936). She considered the induced tension might act as a "distractor". Facilitation by distraction may seem a contradiction in terms, but Block believed that work output was increased in order to overcome the distraction due to the induced tension, and in doing so subjects tended to overcompensate; thus in an indirect way the induction of tension led to facilitation. It is difficult to disprove this hypothesis, but reports from Block's own subjects do not support it. She found no correlation between the effects of induced tension on performance and the degree of distraction experienced. Some subjects became unaware of the presence of the localized tension. On the other hand results from distraction experiments do tend to resemble those derived from work with induced tension. An inversion of Block's argument seems a more satisfactory and parsimonious way to deal with these facts. Resistance to distraction leads to induced tension (Morgan, 1916; Davis, 1937) and in subjects not previously doing their best induced tension leads directly to improvement beyond what is needed to counteract the effects of the distraction. Given motivation to continue the task, the sequence in this view is: distraction - tension - improvement, instead of Block's: tension - distraction - "effort" - improvement. This does not entail a complete dismissal of motivational differences from consideration, for expectations of what is required and interpretations of experimental procedures must be of the utmost importance. These psychological factors presumably have their muscular concomitants, but in the present experiment it is probably necessary to invoke them on a psychological level to explain why similar results were obtained from the presence of "mental" or physical tension.

It is of interest that Klein (1952) induced tension in two ways, indirectly by experimentally induced failure and directly by weight-lifting, and found both methods had the same effect on performance (an increase in the rate of muscular work). Although the present finding is similar, once again no strict comparison is possible, as Klein used maximal effort as his base-line condition.

We are led to the conclusion that the induced tension procedure in the present investigation differs from those used in earlier work, and that, although facilitation occurred, the mechanism may have been a more complex one. In the other work Meyer's theory serves as a partial explanation, but it may be necessary to include psychological variables, such as change in set, to explain the present results.

In the analysis of the variation in output during work and its association with muscular tension a highly significant correlation was obtained between low output and high tension. This does not necessarily throw doubt on the beneficial effects of experimentally induced tension. The discrepancy may be resolved if the high tension is considered as an outcome of an effort to overcome the difficulty. In support of this idea the fluctuations in tension can occasionally be seen to lag behind the fluctuations in speed. (See graphs in Chapter 6, Part 2.) This self-induced tension would have to be regarded as a compensatory mechanism brought into play whenever a difficulty was encountered. As subjects were not generally aware of their fluctuations in speed during work, an unconscious homeostatic tendency would have to be assumed.

Further support is offered for this view when the results from the different length sums are examined. On the longer additions of all types subjects generally became more tense, and this as we have mentioned agrees well with earlier work on the effects of increased difficulty and again suggests that the increase in tension is a device to cope with the difficulty.

This viewpoint would likewise maintain that the higher tension levels generally obtained from the poorer subjects in the present experiment are a result of this compensatory mechanism being brought into play. The poorer subjects have to put out a greater effort in order to achieve a satisfactory level of work.

On the other hand the bulk of previous work summarized in Chapters 2 and 3 suggests that better workers are generally more tense than poorer workers. But a general statement that tension is facilitative meets the objection that psychotics and neurotics with high tension levels are not notably efficient, their tension appears neither to aid the solution of everyday problems, not to improve performance at psychological tests. (See, for example, Shagass and Malmo, 1954; Sainsbury and Gibson, 1954.) Jacobson's work on the therapeutic value of relaxation supports this contention, and an experimental demonstration is to be found in Duffy's research (1932) which appears to show that highly tense children were not the most efficient performers.

But the phenomenon of "trying too hard" is not unknown, and it is conceivable that the poorer workers were putting too much effort into the work. This view would maintain that the mentally ill are <u>over-tense</u>, that is, they are at the extreme end of Stauffacher's U-curve, where such large amounts of tension are disruptive. A reduction of their tension to a more normal level leads to an improvement in performance. However, this seems unlikely as very large amounts of tension must be induced to bring about a deterioration in performance, and comparatively much lower levels are found in abnormals.

Another possible resolution of the seeming contradiction might lie in the suggestion that these people's high energy mobilization is unconsciously directed to some other task, e.g. warding off threat, and is not available for daily activities or laboratory tasks. The better workers in the majority of previous experiments may have been those who put a more directed effort into the task in hand. Whereas in both Duffy's experiment and in the present one the poorer workers were putting out more effort, but this may have been diffuse and directed elsewhere.

Alternatively, we might consider Bills' suggestion of two different kinds of tension, "one due to emotional upset, the other reflecting effort." This view conflicts with theories which equate degree of emotion with amount of energy release (e.g. Woodworth and Schlosberg, 1954). However, objections have been raised to these theories, as if a continuum of activation is envisaged with unconsciousness at one end and strong emotion at the other, then it is difficult to see where intense non-emotional activity should be placed on the same dimension. As Magda Arnold (1955) has put it:

> "Degrees of energy mobilization cannot be readily differentiated either in experience or by observation: extreme effort and emotional excitement, for instance, may have the same measurable energy output, but as experienced, effort is laborious while excitement is not." (p. 167.)

These qualitative differences are at present indistinguishable at the level of bodily physiology, but it does not necessarily follow that it will never be possible to differentiate a useful from a disruptive kind of tension.

It would seem most likely that there exist differences in spatial or temporal pattern. At the present time tension is almost invariably measured in terms of amount, and locus is involved as a secondary factor. The degree to which tension is focused in certain muscle groups and the consistency with which the tension in these muscle groups is maintained provide two more dimensions to assist the investigator in the search for patterns of bodily tension, which although elusive are not necessarily will-o'-the -wisps. Such a programme must await the advent of much more complex recording techniques, able to deal with a large amount of simultaneously available information.

Variation during work.

Mental performance has frequently been shown to drop in efficiency at the beginning of work and this phenomenon has been called a starting spurt. In view of the occasional discrepancies that have arisen an operational definition was suggested for this research. When the highest peak of a work curve was taken as the end point of the period which was to be examined for a trend (in the case of the long sums the highest peak before half-way), results were clean-cut. A trend occurred up to this point with some regularity, and neither the type nor length of the task appeared to affect the length of the period or the consistency of the trend.

There is more agreement in the literature about the end spurt which is very frequently observed, and attributed on common-sense grounds to the subject's expectation of the approaching end of the task. In the present experiment it was defined in a similar way to the starting spurt, the same high peak being taken to mark the beginning of the end spurt, except in the long sums where the highest peak after the half-way point seemed more appropriate. Once again the conditions of work did not appear to influence the trend. With some confidence, then, one is able to say that subjects began this type of addition rapidly, but also began to slow down from the very beginning of the task, and did not show improvement until they had added a little more than half the sum. From this point until the end of the task an improvement occurred. The curves for both the short and medium sums have this inverted U shape. In the long sums it was possible to identify two or three peaks in the work curve although the initial and final trends were as marked as in the shorter sums.

When the tension curves were examined a very similar state of affairs was found. "Spurts" of tension seemed to occur and accompanied the variations in the work curve to a striking degree. The highest points of the two curves coincided significantly often under most conditions. When the long sums are examined (Graphs VI.9, 10, and 11.) the correspondence of the two curves throughout the task can be clearly seen and reflects their high correlation.

In the review of the literature concerned with the variation in tension during work, the conclusion was reached that when work begins a marked rise in tension occurs, possibly to be followed by a further increase, which is succeeded in turn by a decline in tension towards the end of the task.

The initial rise and final decrement were substantiated here and furthermore these phenomena appeared to be "tied" to concomitant variations in work output. This finding stresses that it is meaningless to examine changes in tension without some simultaneous indication of performance; in this respect the present analysis over short time intervals appears to have been fruitful.

The peripheral theory of thought.

The relevance of these results to the peripheral theory of thought is problematical. The earlier statements of this theory were concerned with the rôle played by muscular processes in relation to conscious thought. In its barest essentials the theory is an hypothesis to the effect that muscular tenseness is a *sine qua non* of mental process. Any rigorous attempt to test the theory must obtain indices of both muscular tension and psychological activity. It is not difficult to sample bodily tension so long as it is borne in mind that it is a sample whose representativeness is unknown. The difficulty lies in the apparent impossibility of measuring the psychological activity independent of muscular phenomena. The familiar difficulty of measurement in psychology generally necessitates recourse to behavioural indices, and so in the present experiment verbal output served as an indication of mental effort. But the amount of mental work accomplished is only a partial indication of all the subject has been doing during the experimental session. It is introspectively absurd to identify the two, but perhaps no more absurd than to expect accuracy from the introspective vagaries of Kraepelinian analysis.

In our case a high correspondence was found between speed of addition and muscular tension levels during work, and the behavioural index seems to have been a good measure of mental effort. Whether this is because distraction, and other factors which might be thought to modify the effort-output correspondence, were at a minimum it is difficult to say, although the physical conditions of the experiment make this highly probable.

How are these results relevant to the peripheral theory of thought? The strong tendency for muscular processes to parallel mental ones could as easily be due to "overflow" from the centre as "reinforcement" from the periphery, and I do not believe that this type of experiment can possibly settle the apparent issue. The second approach, the study of the effects of induced tension on mental events, seems a more profitable one, but, as pointed out earlier, there may have been no <u>direct</u> effect in this experiment owing to the use of less than maximum working effort as the base-line condition. No theoretical development has therefore been achieved, and any advance that may have been made has been in the demonstration of a closer correlation than hitherto imagined. In any case, when formulated in a cause and affect relationship the issue is not a real one. The nervous system is best considered as a whole with no artificial dichotomy between "centre" and "periphery". The cortex in its service as an integrator of lower levels is in intimate connexion with both visceral and somatic nerve complexes, a system designed for "action" and "back-action". The level of cortical excitement may be controlled by a hypothalamic pace-maker (Lindsley, 1951) which in turn is partially controlled by afferent stimulation including kinaesthetic feedback.

Such knowledge as is available emphasizes the wholeness of the nervous system, indeed of the whole body. We can do little more than "sample cortical activity" by electrical means, but in view of the complexity of such central analysis, which has become remote from any underlying physiological or psychological meaning, it may be more rewarding to devote future research to peripheral change especially if the instrumentation for simultaneous recording from several loci becomes available.

Summary of Conclusions.

1. Under a set to work quickly subjects became more muscularly tense.

2. Under conditions of induced physical tension subjects worked more quickly. This effect could be ascribed either to the direct result of the induced tension, or to an inability to retain the set towards working "at a comfortable speed".

3. There was a tendency (over all the sums) for poorer workers to be more tense.

4. No differential effect in speed of work between good and poor performers was brought about by induced physical tension.

5. A high correlation was found between tension fluctuations during a task and variations in performance. Slower additions were accompanied by greater tension, and it is suggested that the tension may be self-induced when a difficulty is encountered. This seemed to occur under normal conditions and was not disturbed by the induction of physical tension. A closer relationship between speed and tension was found to occur under the set to work quickly. The length of sum was also relevant, a significantly higher correlation being obtained in the short sums.

6. No consistent relationship between the time taken to add a sum and the total tension exerted during its course was found from one subject to the next, neither were subjects consistent from one condition to another.

7. The mean time taken per addend increased as the length of the task increased, and the longer tasks tended to be accompanied by higher average tension.

8. Starting and end spurts occurred in the type of mental work employed, and were closely paralleled by "spurts" in tension. It is concluded that although earlier work had described these speed and tension increases separately, moment-by-moment analysis appears to show that they are conjoined.

9. The results are not considered directly relevant to the peripheral theory of thought. Any value they may have lies rather in the suggestion that peripheral analysis may be a more rewarding programme for future research than one restricted to central events.

9. The results are not considered directly relevant to the peripheral theory of thought. Any value they may have lies rather in the suggestion that peripheral analysis may be a more rewarding programme for future research than one restricted to central events.

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Appendix I.

Addition sums employed.

(1A)	3	(2A)	1	(3A)	3	(4A)	1	(5A)	4	(6A)	8
	7		5		2		8		3		4
	6		8		7		4		3		5
	2		1		6		7		7		7
	5		6		9		9		8		8
	6		4		6		6		6		6

(1B)	3	(2B)	2	(3B)	9	(4B)	7	(5B)	7	(6B)	5
	4		6		4		1		4		2
	2		5		7		9		6		3
	5		9		4		5		6		3
	6		2		3		3		9		8
	7		9		6		6		2		7
	7		8		7		3		2		8
	3		6		5		5		1		3
	2		4		6		2		1		1
	6		7		9		9		8		2
	7		2		6		5		2		4

(1C)	(2C)	(3C)	(4C)	(5C)	(6C)
6	6	8	2	4	5
2	2	3	2	8	3
6	2	3	3	8	6
6	5	2	5	3	4
8	1	7	8	4	6
9	7	4	7	3	9
7	7	2	5	4	4
6	8	7	8	9	8
8	2	3	2	8	5
9	9	1	2	5	1
4	9	5	4	3	5
4	3	6	8	6	3
2	7	4	8	5	9
3	2	9	8	7	4
6	3	2	4	7	7
8	7	4	7	4	4
3	6	9	9	9	1
5	5	5	9	8	4
9	4	2	6	8	2
8	1	1	4	5	1
6	6	7	9	7	8

Appendix II.

Accuracy of the measurement technique.

Record: 1C
Type: P
Subject: S9

Mean values for each interval.

Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
E1	11	11	11	12	10	10	11	11	10	11	11	10	12	10	14
E2	11	11	11	12	10	10	11	11	10	11	11	10	12	10	14

Interval	16	17	18	19	20
E1	14	10	11	10	11
E2	14	10	11	10	11

Record: 4B
Type: M
Subject: S10

Interval	1	2	3	4	5	6	7	8	9	10
E1	12	12	15	15	16	14	14	16	14	13
E2	12	12	14+	15	16	14	14	16	14	13

+ disagreement

Record: 4B
Type: M
Subject: S4

Interval	1	2	3	4	5	6	7	8	9	10
E1	7	8	9	5	5	8	10	7	8	7
E2	7	8	9	5	5	8	10	7	8	7

Appendix LII.

The effect of practice on speed of work and muscular tension.

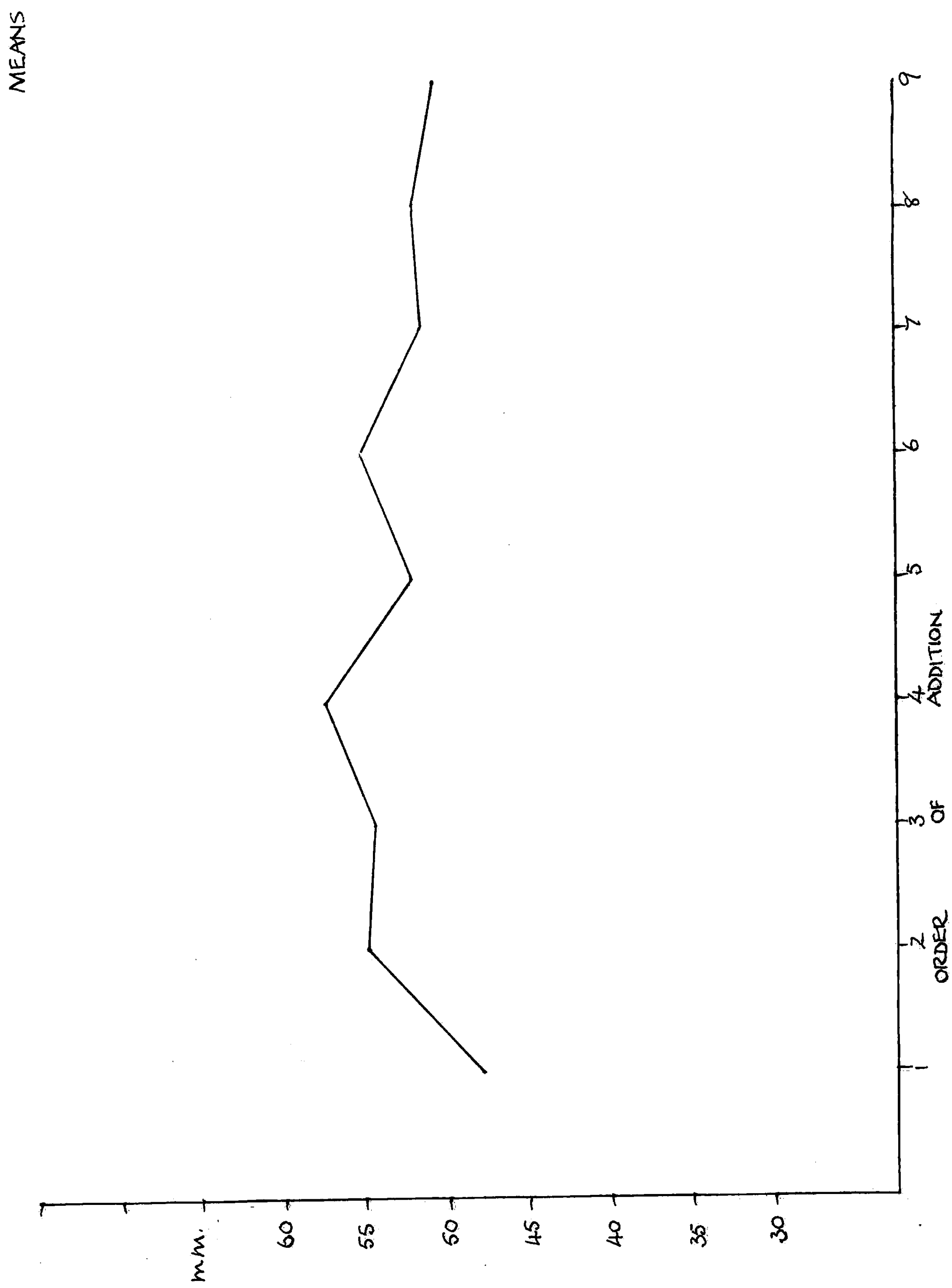
The tables give the mean times and mean tension levels per addend for the sums in groups of three in the order in which they were added. That is, the first figure in the table is the mean for the first three sums added in the session, the second figure for the second group of three, and so on. The nine values obtained from the 27 sums added during the session are graphed for each subject separately on the following pages. The mean values over all subjects are also graphed.

Mean time taken per addend during experimental session.

Order of Addition	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean
1) 2) 3)	56.5	49.1	28.6	49.2	58.8	36.5	51.3	47.6	50.9	48.7	47.7
4) 5) 6)	64.5	53.3	36.9	75.1	68.4	45.5	47.4	51.2	59.9	47.1	54.9
7) 8) 9)	71.2	61.0	38.0	55.5	59.8	52.5	59.1	46.6	55.2	47.7	54.6
10) 11) 12)	78.7	43.3	48.1	57.5	50.4	41.1	64.2	62.5	76.4	52.9	57.5
13) 14) 15)	58.7	40.0	35.3	50.7	56.0	46.5	55.6	70.3	60.2	49.3	52.3
16) 17) 18)	59.3	46.7	48.4	62.2	60.6	56.0	51.6	61.0	53.2	51.9	55.1
19) 20) 21)	61.7	30.9	32.7	70.7	64.2	53.2	33.4	66.8	56.2	48.2	51.8
22) 23) 24)	66.1	45.3	41.0	62.8	50.4	47.2	41.0	63.9	52.9	51.4	52.2
25) 26) 27)	69.2	35.7	35.0	51.2	48.9	61.5	55.3	58.9	70.8	52.5	51.1

Mean tension per addend during experimental session.

