THE EFFECTS OF INDUCED MUSCLE TENSION DURING TRACKING ON LEVEL OF ACTIVATION AND ON PERFORMANCE

by

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Introduction

The relation of muscle tension to mental work has been studied since the days of the Wurzburg school and the controversy over "imageless thought" (Humphrey, 1951, p. 187). In 1887, for example, Lombard (cited by Bills, 1927) found the knee jerk to be enhanced by mental effort, and Loeb reported that pressure on a dynamometer tends to slacken when accompanied by mental effort. Bills has also reviewed extensive studies by Golla, in which it was shown that the tonicity of many muscles measured during mental work was invariably heightened.

Bills (1927) was apparently the first to test the functional significance of experimentally induced muscle tension and psychological activity. In the first of a series of experiments, he required his subjects to learn nonsense syllables while squeezing two hand dynamometers. Learning efficiency was measured by time to criteria, syllables recalled, and per cent saving in relearning. By all three measures of learning, Bills found that tension resulted in more efficient learning. The speed and accuracy of adding a column of digits also improved with tension.

Bills and Stauffacher (1937) found that tension induced by pulling 10-pound weights was helpful in the solving of arithmetic problems. In a second experiment, where subjects were to determine the significant clues in a detective story, they found that tension helped poor Ss but hindered the good Ss. Tension was also beneficial for the solution of the easier problems and detrimental for the harder problems for both the poor and good Ss. The authors concluded that the beneficial effect of induced muscle tension decreases as the complexity of the problem increases.

The amount of tension induced was also found to be an important variable. Stauffacher's (1937) rote learning studies were among the first to demonstrate the importance of this variable, and Courts (1939b) showed that the relation between amount of tension and performance was a regular one which when plotted graphically took the form of an inverted-U (see Figure 1). Courts inferred muscle tension in this experiment from the amplitude of the knee jerk. He had previously shown (Courts, 1939a) that the patellar reflex is linearly related to tension induced by squeezing a hand dynamometer. Figure 1 shows that scores on a task of memorization were significantly improved by tension in the optimal range. The optimum was produced when Ss exerted 1/4 and 3/8 of their maximum pulls.

Still another variable found by Courts in these experiments was the ability of the S. Poor memorizers appeared to profit more from the induced tension than good memorizers, whose level of muscle tension, as measured by amplitude of knee jerk, was higher.

The effects of induced muscle tension were not invariably represented by the inverted-U shown in Figure 1. In some experiments effects were beneficial only; in others detrimental only. Using a slightly different form of induced tension, Freeman (1940) encouraged

Ss to exert various degrees of "effort" in performing a finger oscillation task. He used palmar sweating as a direct measure of the amount of tension present (Freeman, 1938), taking measurements from Ss when they were above, below, and at a normal or "congenial" pace of oscillation. Freeman's results suggested that changes in skin resistance and level of tension were more closely related to subjective effort than to performance level per se.

Sharp (1941) has suggested that residual tension following any activity may act as an induced tension on an immediately subsequent task. He traced the course of residual tension in the resting, but previously reacting, group of muscles, following a standard two-minute ergographic task with maximum effort. His results showed a sharp initial loss in muscular tension, followed by a gradual rise to a much higher level. This was followed by a subsequent decline to a pre-work level in about 30 minutes. The effect of this residual tension was to significantly increase the ergographic output. When the tension induced was equal to that required for the second work period, no effect was obtained.

The relationship between the amount of muscle tension present in a particular locus and the reaction time of response that involves these muscles, has been investigated by Patton (1957). Flexion in the left wrist was used to induce tension in the right arm. If tension in the left wrist was maintained, the tension in the right arm, as measured by muscle action potential, decayed nearly linearly.

By varying the time of the beginning of the right arm movement following left arm flexion, various levels of tension could be experimentally induced in the right arm at the moment of response (manipulating a lever). Patton found that the tension at which the right arm moved to respond depended upon the amount of tension present when the stimulus was presented. When the contralaterally induced tension was highest, reaction time was maximal.

It should be mentioned that some induced tension studies have failed to show any significant effect of tension induction on performance or learning. For instance, Block (1936) induced tension in the hands and feet simultaneously, during performance of continuous addition, analogies testing, and a test of syllogistic reasoning. He found no optimal degree of exertion in any of the tests, even when using five ascending degrees of pressure up to 34 pounds for the hands and 48 for the feet. Adams (1954), who induced up to 30 pounds of tension using foot levers with Ss attempting a two-hand matching test, found no effects of such tension induction on the test. In one study Courts (1940) failed to corroborate Peak's (1931) earlier finding that the amplitude of eyelid response was greater when the S tensed his forearm. Differences in procedure from one experiment to the other make interpretation difficult (Peak, 1942).