Order of Addition	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean
1) 2) 3)	11.9	7.4	13.2	7.6	12.7	9.7	9.0	17.6	8.4	14.5	11.2
4) 5) 6)	16.6	11.6	12.7	8.4	14.8	12.0	7.4	15.7	8.9	12.0	12.0
7) 8) 9)	14.7	9.1	14.3	6.6	15.0	11.5	9.7	14.5	8.7	13.1	11.7
10) 11) 12)	15.9	11.7	9.1	8.1	13.5	10.7	8.1	17.5	7.9	8.3	11.1
13) 14) 15)	16.8	12.0	11.2	7.4	12.5	7.9	9.8	12.3	7.5	8.2	10.6
16) 17) 18)	13.9	14.5	5.9	6.4	12.4	8.1	8.1	17.6	9.2	8.0	10.4
19) 20) 21)	15.8	9.0	11.4	9.1	16.3	11.6	8.6	14.8	10.7	13.8	12.1
22) 23) 24)	16.3	11.6	13.6	9.6	14.0	11.2	9.4	19.4	9.9	8.3	12.3
25) 26) 27)	17.4	12.3	11.5	9.0	14.5	10.0	11.6	17.7	9.4	8.1	12.1


MEANS
m.m.
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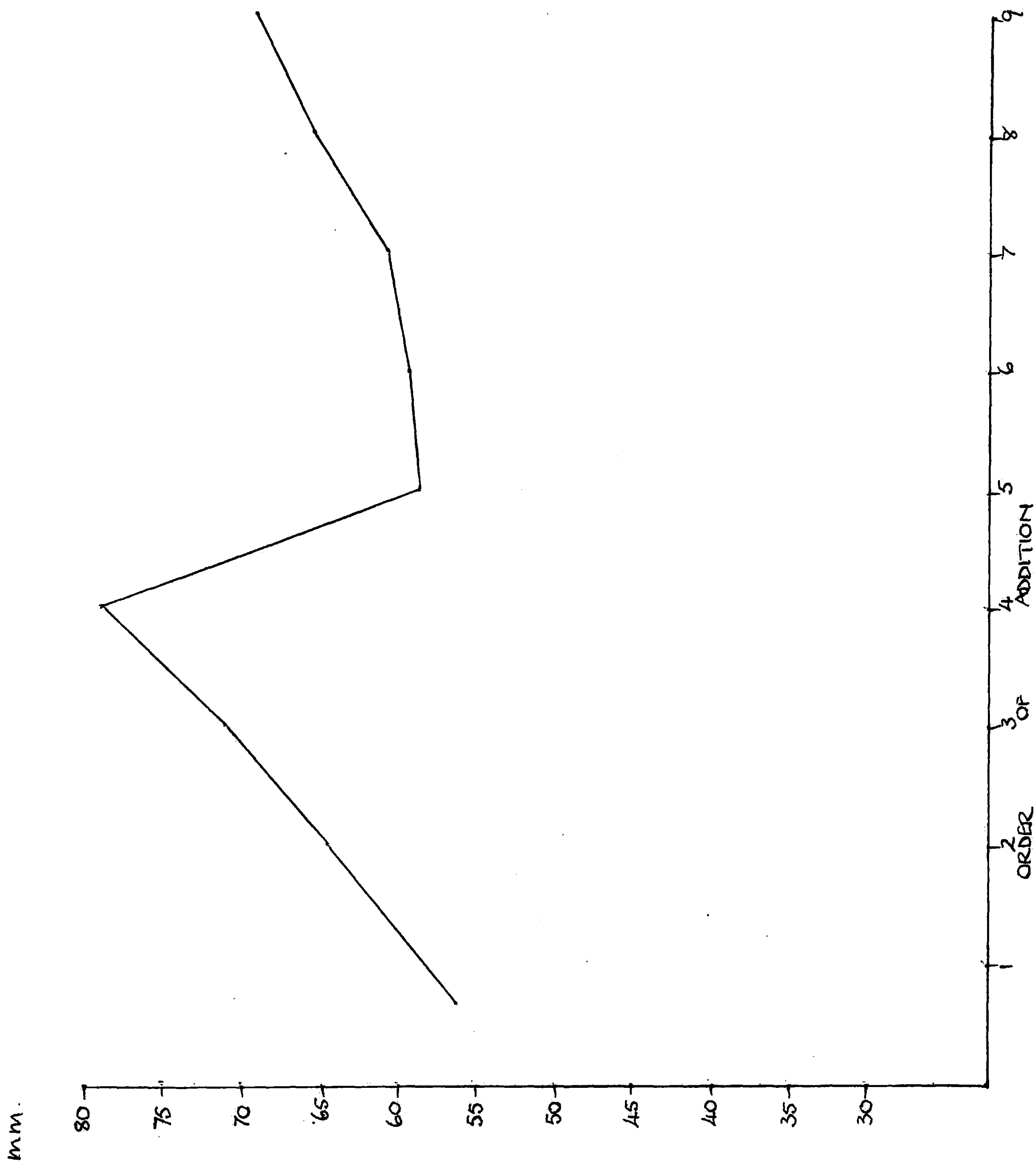
9
ORDER OF ADDITION

51.



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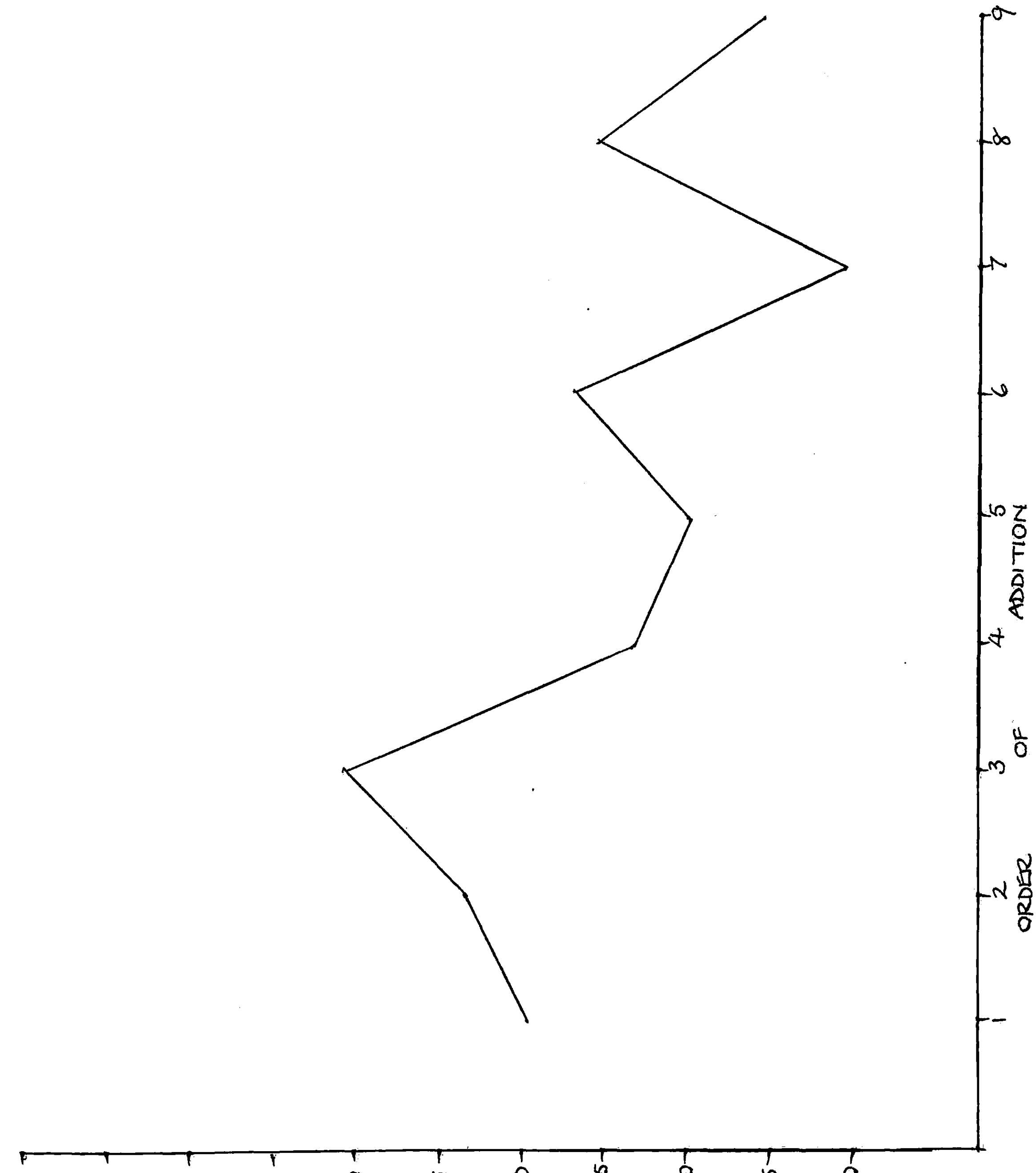

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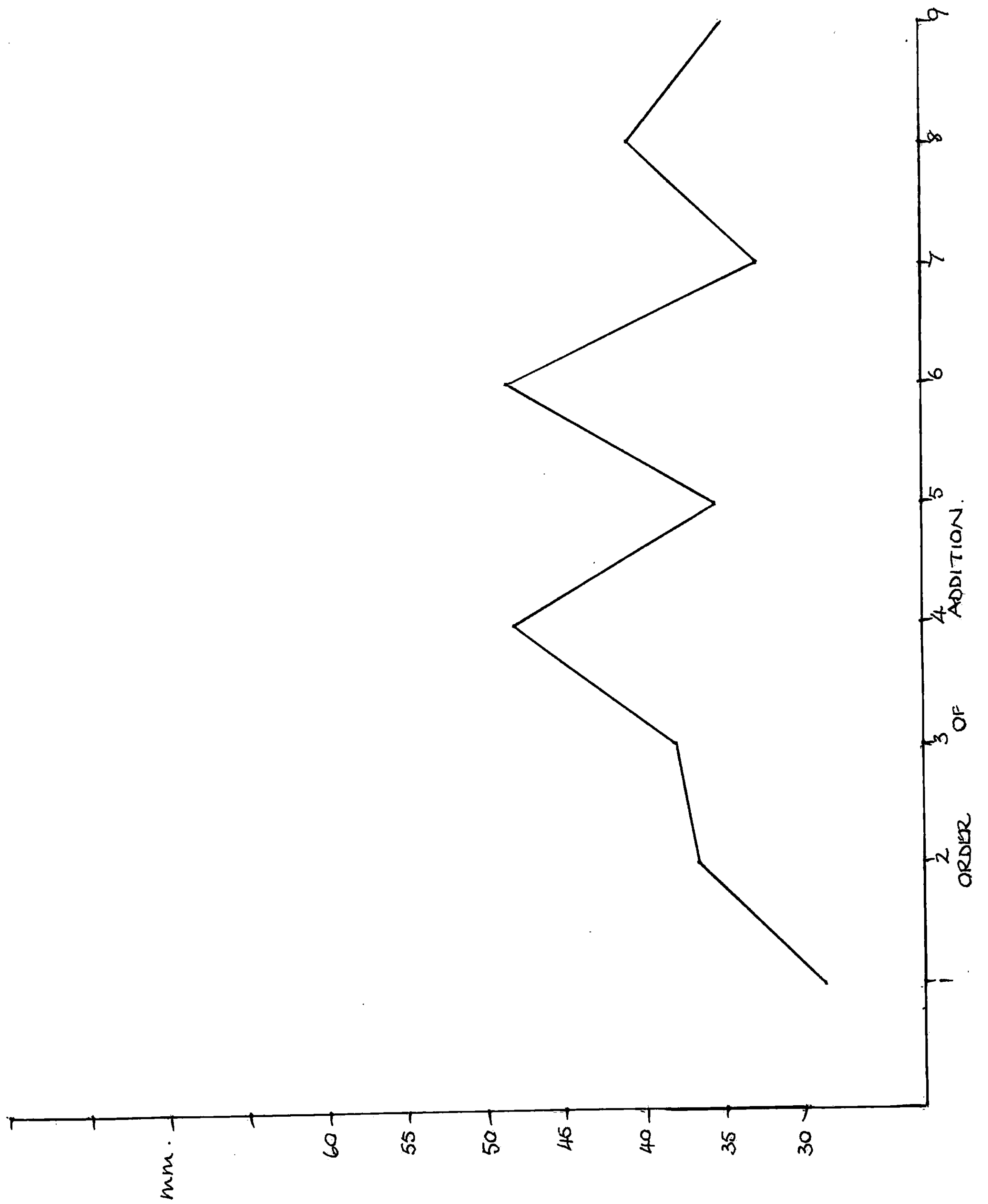

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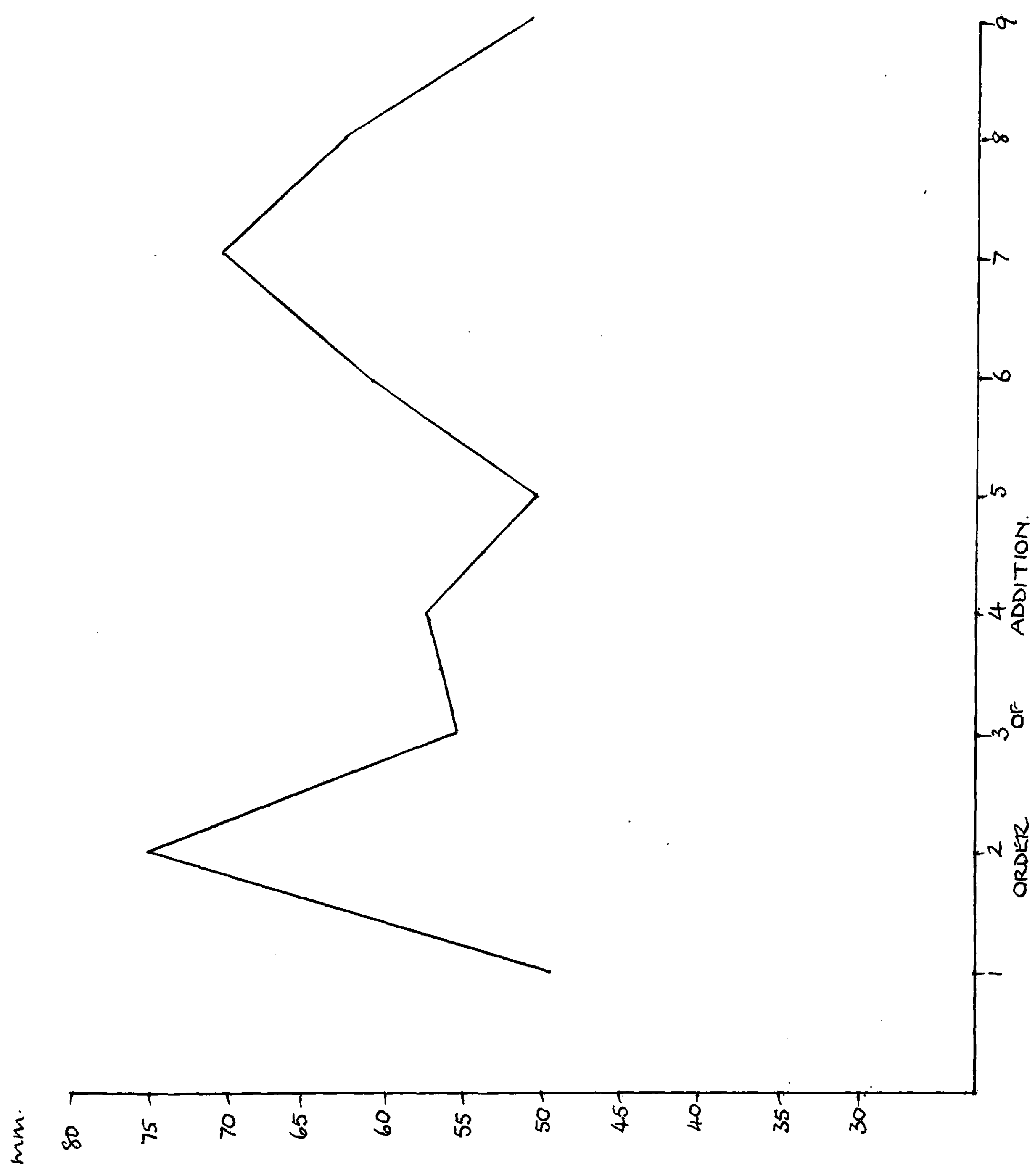

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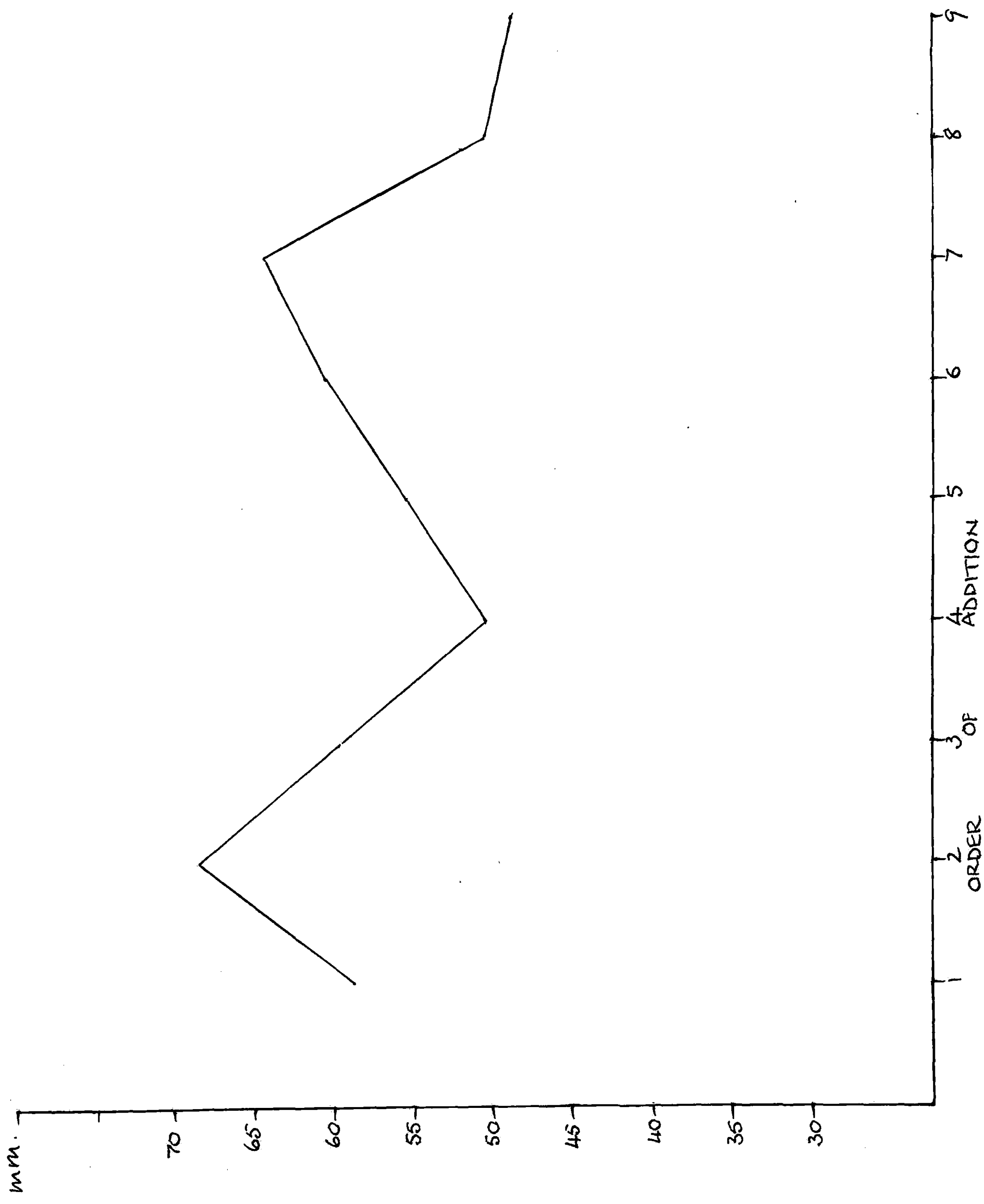

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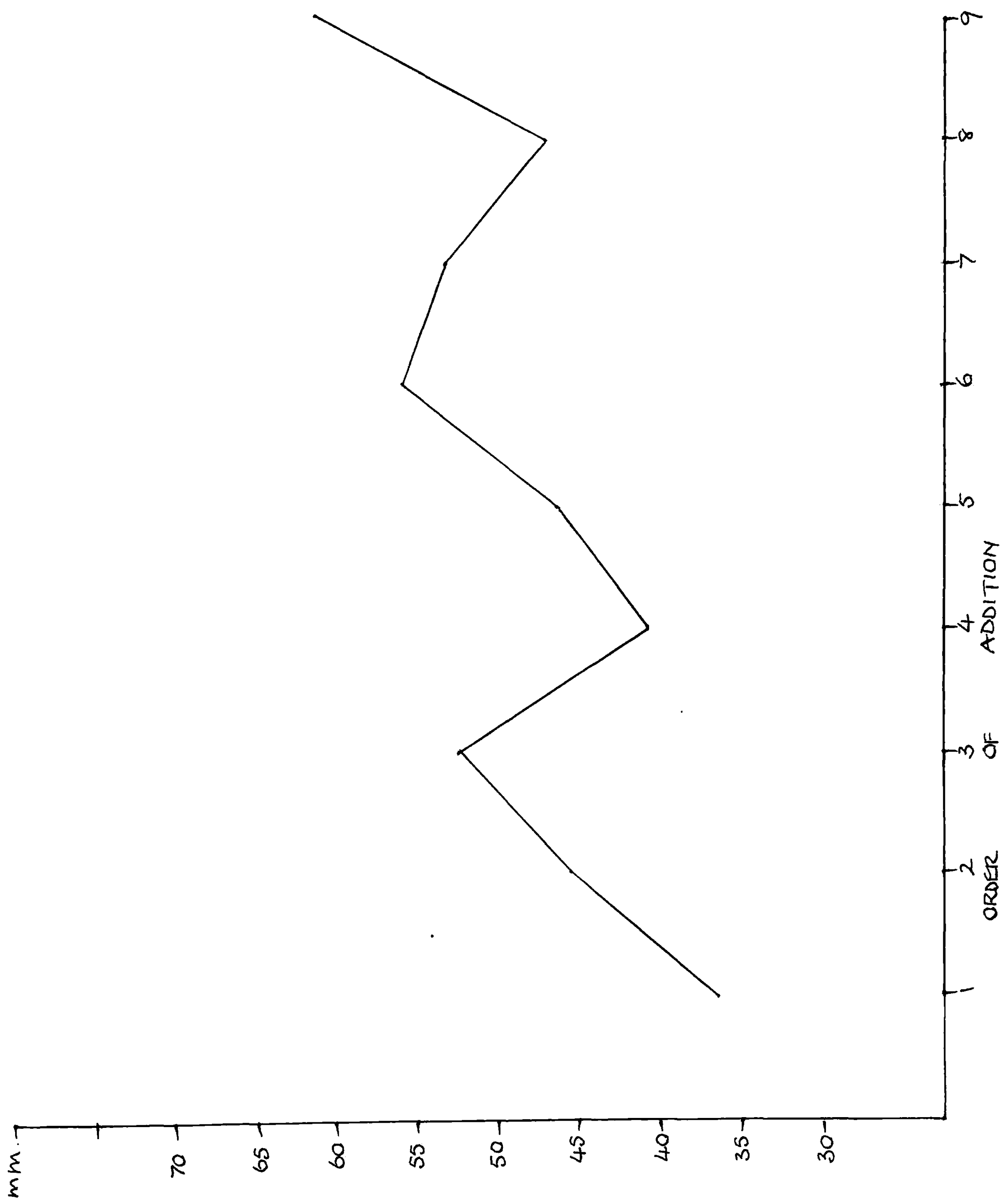

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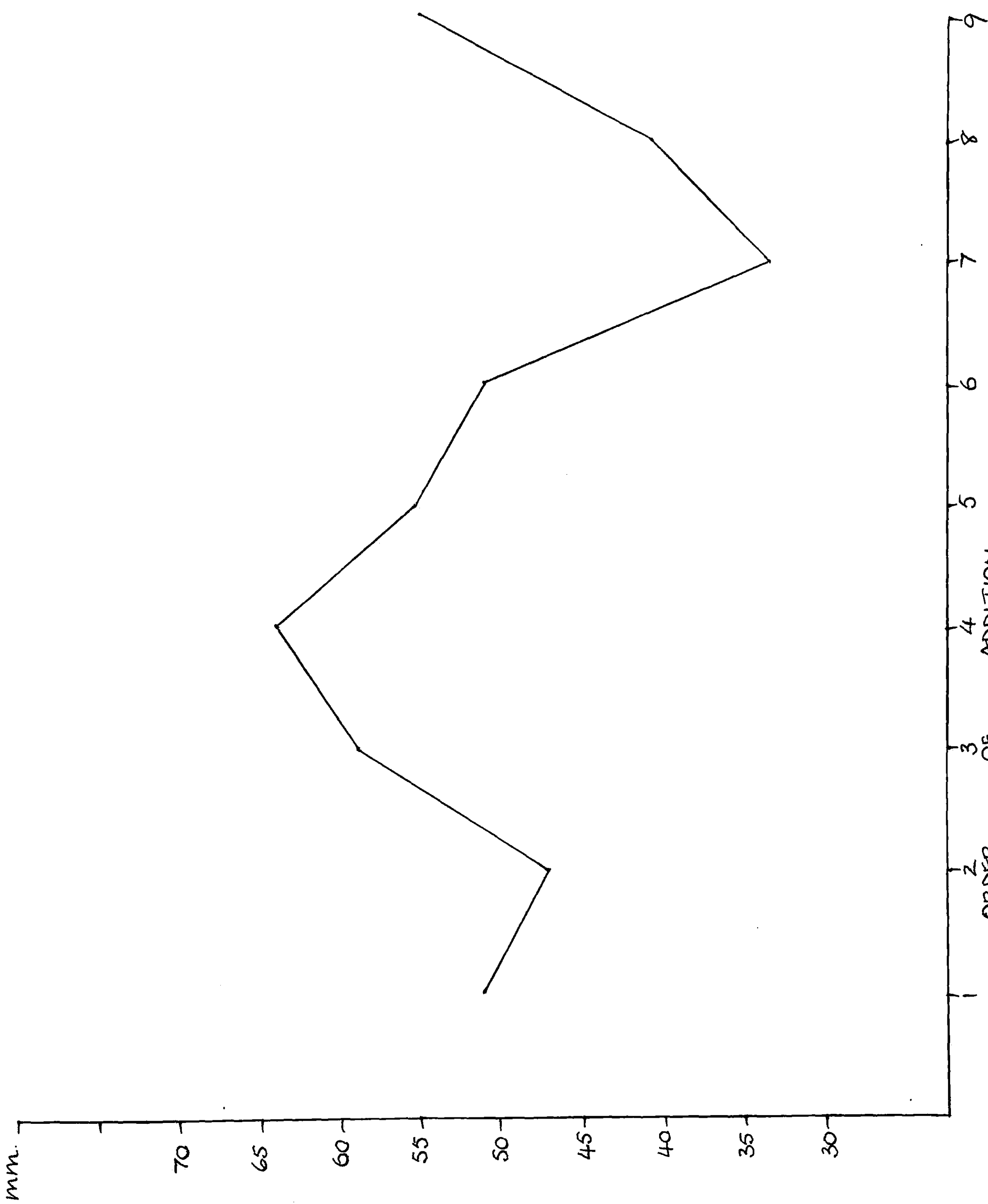

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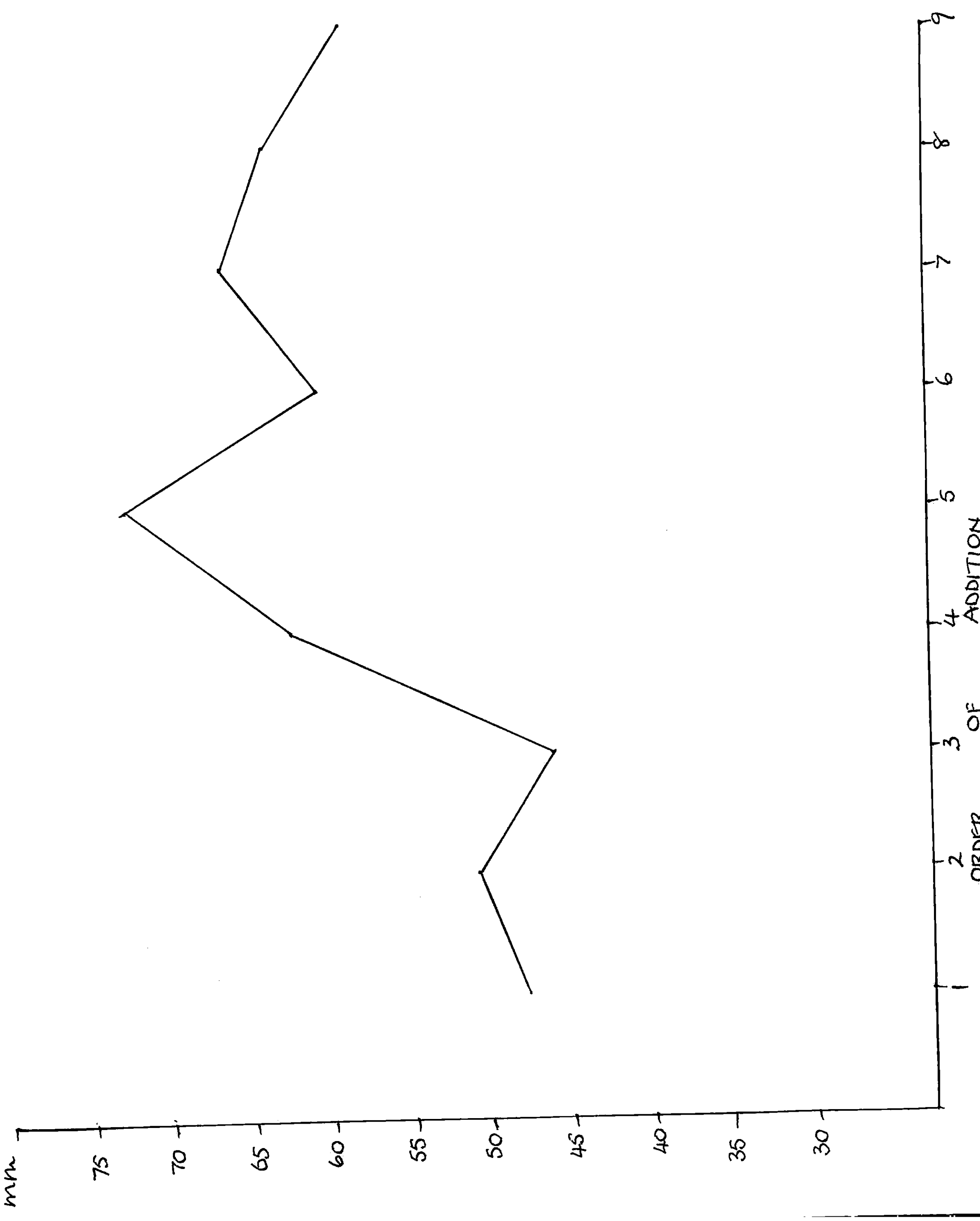

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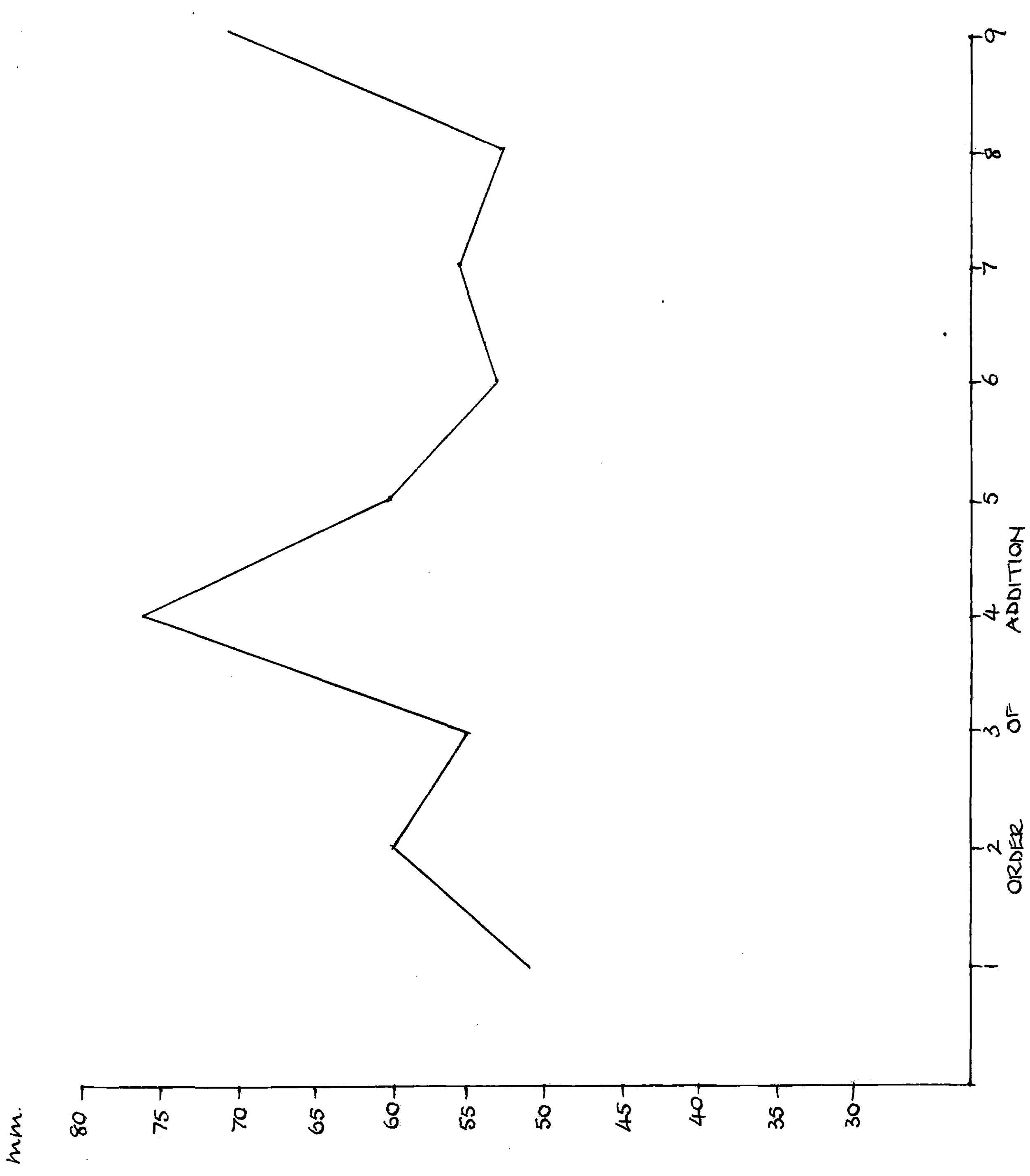

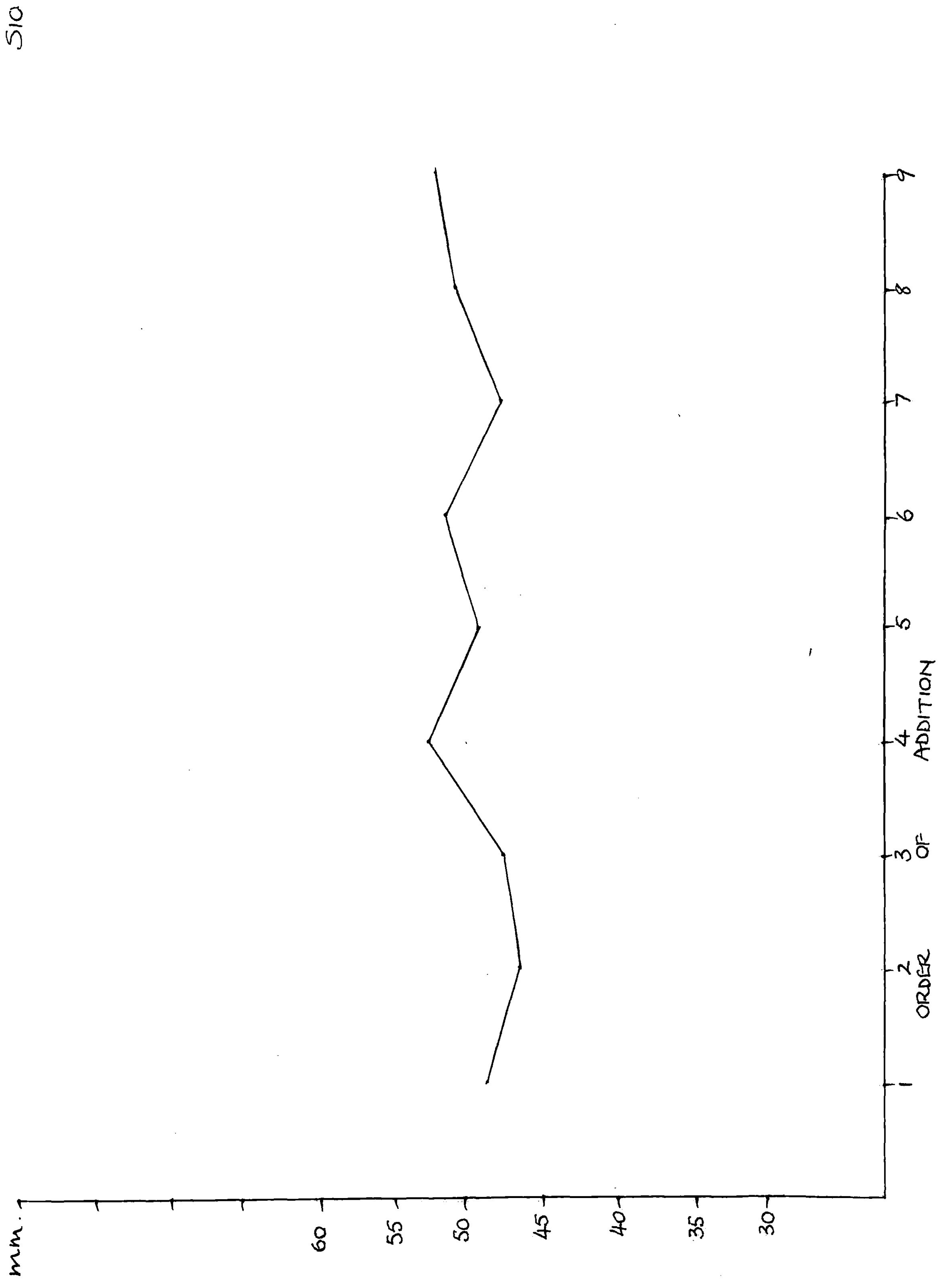
S10
mm.
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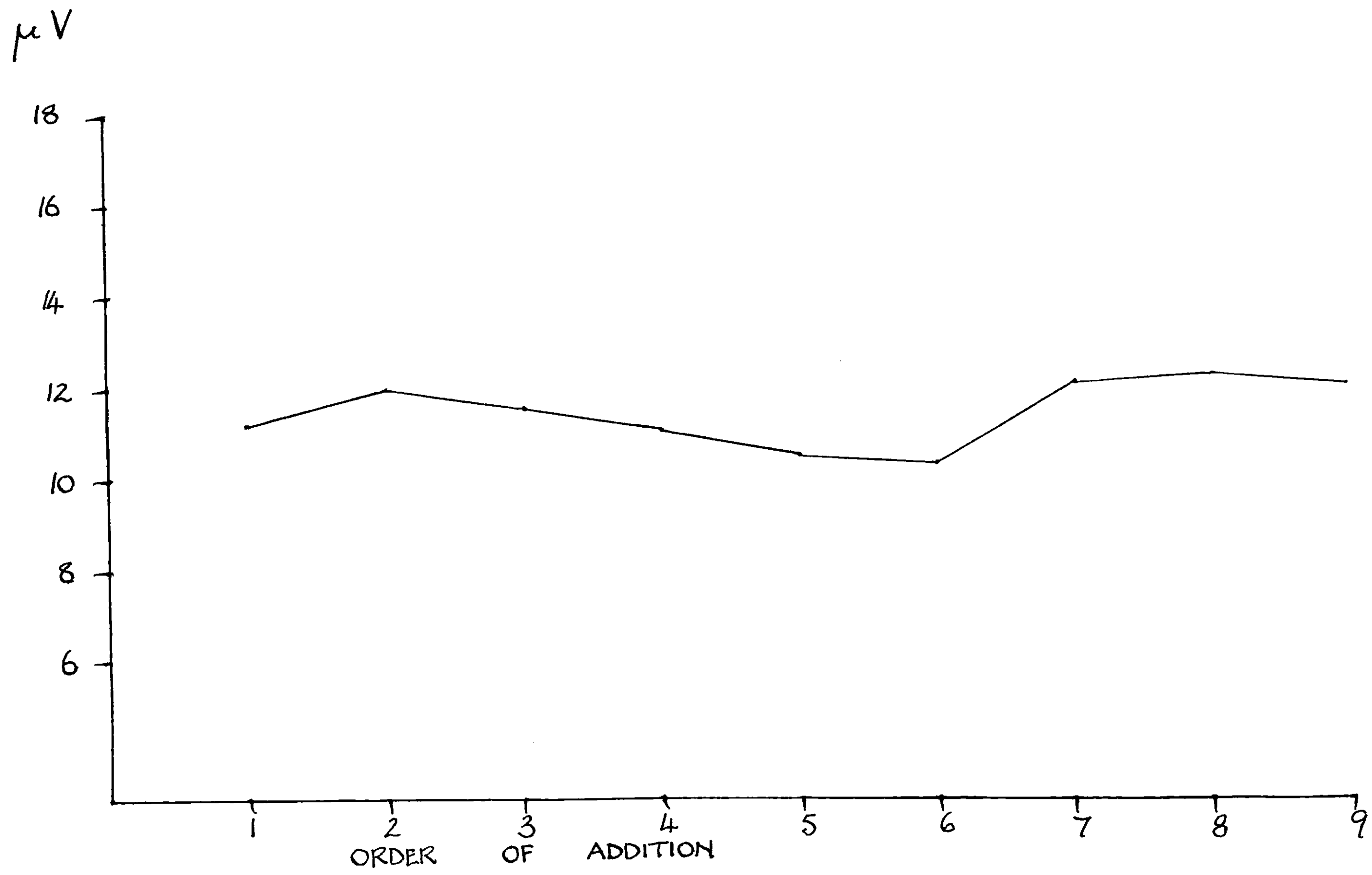
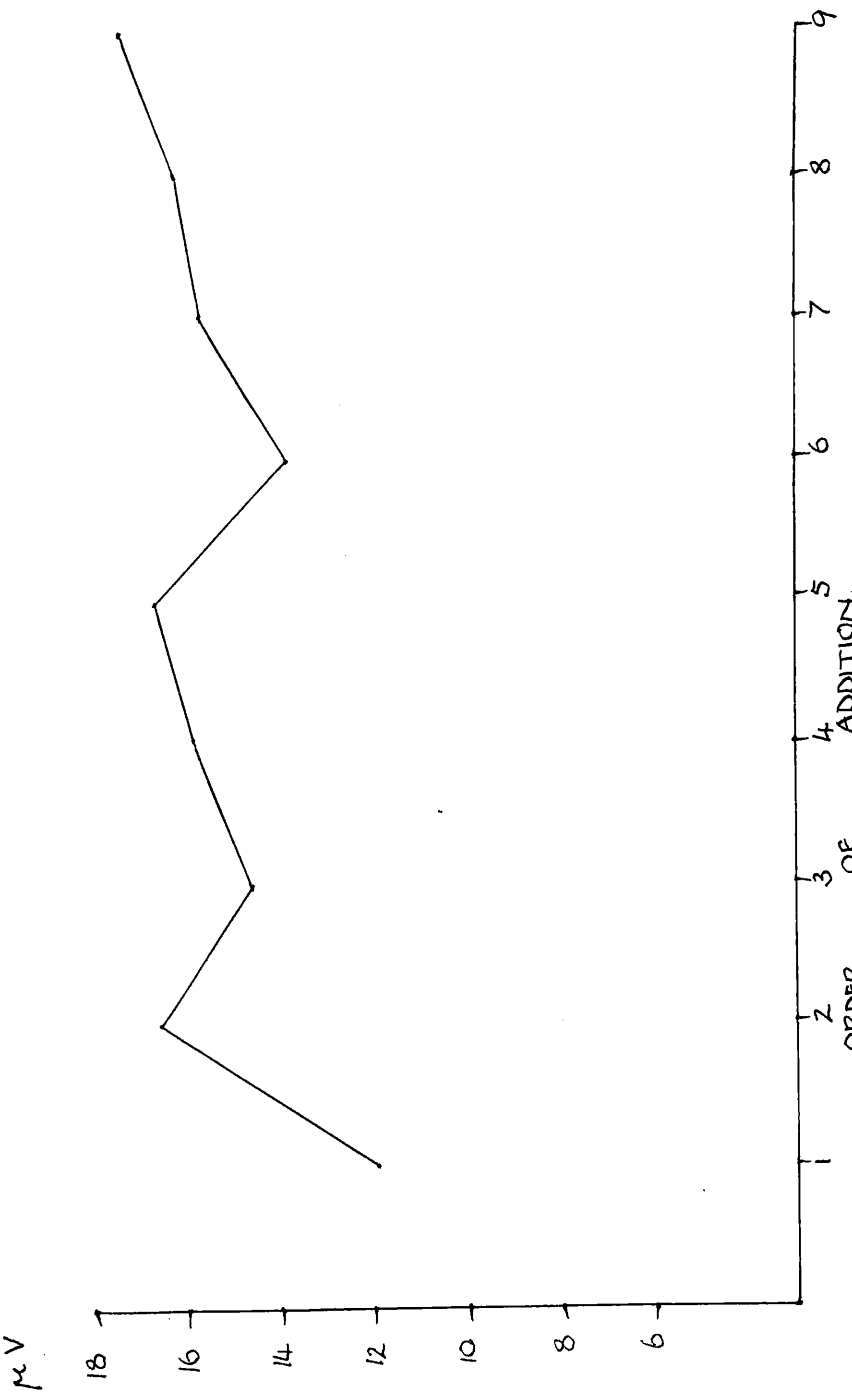
ORDER OF ADDITION