Two studies of perception using the tachistoscopic technique are of particular interest. The first one by Shaw (1956) was concerned with variation in the optimal amount of tension as a function of the complexity of the perception. Varying the length and difficulty of digit series, Shaw found reproduction of the longer, more difficult series, to be improved more by the high-tension condition than reproduction of the shorter, easier series. Performance on both series was improved by the lower level of tension (1/4 of the maximum pull), and good as well as poor performers benefited from the induced tension.

Shore (1958) found an interaction between induced tension and scores on the Manifest Anxiety Scale in his study of tachistoscopic performance. Induced tension improved the performance of Ss with high MAS scores and impaired that of low MAS Ss. In the case of Ss with medium MAS scores, there was first improvement and then impairment in performance with induced tension.

The relationship between mental activity and muscular tension is far from simple. This is quite apparent when mental-type tasks and psychomotor tasks are compared. Freeman (1933) found, for example, that effort in terms of muscular output during a mental task varied with S's estimate of task difficulty and his motivation. Increased tension incident to preparation for a more difficult task was found to be accompanied by an increase in the efficiency of the performance. Tension was notably increased under highly motivating conditions, and this appeared to be detrimental to performance. Performance gain with induced muscle tension depends upon the task itself, as well as upon some of these other factors. Freeman showed that reaction time is enhanced, as is performance in finger oscillation, while performance on manual pursuit he found to be impaired. The beneficial effect of induced muscle tension upon finger oscillation varied inversely with remoteness of the tensed muscle from the reacting member.

In another study, Freeman (1938) attempted to locate the optimal muscular tension for various performances. In general, he found that a tension-load optimal for one type of activity may be detrimental to performance of a different character. The more complex the performance, the more likely that tension increment would show deleterious effects. Freeman thought the optimum level of tension for a given performance would be difficult to find, however, because of (1) practice: a nonhabituated act utilizes more tension to advantage than a habituated act; (2) age differences; (3) major locus of tension in reference to the acting member or reaction pattern; and (4) time factors. If the tension load occurred in different temporal relation to two tasks, it was presumed that performance would be differentially affected. Freeman found such results to be clear-cut only if Ss were highly trained in tensing and relaxing various muscles; the relation was not apparent in Ss who had difficulty relaxing. He found that finger oscillation, sensory discrimination, and touch limen were enhanced by induced tension, while arithmetic and star tracing were deleteriously affected.

To test the suggestion that the timing of the muscular set (i.e., preparation for voluntary reaction), would influence the speed of reaction, Freeman and Kendall (1940) induced tension in the reacting member by placing various loads on a board tied to the arm. The arm was then held back for an appropriate time and allowed to return to the normal position and to then react to the stimulus. They found that tension induced at intervals prior to the response significantly lowered reaction time. The heavier the load, the longer was the optimal preparatory interval. Teichner (1957) also found that reaction time varied inversely with the magnitude of muscular tension. When both the foreperiod and the induced muscle tension were presented irregularly and their combined probability of occurrence made low, reaction time also varied inversely with the length of the foreperiod.

The suggested effects of practice on the dynamogenic effects of muscle tension have been studied by Courts (1942a). He had 32 subjects (16 men, 16 women) practice 50 trials on a pursuit rotor task. Each trial was 20 seconds in duration interpolated with about 40 seconds of rest. _S_s tracked with their right hand and squeezed the dynamometer with their left, maintaining correct pressure during the entire pursuit task. A control group of 12 men and 12 women tracked without using the dynamometer. Results of this experiment showed a bi-modal curve of performance gain due to induced muscle tension, with optimal levels at 1/8 and 1/2 the maximum tension.

Freeman (1937) has also shown that muscular tension will improve or hinder a given performance depending upon a number of other factors including (1) the amount of tension developed; (2) the timing of the proprioceptive impulses in relation to impulses of the primary reaction pattern; and (3) the neuro-anatomical connection which exists between the tonically contracting muscles and those involved in test performance. This latter point is illustrated in an experiment by Freeman where subjects performed a finger oscillation task while the right or left biceps sustained various weights. The results indicated that different loads may optimally affect test performance when acting from different muscle groups. To eliminate complicating central factors, such as attentional shifts and so on, _S_s again performed in response to faradic stimulation of their motor points. Optimal performance was produced by anticipatory tension when muscle groups most closely associated with the reacting member were electrically stimulated. Novocaine nerve block abolished the enhancing effects of contraction developed in the associated muscles.