TENSION.

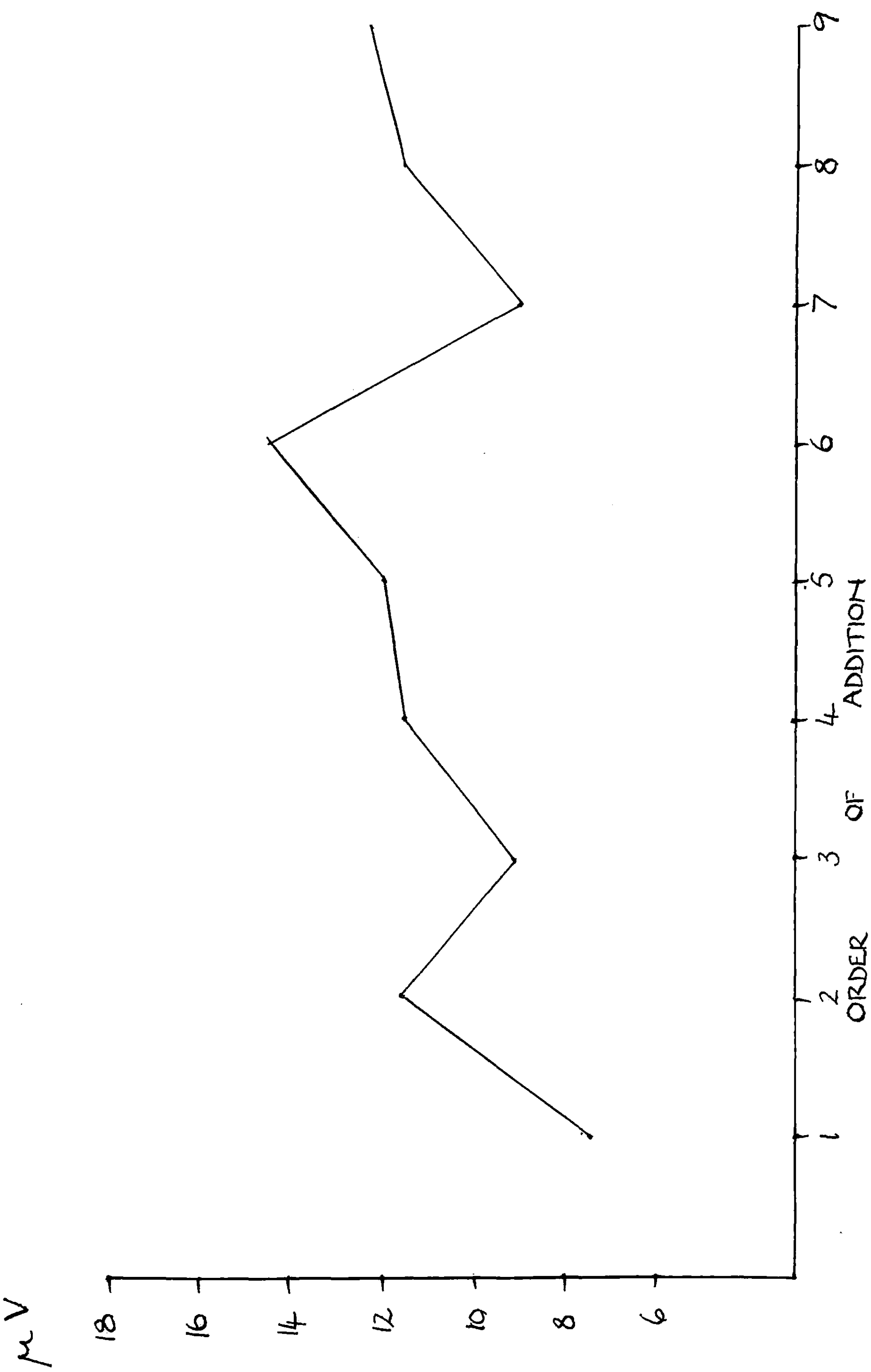
MEANS



S1.



S2



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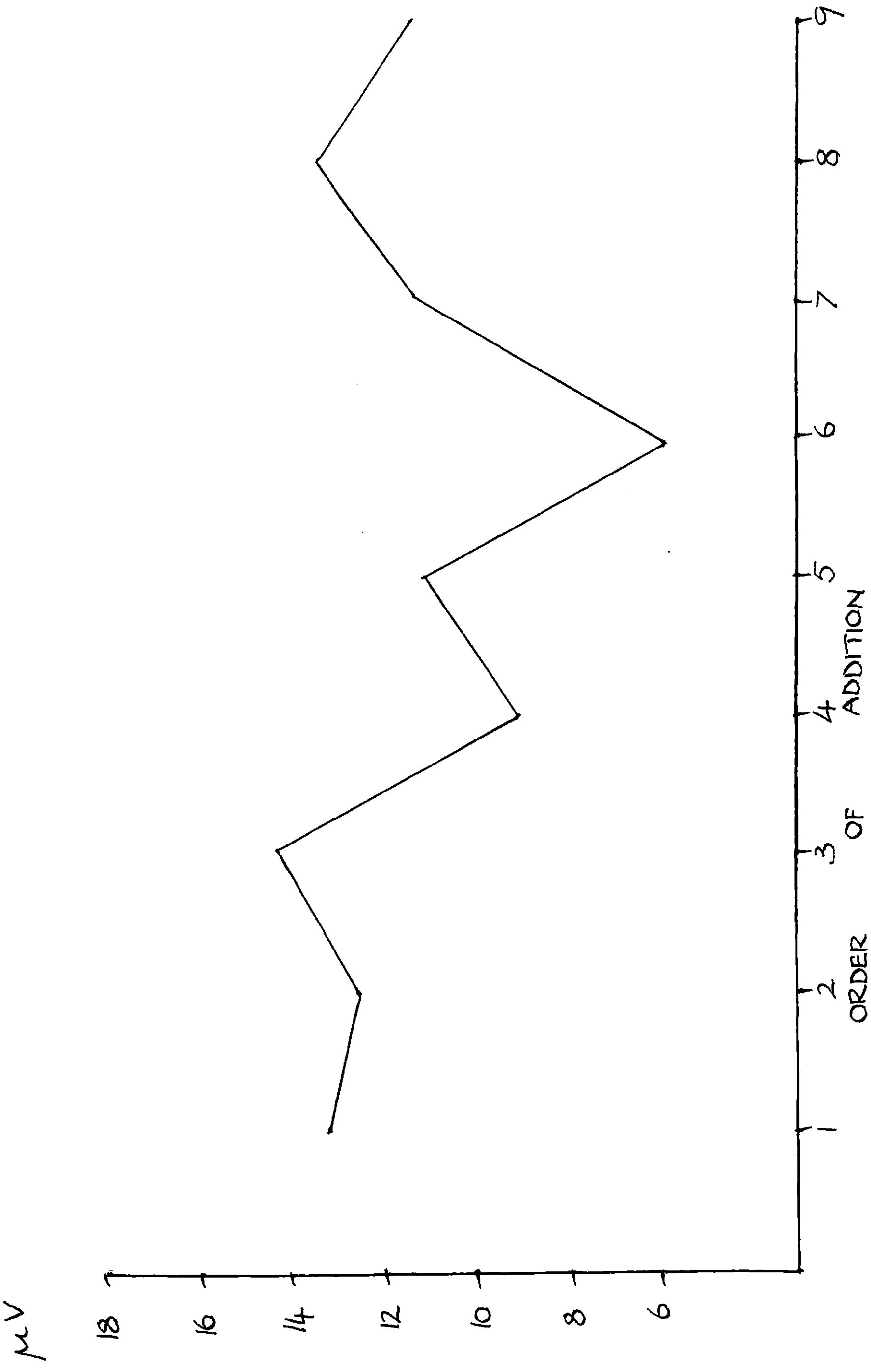

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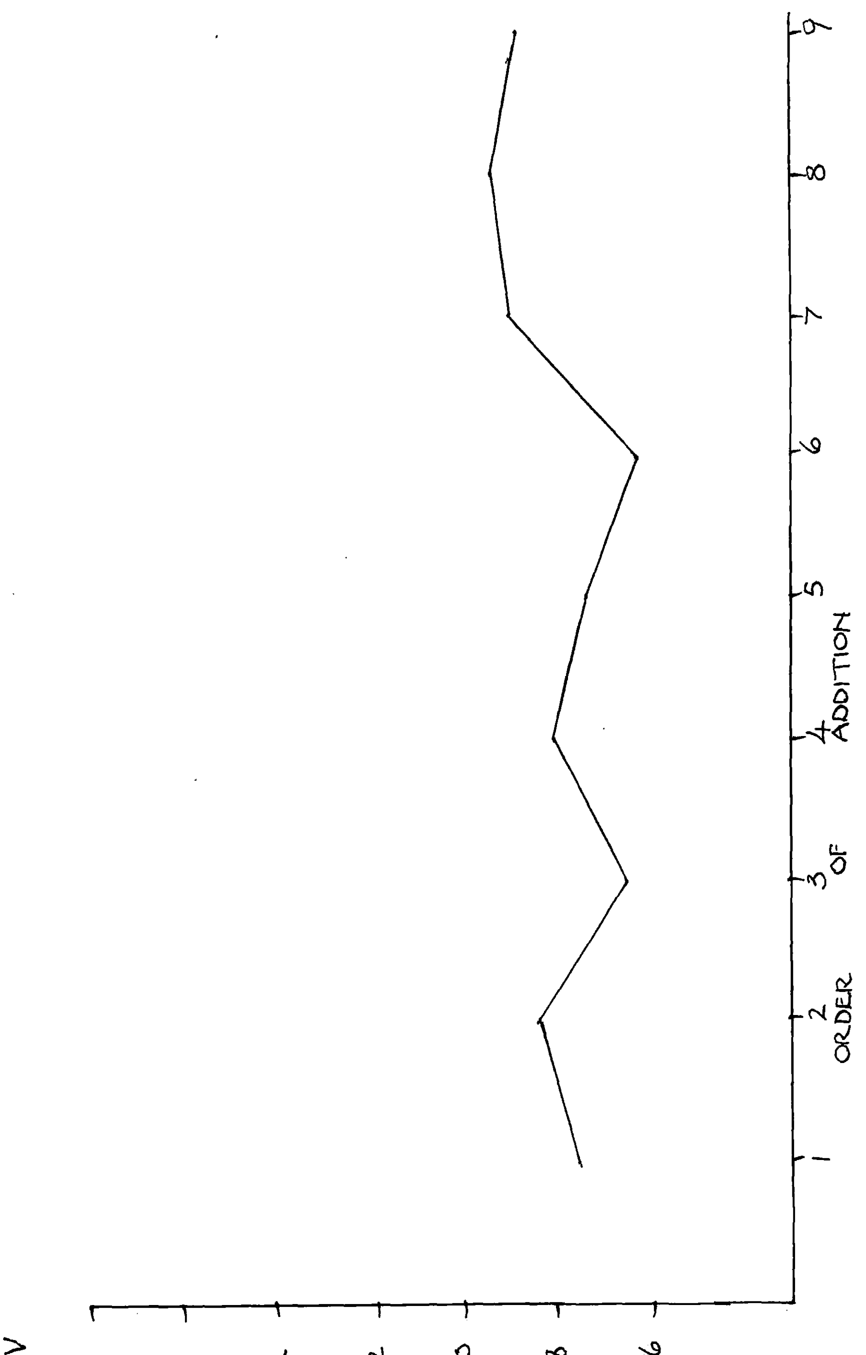

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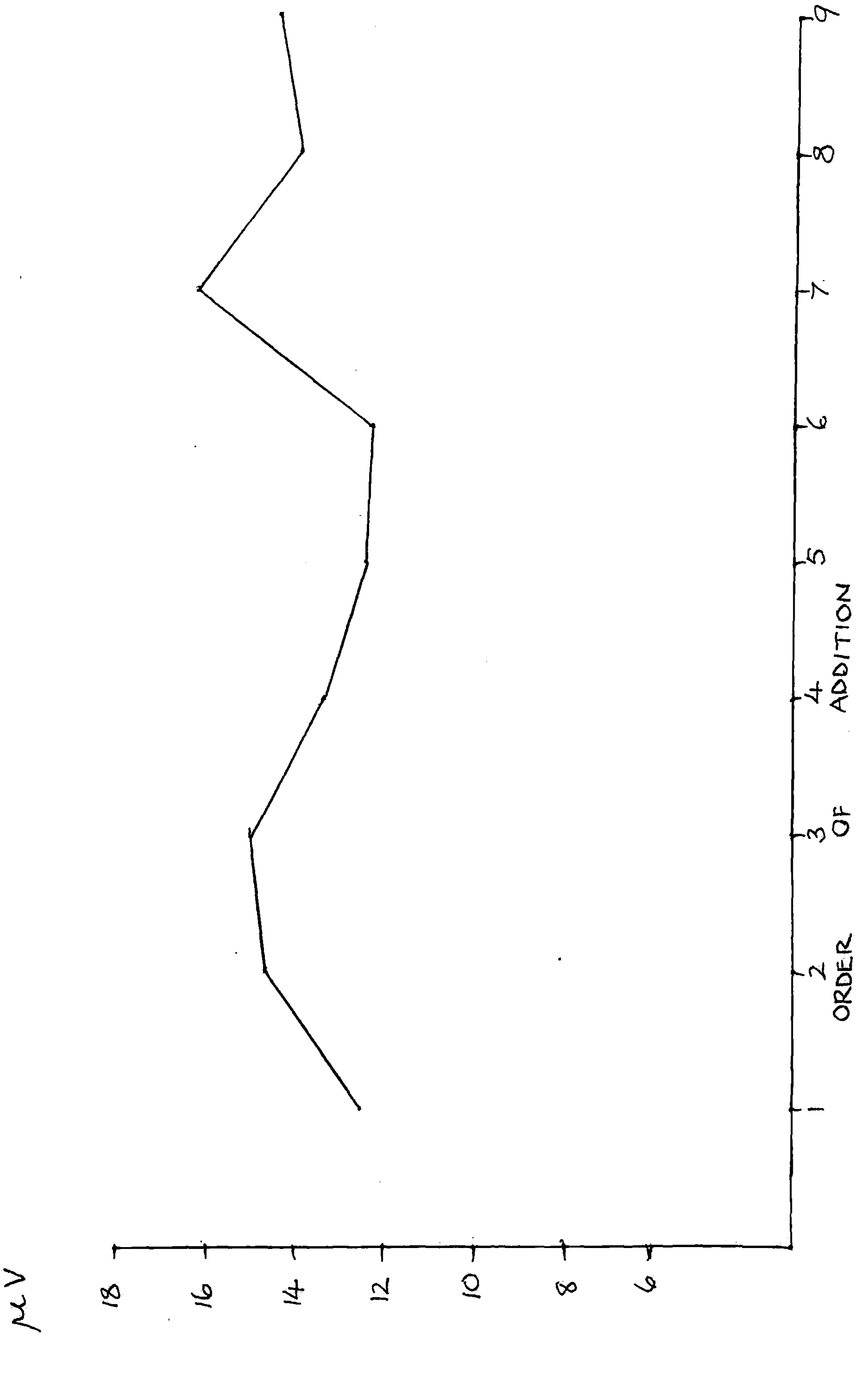

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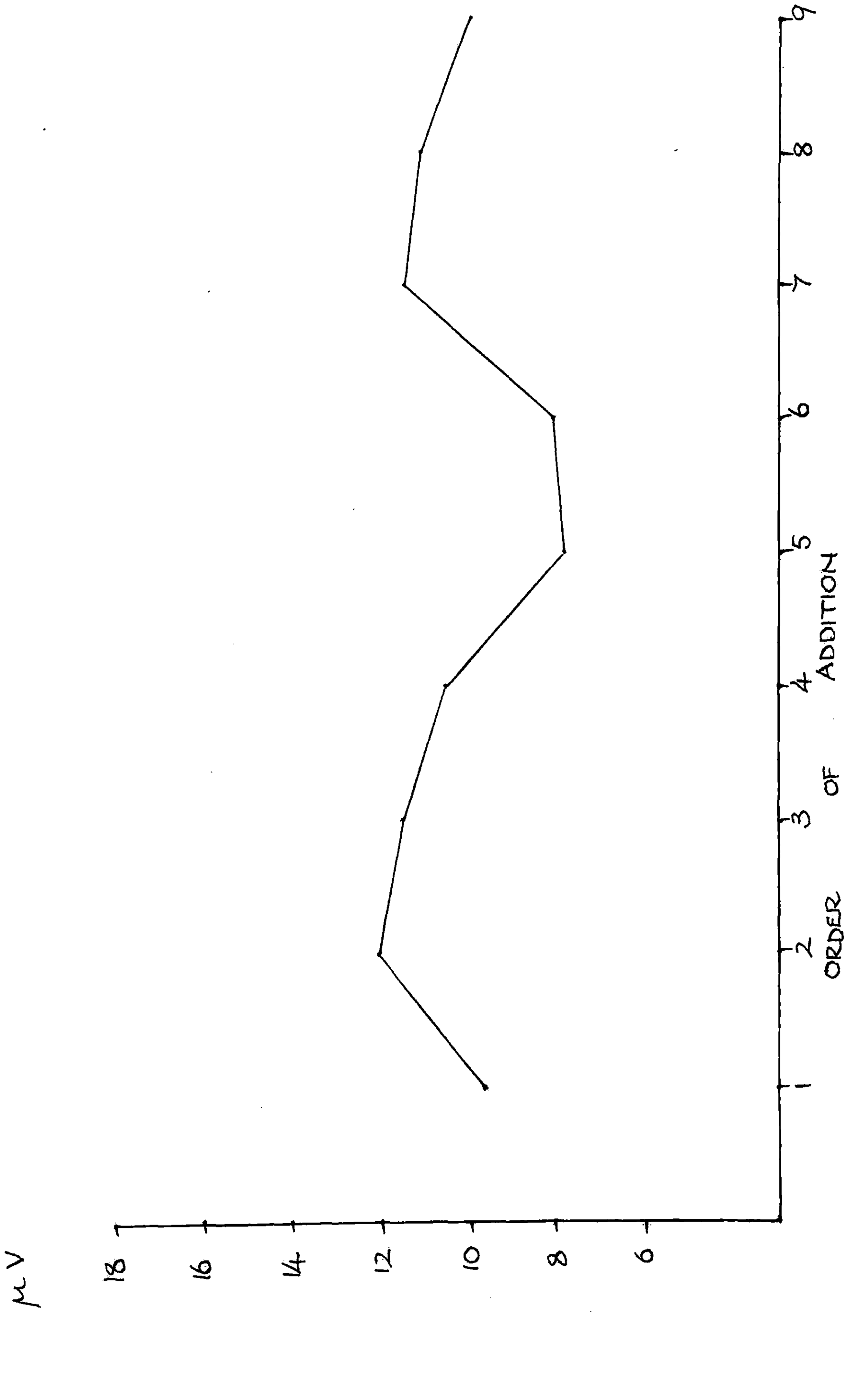

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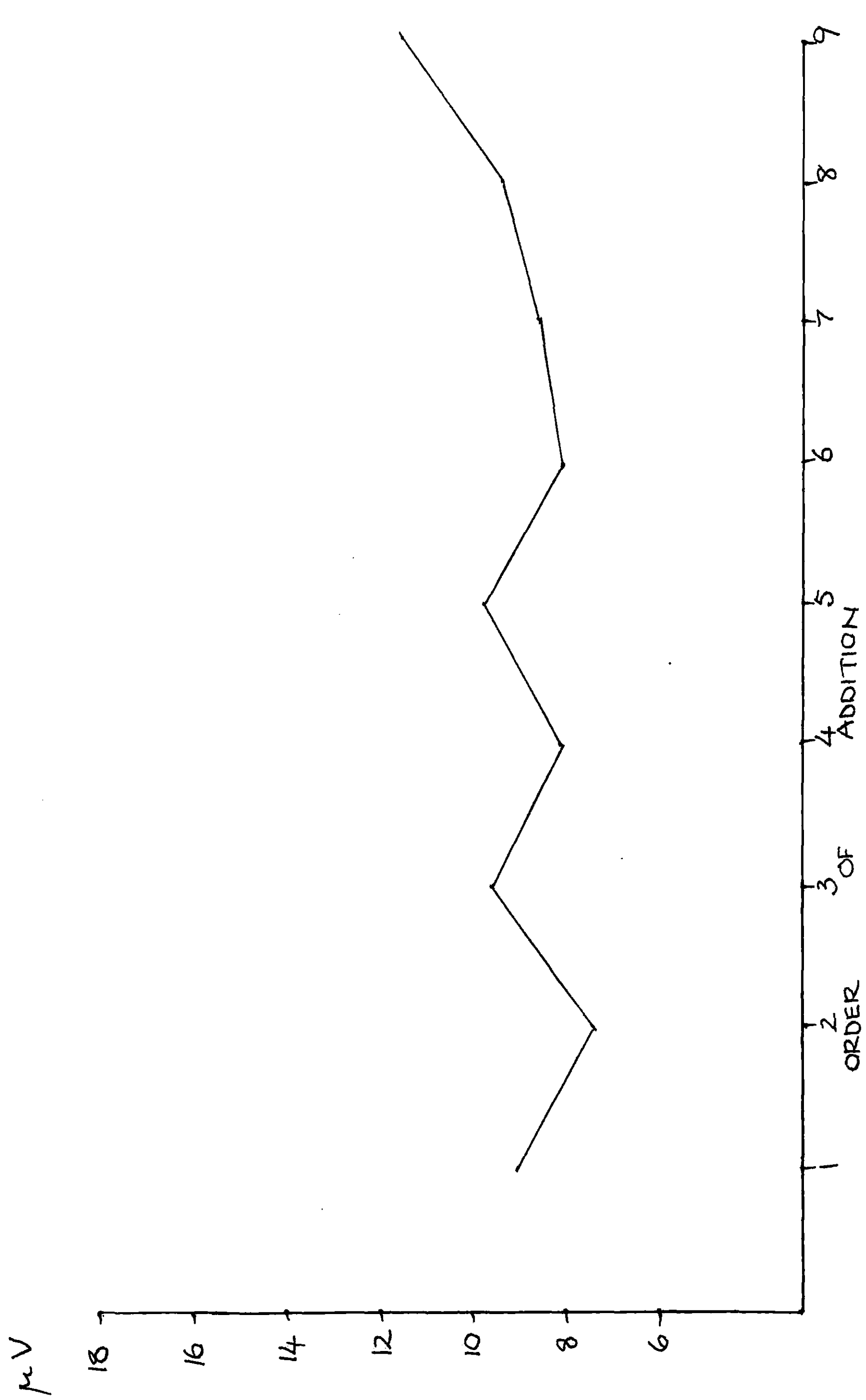

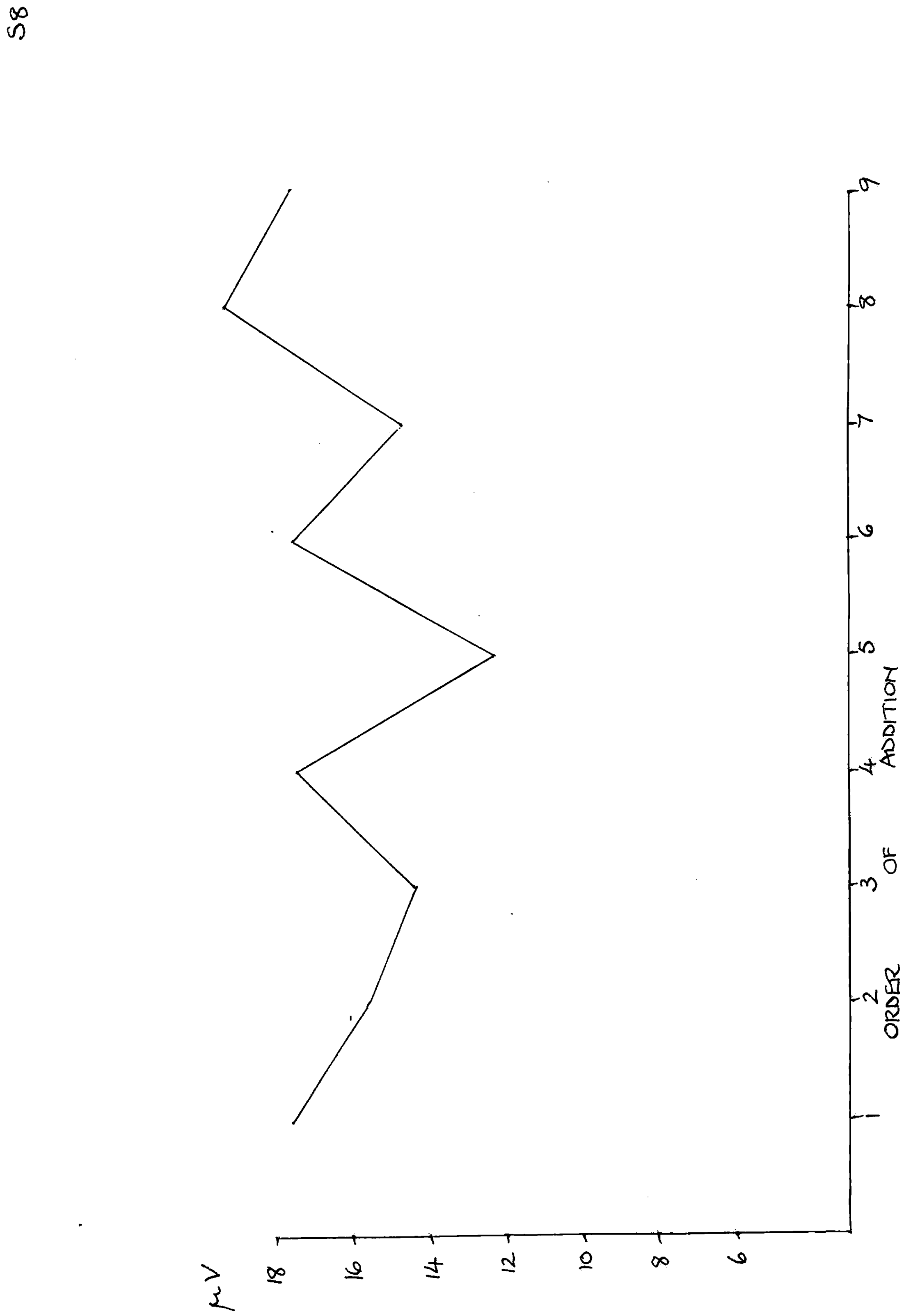
S8
μV
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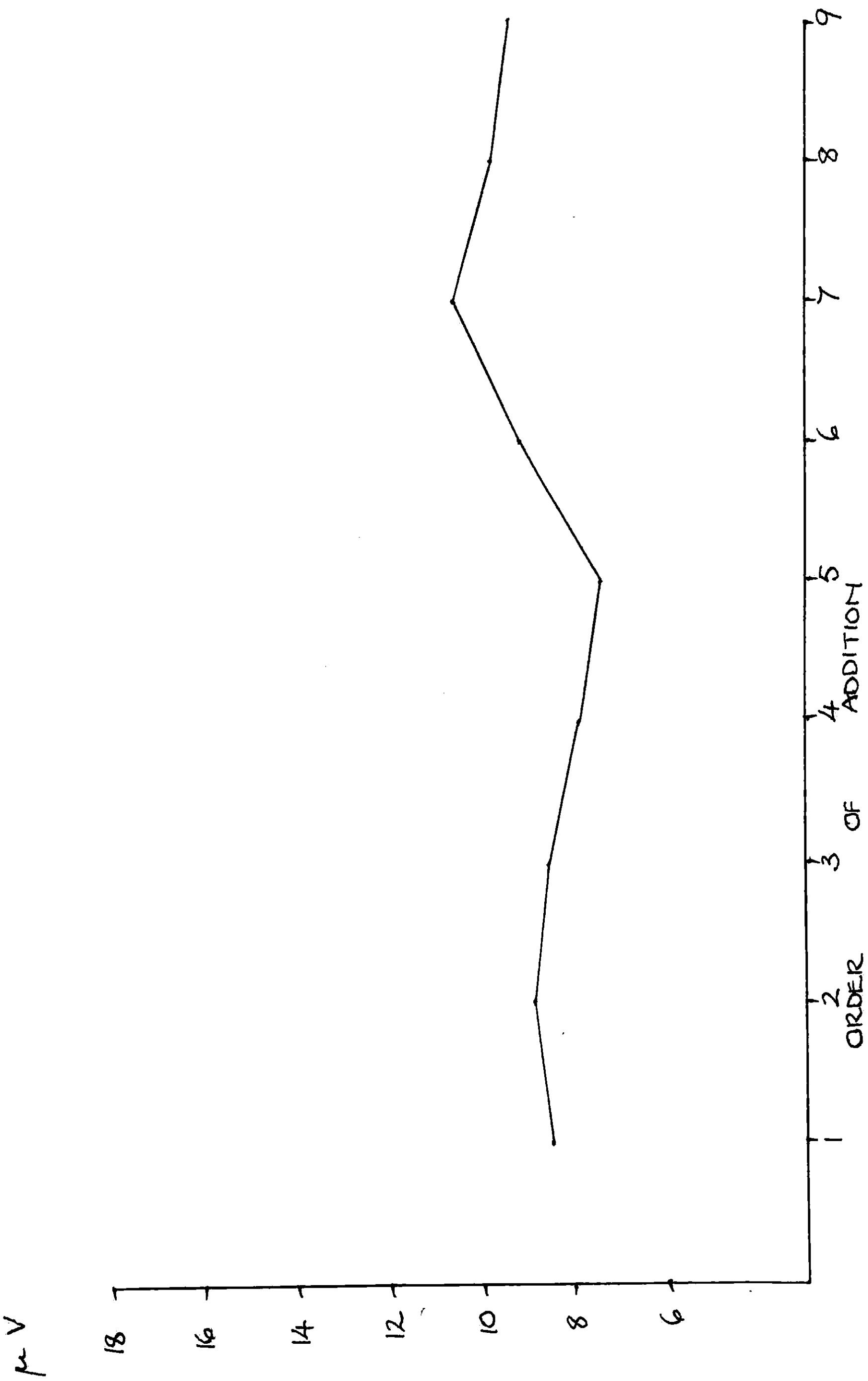
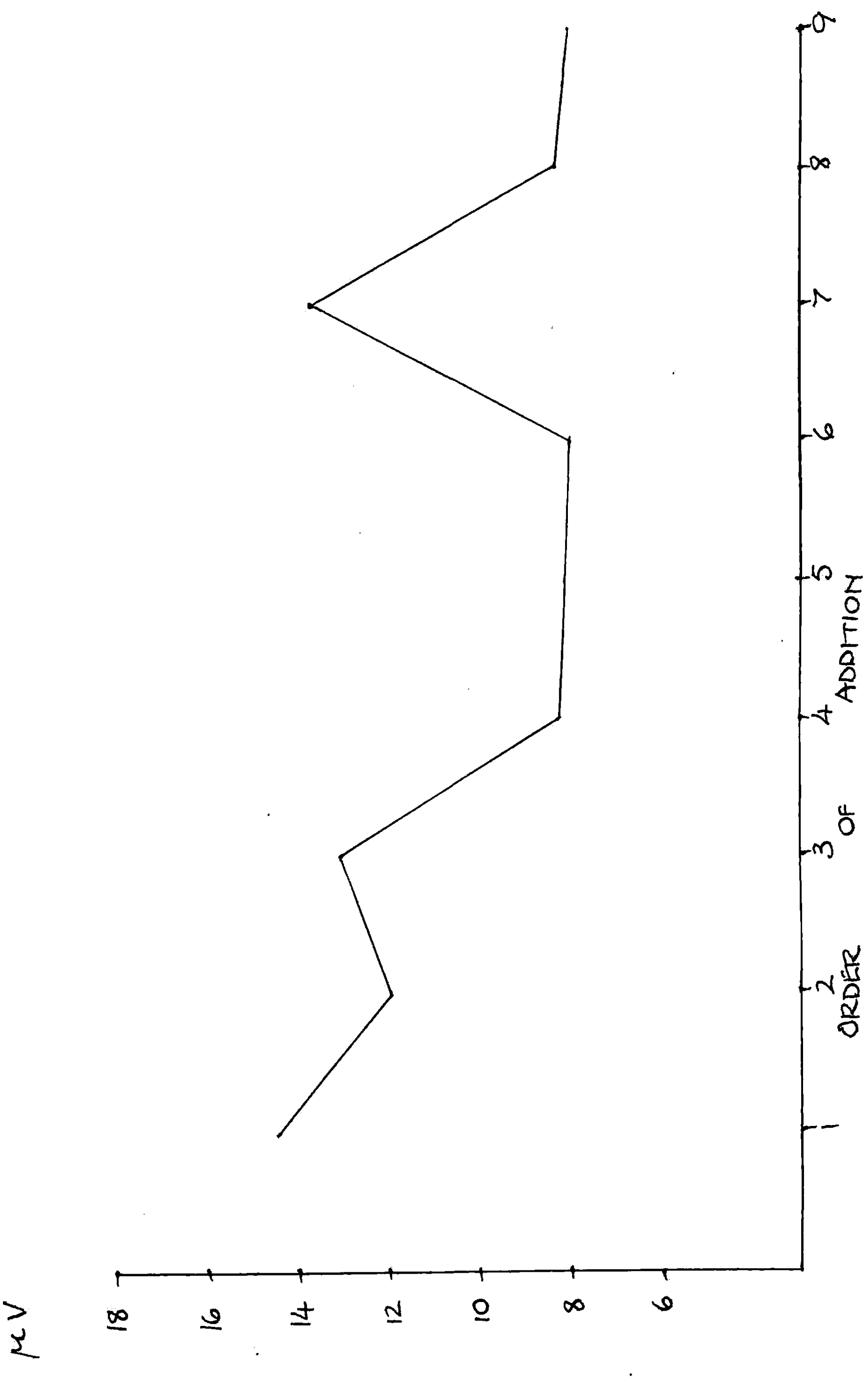
ORDER OF ADDITION

59



S10



Appendix IV.

Correlation coefficients between time and tension totals for individual subjects for the short sums only.

	P	N	M
S1	-.25	-.94	.95
S2	.86	.63	.83
S3	-.99	.58	-.14
S4	-.73	-.26	.84
S5	1.0	-.20	.96
S6	.54	.50	.36
S7	.38	.61	.14
S8	.14	-.64	.80
S9	.97	.49	.50
S10	-.99	.60	-.26

Appendix V.

Raw data with totals and means.

RAW DATA

Type of addition: P

Time in millimetre of trace

Tension in mv

S1

	Interval	1	2	3	4	5	Total	Mean
2A	Time	34	42	36	177	65	354	70·8
	Tension	14	13	12	16	16	71	14·2
4A	Time	21	36	42	46	30	175	35·0
	Tension	14	15	15	17	15	76	15·2
3A	Time	23	25	48	29	24	149	29·8
	Tension	12	13	16	15	14	70	14·0
Totals	Time	78	103	126	252	119	678	
	Tension	40	41	43	48	45	217	

S2

	Interval	1	2	3	4	5	Total	Mean
3A	Time	31	34	45	84	49	243	48·6
	Tension	13	13	13	15	12	66	13·2
2A	Time	20	38	42	21	20	141	28·2
	Tension	13	12	13	12	12	62	12·4
5A	Time	23	24	68	38	18	171	34·2
	Tension	13	13	14	13	12	65	13·0
Totals	Time	74	96	155	143	87	555	
	Tension	39	38	40	40	36	193	

RAW DATA

Type of addition: P

Time in millimetre of trace

Tension in mv

S3

	Interval	1	2	3	4	5	Total	Mean
2A	Time	15	15	17	22	26	95	19
	Tension	12	12	12	13	14	63	12·6
4A	Time	18	30	29	15	17	109	21·8
	Tension	10	14	14	12	10	60	12·0
6A	Time	19	26	31	33	20	129	25·8
	Tension	10	11	12	12	10	55	11·0
Totals	Time	52	71	77	70	63	333	
	Tension	32	37	38	37	34	178	

S4

	Interval	1	2	3	4	5	Total	Mean
1A	Time	38	53	47	44	37	219	43·8
	Tension	5	7	8	5	5	30	6·0
2A	Time	28	41	41	53	45	208	41·6
	Tension	5	7	7	9	9	37	7·4
6A	Time	32	34	30	47	41	184	36·8
	Tension	6	6	6	10	9	37	7·4
Totals	Time	98	128	118	144	123	611	40·7
	Tension	16	20	21	24	23	104	

RAW DATA

Type of addition: P

Time in millimetre of trace

Tension in µv

55

	Interval	1	2	3	4	5	Total	Mean
3A	Time	24	36	30	40	36	166	33.2
	Tension	14	13	13	13	13	66	13.2
4A	Time	28	36	36	54	51	205	41.0
	Tension	13	14	13	15	14	69	13.8
5A	Time	39	43	52	71	28	233	46.6
	Tension	13	14	15	16	13	71	14.2
Totals	Time	91	115	118	165	115	604	
	Tension	40	41	41	44	40	206	

56

	Interval	1	2	3	4	5	Total	Mean
4A	Time	17	18	19	28	29	111	22.2
	Tension	11	11	11	10	10	53	10.6
6A	Time	21	20	28	20	27	116	23.2
	Tension	12	12	13	12	11	60	12.0
1A	Time	18	32	34	32	28	144	28.8
	Tension	11	13	13	13	12	62	12.4
Totals	Time	56	70	81	80	84	371	
	Tension	34	36	37	35	33	175	

RAW DATA

Type of addition: P

Time in millimetre of trace

Tension in µv

57

	Interval	1	2	3	4	5	Total	Mean
1A	Time	32	34	34	21	18	139	27.8
	Tension	8	8	8	7	7	38	7.6
3A	Time	19	26	41	65	21	172	34.4
	Tension	8	9	9	10	10	46	9.2
2A	Time	27	38	81	27	26	199	39.8
	Tension	7	8	10	8	8	41	8.2
Totals	Time	78	98	156	113	65	510	
	Tension	23	25	27	25	25	125	