In his review Courts (1942b) stated that most authors believe that the relation between level of performance and induced tension is best represented by an inverted-U. Several theories concerning this concept of an optimal tension level are of historical interest.

Probably the earliest of these theories was Freeman's (1931), which was later enlarged upon by himself (1937, 1948) and Stauffacher (1937). They assumed that the cortical centers involved in mental work have high thresholds. When these thresholds are lowered, the centers react to stimuli which would otherwise be inadequate. The threshold lowering is supposedly accomplished by the spread of proprioceptive impulses which travel to the cortex from lower centers, especially those involved in muscular contraction. Freeman and Stauffacher also assumed that the threshold for various levels of functional activity required by different tasks are not the same. If proprioceptive stimulation falls below a minimum level, cortical neurons in certain systems become incapable of adequate response. On the other hand, if muscular contraction becomes so intense that proprioceptive stimulation passes beyond a certain point, then it interferes with precise neural integration.

Robinson (1934) has suggested three possible explanations for the relationship between induced muscle tension and performance: (1) that tension induced with the dynamometer may bring about a more constant proprioceptive stimulation to higher centers than would otherwise be the case; this constancy would tend to act as a stabilizer or homeostatic regulator for maintaining the effect of extraneous stimuli; (2) that increased proprioceptive stimulation may bring about a general increase in tension with a resulting readiness to react in all muscle groups; or (3) that increased proprioceptive stimulation raises the general level of excitement in the cortex, increasing the speed and accuracy of more complex response patterns.

The Freeman and Robinson hypotheses are especially interesting as historical antecedents because these writers had no knowledge of the ascending reticular activating system (ARAS) and yet suggested somewhat similar physiological mechanisms on the basis of behavioral evidence. Work on the ARAS began with the chance observation of Moruzzi and Magoun (1949) that electrical stimulation of parts of the reticular formation of the brain stem evoked changes in the cerebral cortex that produced an "arousal" or "activation pattern" in the EEG. That is, there was an abolition of synchronized, eight-per-second discharges and a change in the EEG pattern to low voltage, fast frequency activity. The alteration was a generalized one, appearing over the entire surface of the cerebral cortex. The changes in the EEG were paralleled behaviorally by heightened alertness.

Subsequent investigation (Delafresnaye, Adrian, Bremer and Jasper, 1954; French, 1960; Jasper, 1960; Jasper, Proctor, Knighton, Noshay and Costello, 1958; Lindsley, 1951, 1952, 1957; Lindsley, Schreiner and Magoun, 1949; Rossi and Zanchetti, 1957) revealed that there are two functional systems in the brain stem. The first consists of the ascending somatic and auditory sensory pathways having discrete representation in the cortex. The second is a diffuse series of ascending relays, coursing from collaterals of the specific fiber tracts into the reticular formation and from the reticular formation upward through the subthalamus and hypothalamus and into the diffuse projection nuclei of the thalamus.

The functions of the ARAS appear to be mainly concerned with alterations in the animal's general level of arousal or activation. This has been shown by the fact that (1) stimulation of the reticular formation in the lower brain stem evokes EEG "activation patterns" which are extremely similar to those recorded in an alert animal; (2) this effect is abolished by a mid-brain lesion destroying the reticular formation but leaving classical sensory pathways intact; and (3) the same lesion produces sleep with typical sleeping EEG tracings. The ARAS is apparently part of a larger system that includes a descending influence on motor activity (French, 1960; Magoun and Rhines, 1946; Rossi and Zanchetti, 1957). This down-stream influence is primarily tonic in nature, regulating postural tone and balance, movement, and the general distribution of inhibitory and facilitatory influences necessary for sensori-motor co-ordination.

Current neurophysiological evidence would thus seem to support the basic notions of Freeman and Robinson. Whereas they talked of the "spread of proprioceptive impulses," today one would speak of generalized cortical arousal via the ARAS due to the increase in proprioceptive stimulation. And yet Meyer (1953), one of the more frequently quoted contemporary theorists on the influence of induced muscle tension upon performance, suggests (p. 210) that "there is little evidence for such widespread effects" as Freeman formulated. "There can be no doubt that proprioceptive input alters the level and distribution of excitation within the motor system, but here the fiber bundles are concentrated into a projection system .... Thus it is probable that any unusual properties of the proprioceptive input are a function of the peculiar position of the proprioceptive projection."