58

	Interval	1	2	3	4	5	Total	Mean
4A	Time	50	51	58	57	61	277	55.4
	Tension	19	19	20	20	21	99	19.8
3A	Time	46	46	72	74	60	298	59.6
	Tension	19	20	21	22	22	104	20.8
2A	Time	56	60	61	66	53	296	59.2
	Tension	17	18	19	20	19	93	18.6
Totals	Time	152	157	191	197	174	871	
	Tension	55	57	60	62	62	296	

RAW DATA

Type of addition: P

Time in millimetre of trace

Tension in µv

59

		Interval	1	2	3	4	5	Total	Mean
	3A	Time	48	57	53	84	57	299	59.8
		Tension	9	10	10	11	10	50	10.0
	6A	Time	51	62	44	62	66	285	57.0
		Tension	8	10	10	11	12	51	10.2
	4A	Time	30	31	43	37	40	183	36.6
		Tension	9	9	9	8	8	43	8.6
Totals		Time	129	150	140	183	163	765	
		Tension	26	29	29	30	30	144	

510

		Interval	1	2	3	4	5	Total	Mean
	4A	Time	36	38	48	45	38	205	41.0
		Tension	12	12	13	13	12	62	12.4
	2A	Time	29	30	57	69	56	241	48.2
		Tension	10	10	11	9	10	50	10.0
	1A	Time	40	52	46	49	62	249	49.8
		Tension	10	10	9	10	10	49	9.8
Totals		Time	105	120	151	163	156	695	
		Tension	32	32	33	32	32	161	

RAW DATA

Type of addition: N

Time in millimetre of trace

Tension in µv

51

	Interval	1	2	3	4	5	Total	Mean
1A	Time	69	44	81	44	43	281	56.2
	Tension	12	15	13	10	11	61	12.2
4A	Time	61	49	52	56	50	268	53.6
	Tension	13	11	13	14	10	61	12.2
2A	Time	58	64	59	76	42	299	59.8
	Tension	10	10	11	14	11	56	11.2
Totals	Time	188	157	192	176	135	848	
	Tension	35	36	37	38	32	178	

52

	Interval	1	2	3	4	5	Total	Mean
6A	Time	42	57	48	37	33	217	43.4
	Tension	7	7	8	7	6	35	7.0
5A	Time	48	57	57	61	48	271	54.2
	Tension	6	9	8	8	6	37	7.4
1A	Time	51	50	42	65	41	249	49.8
	Tension	7	7	7	10	8	39	7.8
Totals	Time	141	164	147	163	122	737	
	Tension	20	23	23	25	20	111	

RAW DATA

Type of addition: N

Time in millimetre of trace

Tension in µv

53

	Interval	1	2	3	4	5	Total	Mean
1A	Time	46	46	62	50	58	262	52.4
	Tension	4	5	5	5	5	24	4.8
2A	Time	50	54	54	50	48	256	51.2
	Tension	5	6	6	5	4	26	5.2
6A	Time	40	42	56	60	41	239	47.8
	Tension	4	4	6	6	3	23	4.6
Totals	Time	136	142	172	160	147	767	
	Tension	13	15	17	16	12	73	

54

	Interval	1	2	3	4	5	Total	Mean
6A	Time	44	59	48	49	50	250	50.0
	Tension	6	5	6	6	6	29	5.8
3A	Time	50	52	58	62	64	286	57.2
	Tension	4	4	6	6	6	26	5.2
4A	Time	64	68	60	69	71	332	66.4
	Tension	5	5	5	6	7	28	5.6
Totals	Time	158	179	166	180	185	868	
	Tension	15	14	17	18	19	93	

RAW DATA

Type of addition: N

Time in millimetre of trace

Tension in µv

55

	Interval	1	2	3	4	5	Total	Mean
2A	Time	61	65	68	68	55	317	63.4
	Tension	10	11	11	11	10	53	10.6
4A	Time	58	61	61	61	69	310	62.0
	Tension	7	9	9	8	9	42	8.4
6A	Time	67	60	73	81	49	330	66.0
	Tension	7	8	9	10	9	43	8.6
Totals	Time	186	186	202	210	173	957	
	Tension	24	28	29	29	28	138	

56

	Interval	1	2	3	4	5	Total	Mean
4A	Time	56	61	54	64	45	280	56.0
	Tension	6	7	5	6	4	28	5.6
5A	Time	61	62	68	54	56	301	60.2
	Tension	6	6	8	5	6	31	6.2
6A	Time	58	65	62	54	55	294	58.8
	Tension	5	6	6	5	5	27	5.4
Totals	Time	175	188	184	172	156	875	
	Tension	17	19	19	16	15	86	

RAW DATA

Type of addition: *N*

Time in millimetre of trace

Tension in µv

57

		1	2	3	4	5	Total	Mean
	Interval	1	2	3	4	5	Total	Mean
4A	Time	39	36	42	40	46	203	40.6
	Tension	6	5	7	5	6	29	5.8
5A	Time	38	48	52	50	48	236	47.2
	Tension	5	7	7	6	5	30	6.0
3A	Time	52	40	39	59	47	237	47.4
	Tension	6	7	7	8	8	36	7.2
Totals	Time	129	124	133	149	141	666	
	Tension	17	19	21	19	19	95	

58

		1	2	3	4	5	Total	Mean
	Interval	1	2	3	4	5	Total	Mean
6A	Time	70	71	83	58	79	361	72.2
	Tension	12	12	13	11	11	47	9.4
4A	Time	63	60	71	74	72	340	68.0
	Tension	11	11	12	14	13	61	12.2
3A	Time	58	50	~~48~~ 84	51	54	297	59.4
	Tension	11	11	15	11	11	59	11.8
Totals	Time	191	181	238	183	205	998	
	Tension	34	34	40	36	35	179	

RAW DATA

Type of addition: N

Time in millimetre of trace

Tension in mv

59

	Interval	1	2	3	4	5	Total	Mean
5A	Time	86	88	91	80	63	408	81·6
	Tension	5	5	7	8	6	31	6·2
4A	Time	40	43	51	53	42	229	45·8
	Tension	4	6	7	7	4	28	5·6
3A	Time	75	62	70	74	60	341	68·2
	Tension	6	6	8	9	7	36	7·2
Totals	Time	201	193	212	207	165	978	
	Tension	15	17	22	24	17	95	

510

	Interval	1	2	3	4	5	Total	Mean
6A	Time	42	42	56	61	60	261	52·2
	Tension	3	3	5	4	3	18	3·6
1A	Time	55	37	43	46	48	229	45·8
	Tension	3	3	4	5	5	20	4·0
2A	Time	51	64	55	62	59	291	58·2
	Tension	4	5	4	5	5	23	4·6
Totals	Time	148	143	154	169	167	781	
	Tension	10	11	13	14	13	61	

RAW DATA

Type of addition: M

Time in millimetre of trace

Tension in mv

S1

	Interval	1	2	3	4	5	Total	Mean
4A	Time	36	36	26	49	44	191	38.2
	Tension	13	13	12	14	14	66	13.2
5A	Time	28	28	134	43	41	274	54.8
	Tension	13	14	18	16	15	76	15.2
1A	Time	36	40	91	34	30	231	46.2
	Tension	13	13	15	15	13	69	13.8
Totals	Time	100	104	251	126	115	696	
	Tension	39	40	45	45	42	211	

S2

	Interval	1	2	3	4	5	Total	Mean
6A	Time	20	22	20	22	25	109	21.8
	Tension	9	9	9	9	10	46	9.2
2A	Time	32	34	56	36	30	188	37.6
	Tension	10	11	14	10	9	54	10.8
5A	Time	23	37	26	30	28	144	28.8
	Tension	9	12	12	11	10	54	10.8
Totals	Time	75	93	102	88	83	441	
	Tension	28	32	35	30	29	154	

RAW DATA

Type of addition: M

Time in millimetre of trace

Tension in mv

53

	Interval	1	2	3	4	5	Total	Mean
2A	Time	22	17	18	53	29	139	27.8
	Tension	12	13	13	15	13	66	13.2
6A	Time	24	28	18	37	30	137	27.4
	Tension	11	11	10	14	14	60	12.0
4A	Time	26	30	60	42	21	179	35.8
	Tension	11	11	15	14	11	62	12.4
Totals	Time	73	75	96	132	80	456	
	Tension	34	35	38	43	38	188	

54

	Interval	1	2	3	4	5	Total	Mean
6A	Time	20	49	47	50	129	295	59.0
	Tension	6	8	7	6	10	37	7.4
5A	Time	29	24	56	62	28	199	39.8
	Tension	5	5	8	9	7	34	6.8
3A	Time	30	32	36	85	32	215	43.0
	Tension	5	6	5	8	8	32	6.4
Totals	Time	79	105	139	197	189	709	
	Tension	16	19	20	23	25	103	

RAW DATA

Type of addition: **M**

Time in millimetre of trace

Tension in µv

55

	Interval	1	2	3	4	5	Total	Mean
6A	Time	32	48	68	44	36	228	45.6
	Tension	9	10	12	13	12	56	11.2
5A	Time	32	44	44	56	72	248	49.6
	Tension	10	11	11	12	15	59	11.8
2A	Time	30	36	38	36	32	172	34.4
	Tension	10	11	11	11	10	53	10.6
Totals	Time	94	128	150	136	140	648	
	Tension	29	32	34	36	37	168	

56

	Interval	1	2	3	4	5	Total	Mean
5A	Time	21	34	40	41	38	174	34.8
	Tension	8	10	10	10	9	47	9.4
4A	Time	19	20	43	18	28	128	25.6
	Tension	8	9	11	7	9	44	8.8
6A	Time	22	31	35	31	38	157	31.4
	Tension	10	12	12	11	12	57	11.4
Totals	Time	62	85	118	90	104	459	
	Tension	26	31	33	28	30	148	

RAW DATA

Type of addition: M

Time in millimetre of trace

Tension in mv

57

	Interval	1	2	3	4	5	Total	Mean
5A	Time	18	20	23	29	31	121	24.2
	Tension	7	7	8	10	8	40	8.0
1A	Time	26	17	18	33	18	112	22.4
	Tension	8	7	7	9	8	39	7.8
4A	Time	28	39	22	18	19	126	25.2
	Tension	7	9	8	8	7	39	7.8
Totals	Time	72	76	63	80	68	359	
	Tension	22	23	23	27	23	118	

58

	Interval	1	2	3	4	5	Total	Mean
2A	Time	51	54	53	52	50	260	52.0
	Tension	16	16	16	15	14	77	15.4
1A	Time	29	31	104	38	36	238	47.6
	Tension	13	14	20	13	13	73	14.6
6A	Time	32	49	20	52	51	204	40.8
	Tension	15	16	13	14	15	73	14.6
Totals	Time	112	134	177	142	137	702	
	Tension	44	46	49	42	42	223	

RAW DATA

Type of addition: M

Time in millimetre of trace

Tension in μv.

S9

	Interval	1	2	3	4	5	Total	Mean
5A	Time	78	37	77	39	43	274	54.8
	Tension	9	6	8	6	6	35	7.0
2A	Time	77	40	32	48	42	239	47.8
	Tension	10	6	6	7	7	36	7.2
6A	Time	28	58	68	38	38	230	46.0
	Tension	4	9	7	6	5	31	6.2
Totals	Time	183	135	177	125	123	743	
	Tension	23	21	21	19	18	102	

S10.

	Interval	1	2	3	4	5	Total	Mean
3A	Time	43	44	85	42	44	258	51.6
	Tension	10	10	15	10	10	55	11.0
6A	Time	26	42	54	65	42	229	45.8
	Tension	9	12	12	14	10	57	11.4
4A	Time	41	41	86	42	41	251	50.2
	Tension	9	9	14	11	11	54	10.8
Totals	Time	110	127	225	149	127	738	
	Tension	28	31	41	35	31	166	

RAW DATA

Type of addition: P

Time in millimetre of trace
Tension in mmv.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S1.	6B	Time	62	63	156	57	88	163	56	99	85	110	939	93·9
		Tension	16	17	15	14	15	19	15	15	16	18	160	16·0
	5B	Time	68	74	71	98	56	102	103	58	54	54	738	73·8
		Tension	17	16	17	20	19	22	21	19	17	17	185	18·5
	2B	Time	60	63	58	135	115	73	79	64	61	52	760	76·0
		Tension	17	17	18	20	20	16	17	18	18	18	179	17·9
	Totals	Time	190	200	285	290	259	338	238	221	200	216	2437	
		Tension	50	50	50	54	54	57	53	52	51	53	524	

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S2	2B	Time	41	55	53	50	46	39	65	48	89	32	518	51·8
		Tension	15	14	15	15	15	15	16	16	16	13	150	15·0
	6B	Time	28	31	43	61	52	60	43	55	36	30	439	43·9
		Tension	14	14	15	15	15	15	14	14	15	15	146	14·6
	1B	Time	29	29	37	41	25	42	61	69	32	45	410	41·0
		Tension	14	14	14	15	13	14	15	15	14	14	142	14·2
	Totals	Time	98	115	133	152	123	141	169	172	157	107	1367	
		Tension	43	42	44	45	43	44	45	45	45	42	438	

RAW DATA

Type of addition: P

Time in millimetre of trace
Tension in mmv.

			Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S3	2B		Time	21	27	34	56	58	47	45	40	48	42	400	40.0
			Tension	14	17	17	16	15	10	11	12	14	10	136	13.6
	3B		Time	19	23	28	29	52	67	25	32	23	35	333	33.3
			Tension	14	14	14	14	15	15	15	17	16	16	150	15.0
	4B		Time	18	22	25	31	36	44	52	31	30	26	315	31.5
			Tension	15	16	16	16	19	19	18	16	15	15	165	16.5
		Totals	Time	58	72	87	116	146	158	122	103	101	85	1048	
			Tension	43	47	47	46	49	44	44	45	45	41	451	

			Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S4	1B		Time	47	62	53	80	56	54	57	60	55	67	591	59.1
			Tension	5	5	6	9	6	6	7	7	6	6	63	6.3
	4B		Time	37	39	51	42	65	60	51	43	41	64	493	49.3
			Tension	5	6	6	5	8	8	7	7	7	6	65	6.5
	3B		Time	41	44	47	59	41	92	44	59	38	45	510	51.0
			Tension	6	6	7	8	6	9	5	6	6	5	64	6.4
		Totals	Time	125	145	151	181	162	206	152	162	134	176	1594	
			Tension	16	17	19	22	20	23	19	20	19	17	192	

RAW DATA

Type of addition: P

Time in millimetre of trace
Tension in mmv.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S5	4B	Time	45	56	60	63	69	74	60	55	49	56	587	58.7
		Tension	16	17	17	17	17	18	18	17	17	17	171	17.1
	2B	Time	36	41	30	38	39	40	38	37	51	46	396	39.6
		Tension	16	16	14	16	16	17	16	16	17	16	160	16.0
	3B	Time	47	92	88	41	45	38	52	61	61	70	595	59.5
		Tension	14	15	15	12	15	15	16	16	16	16	150	15.0
	Totals	Time	128	189	178	142	153	152	150	153	161	172	1578	
		Tension	46	48	46	45	48	50	50	49	50	49	481	

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S6	1B	Time	28	32	65	40	47	49	31	58	54	50	454	45.4
		Tension	12	12	14	12	12	13	14	12	12	13	126	12.6
		Time	43	45	59	61	52	74	68	40	41	47	530	53.0
	4B	Tension	12	12	13	15	12	12	11	10	10	11	118	11.8
	2B	Time	31	32	31	47	65	70	53	60	54	53	496	49.6
		Tension	12	13	13	12	14	14	12	13	12	12	127	12.7
	Totals	Time	102	109	155	148	164	193	152	158	149	150	1480	
		Tension	36	37	40	39	38	39	37	35	34	36	371	

RAW DATA

Type of addition: P

Time in millimetre of trace
Tension in mmv.

57

		1	2	3	4	5	6	7	8	9	10	Total	Mean
	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
2B	Time	71	86	43	57	65	80	71	71	60	42	646	64.6
	Tension	9	10	10	8	9	10	16	9	9	8	92	9.2
4B	Time	43	38	44	53	106	58	54	65	53	31	545	54.5
	Tension	7	7	7	7	10	8	6	9	8	7	76	7.6
6B	Time	36	39	49	58	49	153	91	42	45	42	604	60.4
	Tension	7	8	8	9	7	12	10	8	8	7	84	8.4
Totals	Time	150	163	136	168	220	291	216	178	158	115	1795	
	Tension	23	25	25	24	26	30	26	26	25	22	252	

58

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
3B	Time	51	50	54	48	48	57	91	80	46	50	575	57.5
	Tension	22	22	22	21	21	23	25	26	24	24	230	23.0
2B	Time	48	49	49	55	81	65	69	67	43	51	577	57.7
	Tension	22	23	23	20	20	19	19	19	18	18	201	20.1
1B	Time	55	61	65	72	60	49	51	73	98	62	646	64.6
	Tension	20	21	21	22	21	20	20	22	24	21	212	21.2
Totals	Time	154	160	168	175	189	171	211	220	187	163	1798	
	Tension	64	66	66	63	62	62	64	67	66	63	643	

RAW DATA

Type of addition: P

Time in millimetre of trace
Tension in mmv.

59

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
6B	Time	29	32	30	43	56	41	28	71	29	31	390	39.0
	Tension	10	10	10	11	11	11	10	14	12	11	110	11.0
4B	Time	34	35	36	51	43	50	38	34	46	40	407	40.7
	Tension	13	14	14	14	13	13	13	14	15	14	137	13.7
3B	Time	39	40	57	39	31	28	30	36	43	42	385	38.5
	Tension	13	12	11	12	13	11	12	14	10	10	118	11.8
Totals	Time	102	107	123	133	130	119	96	141	118	113	1182	
	Tension	36	36	35	37	37	35	35	42	37	35	365	

510

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
1B	Time	51	38	31	41	49	62	34	35	34	40	415	41.5
	Tension	15	15	15	16	16	15	12	12	12	12	140	14.0
6B	Time	43	46	57	50	61	42	37	43	55	48	482	48.2
	Tension	12	13	14	14	14	13	14	15	15	14	138	13.8
4B	Time	36	37	38	35	43	70	65	67	59	56	505	50.5
	Tension	12	12	13	12	12	15	14	15	13	14	132	13.2
Totals	Time	130	121	126	126	153	174	136	145	148	144	1403	
	Tension	39	40	42	42	42	43	40	42	40	40	410	

<u>RAW DATA</u>

Type of addition: **N**

Time in millimetre of trace
Tension in mmv.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S1	2B	Time	35	38	43	51	192	152	159	143	47	36	896	89·6
		Tension	12	13	13	14	19	18	18	18	15	14	154	15·4
	5B	Time	29	24	50	77	46	60	62	105	200	75	728	72·8
		Tension	15	12	17	14	15	14	13	11	14	12	137	13·7
	4B	Time	68	44	62	59	70	62	166	259	57	50	897	89·7
		Tension	14	13	14	12	13	14	17	19	18	14	148	14·8
	Totals	Time	132	106	155	187	308	274	387	507	304	161	2521	
		Tension	41	38	44	40	47	46	48	48	47	40	437	

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S2	5B	Time	47	41	25	81	99	37	52	41	45	47	515	51·5
		Tension	9	8	8	12	13	12	10	9	9	9	99	9·9
	3B	Time	53	61	56	72	70	68	61	72	43	69	625	62·5
		Tension	9	9	9	10	10	10	9	9	9	10	92	9·2
	6B	Time	45	72	94	46	73	88	91	75	40	65	689	68·9
		Tension	6	8	10	10	7	9	10	8	7	7	82	8·2
	Totals	Time	145	174	175	199	242	193	204	188	128	181	1829	
		Tension	24	25	27	32	30	31	29	26	23	26	273	

RAW DATA

Type of addition: *N*

Time in millimetre of trace
Tension in mmv.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S3	4B	Time	32	46	44	32	62	46	46	46	50	55	459	45·9
		Tension	6	5	5	4	3	3	4	4	4	4	42	4·2
	6B	Time	24	28	35	41	43	45	32	29	30	38	345	34·5
		Tension	6	6	7	9	9	8	5	4	5	5	64	6·4
	5B	Time	26	27	28	33	47	62	71	27	74	82	477	47·7
		Tension	5	5	6	6	8	10	9	5	7	8	69	6·9
	Totals	Time	82	101	107	106	152	153	149	102	154	175	1281	
		Tension	17	16	18	19	20	21	18	13	16	17	176	

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S4	6B	Time	47	64	54	54	61	170	142	72	60	56	780	78·0
		Tension	6	7	7	7	7	10	11	11	10	8	84	8·4
	2B	Time	53	59	51	67	83	71	65	115	47	59	670	67·0
		Tension	7	7	7	9	10	7	7	11	6	7	78	7·8
	1B	Time	59	62	70	84	97	100	46	59	57	59	693	69·3
		Tension	7	8	7	8	9	8	5	6	7	6	71	7·1
	Totals	Time	159	185	175	205	241	341	253	246	164	174	2143	
		Tension	20	22	21	24	26	25	23	28	23	21	233	

RAW DATA

Type of addition: N

Time in millimetre of trace
Tension in mmv.

55

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
4B	Time	69	74	79	70	51	68	72	73	58	62	676	67.6
	Tension	10	11	11	11	9	11	12	12	10	10	107	10.7
3B	Time	75	76	81	72	64	68	43	81	84	60	704	70.4
	Tension	11	12	13	14	14	14	10	15	17	14	134	13.4
1B	Time	81	62	50	72	85	84	70	78	49	76	707	70.7
	Tension	13	10	9	8	12	12	12	13	10	9	108	10.8
Totals	Time	225	212	210	214	200	220	185	232	191	198	2087	
	Tension	34	33	33	33	35	37	34	40	37	33	349	

56

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
3B	Time	50	55	70	41	43	40	52	56	61	56	524	52.4
	Tension	7	7	9	6	6	6	7	7	8	6	69	6.9
2B	Time	71	58	60	71	68	67	52	59	63	68	637	63.7
	Tension	9	7	6	6	6	7	5	5	6	7	64	6.4
6B	Time	65	67	61	48	124	50	68	72	50	49	654	65.4
	Tension	7	7	6	5	10	10	6	8	7	7	73	7.3
Totals	Time	186	180	191	160	235	157	172	187	174	173	1815	
	Tension	23	21	21	17	22	23	18	20	21	20	206	

RAW DATA

Type of addition: **N** — Time in millimetre of trace; Tension in mmv.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
57	3B	Time	65	60	43	72	76	51	87	52	55	61	622	62·2
		Tension	6	6	4	6	8	7	8	7	6	6	64	6·4
	4B	Time	61	68	70	69	74	87	75	73	52	64	693	69·3
		Tension	5	7	9	8	8	10	9	9	6	7	78	7·8
	5B	Time	48	35	40	46	46	53	71	49	51	55	494	49·4
		Tension	5	4	4	5	5	5	8	7	6	7	56	5·6
	Totals	Time	174	163	153	187	196	191	233	174	158	180	1809	
		Tension	16	17	17	19	21	22	25	23	18	20	198	

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
58	2B	Time	71	73	75	46	53	81	89	73	64	62	687	68·7
		Tension	11	11	11	10	9	14	16	15	14	11	121	12·1
	5B	Time	68	72	73	79	71	68	87	64	70	51	703	70·3
		Tension	12	12	12	14	14	13	16	12	12	12	129	12·9
	3B	Time	51	48	53	97	108	49	56	61	60	61	644	64·4
		Tension	10	10	10	14	15	11	9	10	10	10	109	10·9
	Totals	Time	190	193	201	222	232	198	232	198	194	174	2034	
		Tension	33	33	33	38	38	39	40 39	37 ~~40~~	36	33	360	

RAW DATA

Type of addition: N

Time in millimetre of trace
Tension in mmv.

S 9

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
3B	Time	81	81	74	63	51	84	89	90	89	75	777	77·7
	Tension	6	6	7	5	4	8	10	8	6	7	67	6·7
4B	Time	83	103	69	72	80	95	84	63	81	76	806	80·6
	Tension	7	9	7	7	7	9	8	7	8	9	78	7·8
5B	Time	70	72	89	80	86	84	71	93	72	76	793	79·3
	Tension	6	7	10	10	9	9	7	10	10	8	86	8·6
Totals	Time	234	256	232	215	217	263	244	246	242	227	2376	
	Tension	19	22	24	22	20	26	25	25	24	24	231	

S 10

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
3B	Time	34	35	34	39	58	61	60	43	61	58	483	48·3
	Tension	4	4	4	5	7	7	6	4	4	5	50	5·0
4B	Time	38	40	30	63	51	46	60	65	55	45	493	49·3
	Tension	4	4	3	3	4	2	4	8	8	4	44	4·4
5B	Time	43	47	51	48	61	82	70	78	64	50	594	59·4
	Tension	5	5	5	3	2	5	5	5	5	4	44	4·4
Totals	Time	115	122	115	150	170	189	190	186	180	153	1570	
	Tension	13	13	12	11	13	14	15	17	17	13	138	

RAW DATA

Type of addition: M

Time in millimetre of trace
Tension in mmv.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S1	4B	Time	69	93	82	98	175	134	81	147	72	51	1002	100.2
		Tension	16	17	16	16	20	19	17	21	18	16	176	17.6
	6B	Time	73	41	43	22	94	71	41	83	43	44	555	55.5
		Tension	17	16	16	16	18	18	18	19	18	18	174	17.4
	3B	Time	78	86	93	105	151	197	48	67	52	63	940	94.0
		Tension	18	18	16	16	19	21	16	16	17	17	174	17.4
	Totals	Time	220	220	218	225	420	402	170	297	167	158	2497	
		Tension	51	51	48	48	57	58	51	56	53	51	524	

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
S2	2B	Time	26	33	27	27	65	32	66	37	44	30	387	38.7
		Tension	10	11	10	10	12	10	12	11	11	12	109	10.9
	6B	Time	34	41	44	30	33	72	75	47	46	39	461	46.1
		Tension	12	12	12	11	11	15	15	12	11	10	121	12.1
	4B	Time	40	45	52	62	50	45	99	51	43	36	523	52.3
		Tension	11	11	12	14	13	12	15	11	10	9	118	11.8
	Totals	Time	100	119	123	119	148	149	240	135	133	105	1371	
		Tension	33	34	34	35	36	37	42	34	32	31	348	

RAW DATA

Type of addition: **M**

Time in millimetre of trace
Tension in mmv.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
53	5B	Time	21	25	31	24	24	29	24	53	23	27	281	28.1
		Tension	12	12	13	13	10	13	12	15	13	12	125	12.5
	3B	Time	26	28	32	75	60	27	28	35	81	62	454	45.4
		Tension	11	11	12	15	15	14	12	13	15	15	133	13.3
	2B	Time	21	28	34	39	47	31	58	33	61	28	380	38.0
		Tension	12	12	14	14	15	12	11	12	14	11	127	12.7
	Totals	Time	68	81	97	138	131	87	110	121	165	117	1115	
		Tension	35	35	39	42	40	39	35	40	42	38	385	

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
54	5B	Time	18	21	43	25	160	83	65	50	51	38	494	49.4
		Tension	5	5	10	6	10	9	9	10	8	8	80	8.0
	4B	Time	31	35	47	26	33	91	182	102	73	32	656	65.6
		Tension	7	8	9	5	5	8	10	7	8	7	74	7.4
	3B	Time	29	36	39	68	40	32	48	65	81	30	468	46.8
		Tension	7	6	7	10	8	8	9	9	8	6	78	7.8
	Totals	Time	78	92	129	119	173	206	299	217	205	100	1618	
		Tension	19	19	26	21	23	25	28	26	24	21	232	

RAW DATA

Type of addition: **M**

Time in millimetre of trace
Tension in mmv.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
55	6B	Time	40	40	63	78	61	50	53	122	96	89	692	69.2
		Tension	15	15	18	18	17	15	15	20	21	16	170	17.0
	2B	Time	33	35	46	51	60	43	41	52	60	54	475	47.5
		Tension	12	13	14	14	15	14	14	17	18	16	147	14.7
	*5B	Time	81	80	41	36	52	83	42	86	89	37	627	62.7
		Tension	17	18	20	18	20	29	25	23	23	17	210	21.0
	Totals	Time	154	155	150	165	173	176	136	260	245	180	1794	
		Tension	44	46	52	50	52	58	54	60	62	49	527	

* noise of sawing from nearby workshop occurred during this sum.

		Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
56	2B	Time	30	36	45	52	40	86	93	97	35	41	555	55.5
		Tension	9	10	12	13	11	14	15	16	9	9	118	11.8
	3B	Time	38	41	47	54	101	46	49	85	82	44	587	58.7
		Tension	9	10	10	11	14	15	10	15	10	11	121	12.1
	1B	Time	54	56	93	41	33	30	48	39	43	45	482	48.2
		Tension	11	11	14	11	9	8	9	9	9	11	102	10.2
	Totals	Time	122	133	186	147	174	162	190	221	160	130	1624	
		Tension	29	31	36	35	34	37	34	40	34	31	341	

RAW DATA

Type of addition: **M**

Time in millimetre of trace
Tension in mmv.

57

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
2B	Time	35	41	73	40	62	30	42	106	51	57	537	53.7
	Tension	8	9	12	10	9	8	8	13	13	9	99	9.9
3B	Time	25	25	23	36	35	51	30	72	50	48	430	43.0
	Tension	7	7	7	7	6	10	7	12	12	8	83	8.3
5B	Time	31	32	35	33	44	45	126	118	43	45	552	55.2
	Tension	7	8	8	8	9	9	15	13	12	10	99	9.9
Totals	Time	91	98	131	109	141	126	198	296	144	150	1484	
	Tension	22	24	27	25	24	27	30	38	37	27	281	

58

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
4B	Time	32	22	34	25	29	27	44	54	31	20	318	31.8
	Tension	16	16	17	16	16	16	19	20	20	16	172	17.2
5B	Time	95	102	49	91	24	21	26	22	48	46	524	52.4
	Tension	19	20	18	19	15	14	15	14	15	16	165	16.5
3B	Time	17	35	54	56	51	52	29	23	53	49	419	41.9
	Tension	14	17	19	20	19	19	15	12	18	19	172	17.2
Totals	Time	144	159	137	172	104	100	99	99	132	115	1261	
	Tension	49	53	54	55	50	49	49	46	53	51	509	

RAW DATA

Type of addition: **M**

Time in millimetre of trace
Tension in mmv.

59

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
2B	Time	39	41	28	48	38	40	80	75	37	76	502	50.2
	Tension	8	9	8	12	12	11	13	13	9	15	110	11.0
4B	Time	39	40	37	40	39	38	38	73	193	65	602	60.2
	Tension	6	6	6	6	6	6	7	8	15	12	78	7.8
6B	Time	39	42	120	84	78	40	40	39	109	38	629	62.9
	Tension	6	7	14	12	11	10	9	7	12	6	94	9.4
Totals	Time	117	123	185	172	155	118	158	187	339	179	1733	
	Tension	20	22	28	30	29	27	29	28	36	33	282	

S10

	Interval	1	2	3	4	5	6	7	8	9	10	Total	Mean
5B	Time	63	46	44	44	51	84	58	58	42	28	518	51.8
	Tension	14	13	13	13	15	19	20	20	18	12	157	15.7
4B	Time	20	18	48	55	72	29	34	66	33	32	407	40.7
	Tension	12	12	15	15	16	14	14	16	14	13	141	14.1
3B	Time	29	38	57	71	40	40	48	57	58	52	490	49.0
	Tension	10	14	16	19	16	16	16	16	17	15	155	15.5
Totals	Time	112	102	149	170	163	153	140	181	133	112	1415	
	Tension	36	39	44	47	47	49	50	52	49	40	453	

P TYPE

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S1	3C	Time	21	43	35	64	98	74	54	208	83	70	140	47	63	121	82	66	45	81	41	84	1520	76·0
		Tension	16	18	14	16	17	13	14	20	16	16	18	14	17	19	16	16	15	15	15	16	321	16·1
	4C	Time	25	32	25	30	61	72	89	26	24	35	79	25	128	34	51	31	35	80	26	25	933	46·7
		Tension	18	18	18	18	20	20	22	19	18	17	19	16	23	23	20	19	19	20	20	20	387	19·4
	2C	Time	20	21	21	88	76	91	83	40	42	31	26	52	89	72	63	39	32	34	53	29	1002	50·1
		Tension	16	16	17	19	19	20	20	18	17	15	16	18	20	20	18	17	16	20	19	18	359	18·0
	Totals	Time	66	98	81	182	235	237	226	274	149	136	245	124	280	227	196	136	112	195	120	138	3455	
		Tension	50	52	49	53	56	53	56	57	51	48	53	48	60	60	54	52	50	55	54	54	1067	

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S2	2C	Time	40	53	68	41	75	59	77	39	46	54	50	52	68	44	56	52	65	86	87	58	1170	58·5
		Tension	13	14	14	12	14	14	14	12	14	14	14	12	15	13	13	14	13	15	15	14	273	13·7
	1C	Time	41	48	49	56	29	73	51	86	95	81	48	49	54	59	54	53	36	34	31	42	1069	53·5
		Tension	14	14	14	15	13	16	14	16	16	12	14	14	14	14	13	13	14	13	13	15	281	14·1
	4C	Time	48	54	58	61	38	51	43	76	49	35	62	81	54	64	38	47	61	72	60	50	1102	55·1
		Tension	15	15	16	16	14	15	14	17	17	14	15	16	15	16	13	12	14	15	14	13	296	14·8
	Totals	Time	129	155	175	158	142	183	171	209	190	170	160	182	176	167	148	152	162	192	178	156	3341	
		Tension	42	43	44	43	41	45	42	45	47	40	43	42	44	43	39	39	41	43	42	42	850	

P TYPE

53

	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
6C	Time	26	37	36	35	32	49	39	62	46	46	39	44	36	44	86	29	41	46	79	41	893	44·7
	Tension	16	15	16	16	14	17	15	17	17	15	14	14	14	14	16	14	16	15	17	16	308	15·4
1C	Time	27	24	21	43	40	31	52	43	65	47	36	60	68	43	71	29	36	35	33	31	835	41·8
	Tension	14	14	14	16	16	16	17	15	16	13	13	16	15	17	19	16	17	17	17	17	315	15·8
3C	Time	24	28	33	46	51	62	43	39	36	41	38	43	71	52	43	36	51	38	32	32	839	42·0
	Tension	16	16	18	20	18	19	20	20	20	21	22	24	28	28	26	24	21	22	20	20	423	21·2
Totals	Time	77	89	90	124	123	142	134	144	147	134	113	147	175	139	200	94	128	119	144	104	2567	
	Tension	46	45	48	52	48	52	52	52	53	49	49	54	57	59	61	54	54	54	54	53	1046	

54

	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
6C	Time	53	70	72	79	80	82	133	100	58	80	61	26	86	91	84	92	70	86	144	58	1605	80·3
	Tension	10	6	7	9	8	9	10	11	7	10	11	7	9	10	10	9	9	8	10	8	178	89
3C	Time	52	56	61	73	71	94	100	121	72	59	64	61	34	36	61	62	50	43	31	30	1231	61·6
	Tension	10	11	11	12	12	16	14	12	13	12	11	12	10	11	12	12	9	9	11	11	231	11·6
1C	Time	46	41	47	53	54	62	106	35	31	28	36	73	132	101	75	39	46	56	55	45	1161	58·1
	Tension	8	8	7	6	9	12	12	12	10	9	9	10	12	12	12	10	10	9	9	8	194	9·7
Totals	Time	151	167	180	205	205	238	339	256	161	167	161	160	252	228	220	193	166	185	230	133	3997	
	Tension	28	25	25	27	29	37	36	35	30	31	31	29	31	33	34	31	28	26	30	27	603	

P TYPE

55

	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
1C	Time	41	46	62	83	49	58	110	46	59	61	69	84	93	71	94	70	59	83	42	44	1324	66·2
	Tension	17	17	18	16	17	18	21	19	19	19	19	24	20	18	14	16	15	18	20	20	365	18·3
3C	Time	50	39	53	58	71	42	44	37	29	31	28	105	48	52	58	83	46	40	40	39	993	49·7
	Tension	18	19	18	17	16	15	14	14	12	12	13	18	16	16	16	16	18	17	17	17	319	16·0
4C	Time	39	41	41	47	72	68	50	53	52	40	39	36	67	83	89	70	62	64	48	43	1104	55·2
	Tension	19	20	20	20	22	22	15	15	15	14	15	15	19	17	16	15	15	14	15	15	338	16·9
Totals	Time	130	126	156	188	192	168	204	136	140	132	136	225	208	206	241	223	167	187	130	126	3421	
	Tension	54	56	56	53	55	55	50	48	46	45	47	54	55	51	49	47	48	49	52	52	1022	

56

	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
3C	Time	22	25	60	43	58	47	39	54	52	56	59	43	58	37	39	46	47	59	62	59	965	48·8
	Tension	11	11	15	14	14	15	15	17	17	17	17	15	14	13	14	16	15	15	14	13	292	14·6
4C	Time	39	40	37	53	70	71	59	56	40	46	58	43	61	47	58	52	55	41	40	36	1002	50·1
	Tension	13	13	14	15	17	17	15	15	14	14	13	14	16	15	14	14	15	14	13	13	288	14·4
1C	Time	43	43	46	51	69	84	63	50	54	48	47	49	56	50	48	59	44	43	40	46	1053	52·7
	Tension	13	13	14	14	15	16	10	12	12	13	13	13	14	12	13	13	13	15	13	13	264	13·2
Totals	Time	104	108	143	147	197	202	161	160	146	150	164	135	175	134	145	157	146	163	142	141	3020	
	Tension	37	37	43	43	46	48	40	44	43	44	43	42	44	40	41	43	43	44	40	39	844	

P TYPE

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
57	3c	Time	48	62	66	49	53	61	60	61	72	81	60	54	66	73	74	76	64	65	65	68	1278	63·9
		Tension	13	14	14	13	14	12	12	12	11	14	13	13	14	13	12	13	14	14	14	13	262	13·1
	4c	Time	56	51	66	60	48	51	73	86	64	75	49	56	72	81	70	52	49	48	53	54	1214	60·7
		Tension	15	15	16	16	14	14	16	17	15	15	16	18	16	15	15	14	13	14	15	15	304	15·2
	5c	Time	59	63	66	72	81	62	74	76	77	70	63	64	83	80	79	88	91	62	40	51	1401	70·1
		Tension	16	16	15	15	17	14	15	15	15	16	16	17	19	19	18	18	20	20	16	15	332	16·6
	Totals	Time	163	176	198	181	182	174	207	223	213	226	172	174	221	234	223	216	204	175	158	173	3893	
		Tension	44	45	45	44	45	40	43	44	41	45	45	48	49	47	45	45	47	48	45	43	898	

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
58	1C	Time	52	53	72	90	48	81	63	62	75	50	64	58	73	58	59	86	81	80	76	54	1335	66·8
		Tension	22	22	23	26	23	25	23	23	25	22	22	21	22	23	22	24	23	23	23	20	457	22·9
	6C	Time	58	41	56	54	53	61	49	58	74	106	41	49	54	62	60	51	54	43	41	50	1115	55·8
		Tension	23	24	24	24	23	24	22	21	24	26	26	20	22	23	23	21	22	20	20	20	452	22·6
	4c	Time	61	54	60	46	73	75	78	52	51	90	46	45	54	65	62	60	48	51	40	49	1160	58·0
		Tension	23	23	23	21	22	24	24	24	21	22	23	21	22	25	25	24	20	21	21	22	451	22·6
	Totals	Time	171	148	188	190	174	217	190	172	200	246	151	152	181	185	181	197	183	174	157	153	3610	
		Tension	68	69	70	71	68	73	69	68	70	70	71	62	66	71	70	69	65	64	64	62	1360	

P TYPE

S9

	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
4c	Time	41	42	41	56	45	31	53	62	39	40	43	36	52	50	116	61	46	42	45	53	1004	50.2
	Tension	11	11	11	12	10	10	11	11	10	11	11	10	12	10	14	14	16	11	10	11	221	11.1
6c	Time	38	41	42	40	72	36	54	56	43	48	31	84	82	80	66	70	43	36	38	40	1040	52.0
	Tension	10	11	11	12	13	10	11	11	10	11	9	12	12	12	10	11	10	10	16	10	216	10.8
1c	Time	37	38	52	61	126	43	51	39	48	79	52	50	36	39	43	44	52	39	60	62	1051	52.6
	Tension	10	10	12	13	16	14	12	10	11	13	11	11	11	12	12	12	10	11	13	13	237	11.9
Totals	Time	116	121	135	157	243	110	158	157	130	167	126	170	170	169	225	175	141	127	143	155	3095	
	Tension	31	32	34	37	39	34	34	32	31	35	31	33	35	34	36	37	30	32	33	34	674	

S10

	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
1c	Time	46	41	51	40	39	38	53	55	41	62	43	48	53	51	41	40	35	38	57	50	922	46.1
	Tension	15	15	14	14	13	13	15	14	14	16	17	18	18	18	17	18	16	15	15	15	310	15.5
3c	Time	48	41	40	46	49	53	71	75	62	61	50	49	47	42	49	57	61	62	51	48	1062	53.1
	Tension	16	16	17	16	17	17	18	19	16	16	15	15	15	14	14	15	16	16	15	15	318	15.9
2c	Time	31	46	148	90	32	34	29	30	31	31	38	46	38	31	32	73	70	31	38	32	931	46.6
	Tension	15	15	13	14	16	18	16	16	15	15	15	17	16	16	15	16	18	18	18	18	320	16.0
Totals	Time	125	128	239	176	120	125	153	160	134	154	131	143	138	124	122	170	166	131	146	130	2915	
	Tension	46	46	44	44	46	48	49	49	45	[illegible]	47	50	49	48	46	49	50	49	48	48	948	

N TYPE

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S1	2C	Time	31	33	90	78	46	110	78	62	42	31	80	167	126	63	101	115	168	75	127	69	1692	84·6
		Tension	12	14	14	13	10	12	13	14	20	12	13	12	11	16	14	14	12	12	10	11	259	13·0
	4C	Time	45	47	46	41	57	58	40	33	72	81	49	53	31	39	56	78	78	32	31	35	1002	50·1
		Tension	13	13	13	12	16	14	13	13	15	16	16	15	14	14	15	18	17	13	13	15	288	14·4
	6C	Time	42	49	40	83	51	42	96	64	63	72	60	45	72	81	40	57	58	63	51	41	1170	58·5
		Tension	11	11	12	14	14	12	15	14	14	14	12	11	16	15	15	13	12	13	11	10	259	13·0
	Totals	Time	118	129	176	202	154	210	214	159	177	184	189	265	229	183	197	250	304	170	209	145	3864	
		Tension	36	38	39	39	40	38	41	41	49	42	41	38	41	45	44	45	41	38	34	36	806	

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S2	4C	Time	32	35	50	42	66	50	35	60	30	66	60	48	63	76	37	45	35	84	39	40	993	49·7
		Tension	6	6	6	6	6	6	5	7	5	7	7	6	6	8	5	4	4	7	7	5	119	6·0
	3C	Time	46	49	55	50	39	53	59	38	41	59	60	62	67	38	51	53	48	69	71	52	1060	53·0
		Tension	7	7	9	10	9	11	11	9	9	9	12	11	11	9	9	9	8	9	11	10	190	9·5
	2C	Time	23	24	34	31	39	32	34	31	39	22	32	27	46	38	27	30	63	23	27	24	646	32·3
		Tension	8	8	9	9	9	8	8	8	9	8	10	6	9	7	6	7	10	9	9	8	165	8·8
	Totals	Time	101	108	139	123	144	135	128	129	110	147	152	137	176	152	115	128	146	176	137	116	2699	
		Tension	21	21	24	25	24	25	24	24	23	24	29	23	26	24	20	20	22	25	27	23	474	

N TYPE.

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S3	6c	Time	37	36	40	34	57	47	45	59	38	43	66	60	27	67	51	51	53	51	38	44	944	47·2
		Tension	5	5	15	8	13	8	6	9	8	5	8	5	9	5	5	8	5	5	5	5	142	7·1
	4c	Time	44	41	49	53	31	39	52	56	61	48	53	55	60	50	43	41	39	48	37	35	935	46·8
		Tension	5	5	5	6	6	4	8	10	12	9	9	10	12	9	8	8	6	6	5	6	148	7·4
	5c	Time	35	35	38	32	55	62	50	43	50	46	47	45	29	33	53	67	70	61	60	52	963	48·2
		Tension	6	7	7	6	8	10	10	8	7	7	8	7	5	6	8	12	12	11	10	9	164	8·2
	Totals	Time	116	112	127	119	143	148	147	158	149	137	166	160	116	150	147	159	162	160	135	131	2842	
		Tension	16	17	27	20	26	22	24	27	27	21	25	22	26	20	21	28	23	22	20	20	454	

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S4	2c	Time	49	52	56	71	62	80	52	88	64	61	51	72	75	70	61	58	59	54	64	43	1242	62·1
		Tension	5	5	9	8	8	8	8	10	10	11	11	13	13	11	10	10	10	10	9	10	189	9·3
	1c	Time	51	46	53	56	49	56	59	43	62	66	64	48	49	53	60	61	72	73	62	66	1149	57·5
		Tension	6	8	8	8	8	9	9	6	7	8	8	8	7	6	7	7	9	9	8	7	153	7·7
	4c	Time	73	58	72	64	73	71	76	48	51	52	75	46	51	58	70	62	69	71	51	42	1233	61·7
		Tension	5	5	7	7	6	7	7	4	5	5	8	7	7	6	8	7	6	7	5	4	123	6·2
	Totals	Time	173	156	181	191	184	207	187	179	177	179	190	166	175	181	191	181	200	198	177	151	3624	
		Tension	16	18	24	23	22	24	24	20	22	24	27	28	27	23	25	24	25	26	22	21	465	

N TYPE

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
55	3c	Time	70	74	74	79	83	88	72	61	95	60	64	101	99	96	73	74	62	68	61	60	1514	75.7
		Tension	13	13	13	14	15	16	17	14	18	12	12	15	16	16	13	13	13	14	13	12	282	14.1
	6c	Time	73	81	85	80	89	76	77	62	69	79	83	61	64	88	90	81	65	64	72	83	1522	76.1
		Tension	10	12	13	13	16	16	15	14	14	15	15	13	13	13	16	16	14	12	13	13	276	13.8
	1c	Time	69	58	62	59	54	59	60	63	58	72	49	56	61	91	40	53	58	62	70	60	1214	60.7
		Tension	11	12	13	13	14	12	10	11	10	14	10	11	12	16	10	11	11	12	11	10	234	11.7
	Totals	Time	212	213	221	218	226	223	209	186	222	211	196	218	224	275	203	208	185	194	203	203	4250	
		Tension	34	37	39	40	45	44	42	39	42	41	37	39	41	45	39	40	38	38	37	35	792	

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
56	2c	Time	61	63	65	69	52	43	59	68	68	51	43	89	56	56	50	41	49	43	51	54	1131	56.6
		Tension	8	8	8	9	7	6	8	8	9	9	7	11	9	10	10	8	8	7	9	10	169	8.5
	1c	Time	55	62	51	63	70	52	68	71	70	60	54	55	56	73	49	70	56	57	56	51	1199	60.0
		Tension	8	9	6	7	9	6	7	8	8	8	7	9	9	10	7	10	9	9	8	7	161	8.1
	6c	Time	69	60	52	68	66	193	42	51	54	63	72	66	61	65	73	71	76	52	55	43	1392	69.6
		Tension	9	9	9	10	10	17	11	9	10	10	11	14	10	10	10	8	8	10	8	6	199	10.0
	Totals	Time	185	185	168	200	188	288	169	190	192	174	169	250	173	194	172	182	181	152	162	148	3722	
		Tension	25	26	23	26	26	29	26	25	27	27	25	34	28	30	27	26	25	26	25	23	529	

N TYPE.

Subject	Condition	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
57	6C	Time	61	72	74	63	65	61	64	73	52	79	81	72	66	67	60	71	80	71	61	50	1343	67·2
		Tension	5	8	7	6	7	6	6	8	6	9	9	9	8	8	7	6	8	9	6	5	143	7·2
	5C	Time	53	81	58	64	66	67	73	64	51	76	70	49	56	53	53	50	49	56	58	61	1208	60·4
		Tension	7	8	7	7	7	7	8	8	6	9	8	7	7	7	7	6	5	7	7	8	143	7·2
	2C	Time	58	56	52	49	63	60	71	60	78	69	84	85	73	76	79	80	72	64	60	64	1353	67·7
		Tension	6	6	5	4	6	6	6	7	9	9	10	11	11	11	12	12	8	7	6	7	159	8·0
	Totals	Time	172	209	184	176	194	188	208	197	181	224	235	206	195	196	192	201	201	191	179	175	3904	
		Tension	18	22	19	17	20	19	20	23	21	27	27	27	26	26	26	24	28	23	19	20	445	

Subject	Condition	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
58	5C	Time	71	73	78	80	82	86	73	71	64	70	50	68	65	89	76	61	74	63	82	61	1437	71·9
		Tension	11	12	13	13	13	12	12	10	10	11	10	13	13	15	15	13	12	10	11	11	240	12·0
	2C	Time	72	70	68	78	69	87	51	70	76	83	71	70	64	63	68	82	70	62	69	83	1426	71·3
		Tension	11	11	11	12	13	14	13	12	14	14	11	11	10	11	12	15	13	12	12	12	244	12·2
	6C	Time	60	82	84	76	79	101	84	90	68	62	60	56	59	62	60	58	61	62	61	56	1381	69·1
		Tension	11	14	15	12	12	16	17	14	14	13	12	11	11	11	11	12	12	12	12	11	253	12·7
	Totals	Time	203	225	230	234	230	274	208	231	208	215	181	194	188	214	204	201	205	187	212	200	4244	
		Tension	33	37	39	37	38	42	42	36	38	38	33	35	34	37	38	40	37	34	35	34	737	

N TYPE

S9		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
	3c	Time	86	90	86	91	103	74	85	88	90	90	104	91	93	76	79	84	88	85	85	88	1756	87·8
		Tension	6	6	6	6	8	5	5	6	9	9	10	9	9	9	7	8	8	8	8	8	150	7·5
	1c	Time	85	89	93	94	81	79	79	80	79	86	93	106	71	72	75	83	81	80	89	87	1682	84·1
		Tension	7	7	8	9	8	8	8	8	8	9	9	10	7	7	7	8	8	8	9	8	161	8·1
	5c	Time	79	88	76	81	83	56	64	65	71	76	81	83	70	61	78	78	75	88	92	105	1550	77·5
		Tension	5	6	6	7	7	4	5	5	5	8	9	10	7	5	9	8	7	9	9	12	143	7·2
	Totals	Time	250	267	255	266	267	209	228	233	240	252	278	280	234	209	232	245	244	253	266	280	4988	
		Tension	18	19	20	22	23	17	18	19	22	26	28	29	23	21	23	24	23	25	26	28	454	

S10		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
	2c	Time	51	62	49	54	53	51	62	63	68	62	71	75	61	64	60	73	56	55	61	56	1207	60·4
		Tension	6	6	5	4	4	5	6	6	6	5	7	8	6	6	6	8	5	5	5	4	113	5·7
	6c	Time	48	48	52	54	51	50	64	43	48	54	50	56	48	55	62	98	97	51	63	76	1162	58·1
		Tension	4	4	4	5	5	4	6	7	4	4	4	5	4	5	7	10	10	10	6	5	113	5·7
	4c	Time	46	48	49	61	55	63	61	64	69	74	68	75	69	51	83	79	49	53	58	61	1236	61·8
		Tension	4	4	4	6	6	7	7	7	8	8	8	8	7	4	8	8	4	5	5	4	122	6·1
	Totals	Time	145	158	150	169	159	164	187	176	185	190	189	206	178	170	205	250	202	159	182	187	3605	
		Tension	14	14	13	15	15	16	19	20	18	17	19	21	17	15	21	26	19	20	16	13	348	

M TYPE

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S1.	6c	Time	36	36	32	40	42	40	126	81	41	69	62	41	40	77	69	224	287	140	323	38	1844	92.2
		Tension	17	17	18	20	19	17	22	23	20	18	16	15	15	16	16	23	23	23	23	17	378	18.9
	5c	Time	31	32	35	37	98	34	43	139	76	29	34	63	40	51	48	50	79	42	40	36	1037	51.9
		Tension	16	17	17	17	20	16	17	22	20	20	19	19	17	17	17	16	18	16	15	14	350	17.5
	3c	Time	29	34	36	231	27	35	52	57	53	67	89	115	32	38	46	70	40	39	38	33	1161	58.1
		Tension	14	15	15	22	21	18	19	20	18	17	16	18	18	15	16	18	18	17	16	16	347	17.4
	Totals	Time	96	102	103	308	167	109	221	277	170	165	185	219	112	166	163	344	406	221	401	107	4042	
		Tension	47	49	50	59	60	51	58	65	58	55	51	52	50	48	49	57	59	56	54	47	1075	

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S2.	6c	Time	23	24	34	31	39	32	34	31	39	22	32	27	46	38	27	30	63	23	27	24	646	32.3
		Tension	7	7	6	6	7	7	7	6	6	5	8	7	8	8	7	6	9	9	7	6	139	7.0
	1c	Time	32	31	43	51	36	38	43	51	30	29	56	28	39	51	50	24	51	26	35	25	769	38.5
		Tension	13	13	13	15	12	12	11	13	12	12	14	12	13	14	13	13	15	14	13	12	259	13.0
	3c	Time	31	39	44	61	27	39	47	29	38	37	48	56	31	62	48	31	35	30	36	28	797	39.9
		Tension	12	13	14	16	12	14	13	12	13	13	14	12	12	14	12	13	13	12	14	12	260	13.0
	Totals	Time	86	94	121	143	102	109	124	111	107	88	136	111	116	151	125	85	149	79	98	77	2212	
		Tension	32	33	33	37	31	33	31	31	31	30	36	31	33	36	32	32	37	35	34	30	658	

M TYPE

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S3	3C	Time	22	20	24	19	25	27	27	21	32	41	47	21	24	27	79	31	26	31	30	23	597	29·9
		Tension	14	13	13	13	15	15	15	14	16	16	14	13	13	12	17	13	13	14	13	13	279	14·0
	1C	Time	28	29	31	28	29	36	69	54	38	56	45	35	29	36	33	46	43	36	29	27	757	37·9
		Tension	14	14	14	15	15	16	18	14	13	14	14	13	13	14	15	16	16	15	14	14	291	14·6
	6C	Time	26	28	21	38	39	41	40	61	33	62	61	27	35	44	51	50	48	35	26	38	804	40·2
		Tension	16	17	15	16	17	15	15	18	18	18	16	14	14	16	16	16	15	14	15	14	315	15·8
Totals		Time	76	77	76	85	93	104	136	136	103	159	153	83	88	107	163	127	117	102	85	88	2158	
		Tension	44	44	42	44	47	46	48	46	47	48	44	40	40	42	48	45	44	43	42	41	885	

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S4	2C	Time	17	22	48	151	46	116	157	24	55	98	53	159	175	41	241	163	117	226	116	237	2263	113·2
		Tension	12	9	9	12	8	16	11	10	11	13	12	13	13	15	17	15	15	16	16	16	259	13·0
	4C	Time	51	54	29	47	53	95	28	47	49	51	121	28	39	153	71	70	262	84	38	99	1469	73·5
		Tension	13	13	12	13	13	16	10	11	12	14	17	10	12	16	14	14	18	14	12	16	270	13·5
	1C	Time	26	28	34	123	136	101	64	35	38	59	110	73	81	46	41	52	50	41	106	30	1274	63·7
		Tension	10	11	10	16	16	16	16	12	12	12	14	14	12	11	10	11	11	12	15	16	257	12·9
Totals		Time	94	104	111	321	235	312	249	106	142	208	284	260	295	240	354	285	429	351	260	366	5006	
		Tension	35	33	31	41	37	48	47	33	35	39	43	37	37	42	41	40	44	42	43	48	786	

M TYPE

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
	6c	Time	34	39	56	73	126	91	64	48	51	63	72	81	70	65	64	59	73	49	52	55	1285	64·3
		Tension	15	15	17	18	20	20	17	14	14	14	16	17	16	16	15	15	17	15	14	13	318	15·9
S5	4C	Time	41	71	62	49	40	76	81	74	52	64	55	106	61	53	52	58	61	43	44	40	1183	59·2
		Tension	13	16	16	15	14	16	15	15	14	17	17	20	16	17	17	18	17	16	16	16	321	16·1
	5C	Time	50	53	51	58	59	52	54	56	58	60	51	43	89	46	52	57	65	57	101	51	1163	58·2
		Tension	14	14	14	16	16	15	14	14	14	15	16	17	20	15	16	16	16	16	20	21	319	16·0
Totals		Time	125	163	169	180	225	219	199	178	161	187	178	230	220	164	168	174	199	149	197	146	3631	
		Tension	42	45	47	49	50	51	46	43	42	46	49	54	52	48	48	49	50	47	50	50	958	

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
	4C	Time	38	38	34	60	56	43	49	41	56	64	59	63	62	40	38	43	46	51	49	50	980	49·0
		Tension	11	11	11	15	14	12	12	10	11	9	11	11	10	9	8	9	10	12	11	11	218	10·9
S6	6c	Time	36	32	47	43	59	48	62	59	39	35	48	44	55	55	66	70	62	53	41	38	992	49·6
		Tension	9	11	14	15	16	12	12	11	9	9	11	12	13	13	15	18	16	14	13	12	255	12·8
	5C	Time	39	42	48	56	52	51	44	58	50	62	78	61	43	41	53	40	62	39	48	42	1009	50·5
		Tension	11	11	12	12	14	13	12	13	12	12	17	18	14	12	11	10	13	10	10	9	246	12·3
Totals		Time	113	112	139	159	167	142	155	158	145	161	185	168	160	136	157	153	170	143	138	120	2981	
		Tension	31	33	37	42	44	37	36	34	32	30	39	41	37	34	34	37	39	36	34	32	719	

M TYPE

	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
6c	Time	31	46	30	38	53	61	49	42	55	50	48	89	50	116	34	39	53	91	62	46	1083	54.2
	Tension	10	14	12	13	15	15	11	11	11	12	10	12	10	16	15	11	10	13	11	10	242	12.1
57 4c	Time	42	51	35	39	38	49	53	40	68	70	78	106	48	62	59	33	42	40	52	48	1053	52.7
	Tension	11	11	11	12	12	12	13	12	14	16	15	17	16	13	13	12	10	10	11	10	251	12.6
5c	Time	35	50	42	137	106	38	38	40	44	33	65	60	51	54	53	49	65	88	60	53	1161	58.1
	Tension	9	11	10	15	16	10	10	11	11	11	13	14	14	13	13	12	13	15	15	12	248	12.4
Totals	Time	108	147	107	214	197	148	140	122	167	153	191	255	149	232	146	121	160	219	174	147	3297	
	Tension	30	36	33	40	43	37	34	34	36	39	38	43	40	42	41	35	33	38	37	32	741	

	Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
5c	Time	51	56	58	64	76	80	71	64	53	59	66	58	56	61	52	59	43	48	52	44	1171	58.6
	Tension	20	20	21	22	20	20	20	19	18	18	18	18	17	18	19	19	18	18	19	18	386	19.0
58 6c	Time	43	43	55	61	56	73	62	51	50	46	55	59	96	101	58	42	69	70	54	49	1193	59.7
	Tension	18	19	22	22	20	21	20	18	18	17	18	19	20	23	20	20	19	20	18	17	389	14.5
2c	Time	36	58	60	52	54	62	66	46	45	53	49	71	70	45	48	53	49	52	29	28	1026	51.3
	Tension	19	22	23	21	21	20	22	19	18	18	16	19	20	16	17	20	18	19	18	18	384	14.2
Totals	Time	130	157	173	177	186	215	199	161	148	158	170	188	222	207	158	154	161	170	135	121	3390	
	Tension	57	61	66	65	61	61	62	56	54	53	52	56	57	57	56	59	55	57	55	53	1153	

M TYPE

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S9	2c	Time	43	44	40	56	41	46	62	41	80	72	33	36	72	41	73	164	61	45	40	44	1134	56.7
		Tension	8	8	7	10	8	9	10	8	12	11	9	8	8	8	12	18	10	9	8	8	189	9.5
	1c	Time	53	53	56	61	38	45	72	56	58	55	101	38	42	54	56	54	53	58	51	45	1099	55.0
		Tension	9	9	9	10	7	8	11	9	9	9	14	10	10	9	9	9	9	9	8	8	185	9.3
	3c	Time	53	54	50	36	109	53	71	76	82	118	93	60	54	59	61	52	50	46	53	58	1288	64.4
		Tension	8	8	8	9	14	13	11	11	13	17	16	15	11	10	10	9	9	7	7	8	214	10.7
	Totals	Time	149	151	146	153	188	144	205	173	220	245	227	134	168	154	190	270	164	149	144	147	3521	
		Tension	25	25	24	29	29	30	32	28	34	37	39	33	29	27	31	36	28	25	23	24	588	

		Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Mean
S10	6c	Time	47	46	51	40	71	68	61	50	48	54	62	50	106	29	35	52	68	44	47	42	1071	53.6
		Tension	14	14	15	14	15	17	16	14	15	15	16	14	18	10	11	12	12	10	10	11	273	13.7
	3c	Time	41	40	50	50	44	25	28	36	33	41	44	52	51	38	54	60	48	31	60	53	879	44.0
		Tension	14	14	16	16	15	12	12	12	12	13	14	14	13	12	15	15	14	14	13	12	272	13.6
	4c	Time	39	39	41	43	46	51	43	44	36	44	41	52	48	49	47	47	51	33	39	44	877	43.9
		Tension	12	12	12	13	13	14	11	11	11	13	13	17	15	14	14	14	15	11	13	12	260	13.0
	Totals	Time	127	125	142	133	161	144	132	130	117	139	147	154	205	116	136	159	167	108	146	139	2827	
		Tension	40	40	43	43	43	43	39	37	38	41	43	45	46	36	40	41	41	35	36	35	805	