Meyer failed to consider the highly probable involvement of the ascending reticular activating system in induced tension phenomena. From his article, one gains the impression that he may have been seeking to avoid overspeculation by considering only the motor system. However, he does not entirely succeed, since by complete neglect of the important literature on the neurophysiology of the reticular system Meyer is forced to fall back on assumptions that are not supported by experimental evidence. For instance, his assumption that "distributed excitation from the hand channel fires more extensor than flexor neurones" (1953, p. 209) is, as far as I am aware, completely undocumented.

Malmo (1959, p. 370) has implicated the reticular activating system in the generalized behavioral phenomena associated with induced muscle tension. He suggests that induced tension may be one of the many ways in which activation level can be varied, and believes that activation level, in turn, is a function of the reticular activating system. He has also reviewed various lines of evidence bearing on the general proposition that activation level is an important behavioral dimension which can be gauged objectively by means of various physiological indicants. This evidence conclusively shows a high concordance of various physiological indicants with respect to changes in behavioral arousal (e.g., in going from a state of relaxed attentiveness to one of high alertness). An upward shift along the continuum of activation is regularly accompanied by physiological changes such as increased heart rate, respiration rate, blood pressure, palmar sweating, skeletal muscle tension, as well as by measureable changes in the EEG. Conversely, a downward shift is accompanied by opposite changes.

Now it follows that if induced tension is a reliable means of varying activation level, then in addition to the behavioral effects, induced tension should also produce regular and consistent changes in the various physiological indicants of activation. Experiments by Freeman and Simpson (1938) encourage this idea. They have shown that palmar conductance does indeed rise as a function of muscle tension induced in the legs, and Freeman (1938, 1940) has shown that palmar resistance changes linearly with muscle tension during performance.

These experiments, however encouraging, are insufficient to establish the general relation between induced tension and activation, limited as they are to the one physiological measure of palmar conductance. The need for wide coverage of physiological functions in studies of activation has recently been stated by Malmo (1959) and Schnore (1959). The main purpose of the experiment to be reported was the exploration of what is a relatively unexplored field, the relation between induced tension and activation.

Method

Subjects

A total of 38 McGill University undergraduate and graduate males, ranging in age from 18 to 30, served as Ss. An additional 15 Ss were used in pilot studies. All Ss were paid $5.00 for the three-hour session. Only right-handed subjects with normal hearing were used. In order to insure uniformity of conditions from S to S, all Ss in this experiment were used only after they had served in a previous auditory tracking experiment in which various physiological recordings were taken. Although tracking in the previous experiment was performed with the right hand instead of with the right foot as in the present experiment, there appeared to be a considerable amount of positive transfer from one situation to the other. However, all Ss required some further learning in order to master the foot tracking.

Apparatus[1]

Muscle Tension Induction System. Figure 2 is a photograph of the strain gauge dynamometer used for inducing tension. "A" is the handle of the dynamometer gripped by the subject, and "B" is a curved length of spring steel upon which two strain gauges, "C," are mounted. When the steel of the dynamometer is compressed, the wire in the strain gauges is deformed. This results in a change of the electrical resistance of the wire in the strain gauge that is proportional to the strain or the grip on the dynamometer. Each strain gauge was an arm of a balanced Wheatstone bridge. Changes in the resistance of either or both of the strain gauges upset the electrical balance of the bridge. The change in signal due to this imbalance was fed into a push-pull, strain gauge amplifier.

Part of the amplified signal was used to continuously monitor and permanently record the S's instantaneous performance, and part was fed back to the S to enable him to maintain his level of pull within prescribed limits. These limits were set by an a-c microammeter relay equipped with two movable contacts. Both contacts could be positioned anywhere on the meter face and their relative positions could also be varied. By calibrating the meter deflection in kilograms, and using each of the meter-relay contacts as a switch to an audio oscillator, "low" and "high" tension limits could be determined. When the S did not squeeze the dynamometer sufficiently hard, he heard a 600-cycle tone via one contact, while if he squeezed too hard he heard an 800 cycle tone via the other contact. The desired pressure was obtained when S gripped the dynamometer such that he heard no tone at all.

Auditory Tracking System. This system was similar to that described by Davis, Stennett, and Quilter (1957), except that tracking was done with the right foot instead of with the hand. In addition, the function generator used in this system consisted of a potentiometer bridge circuit whose imbalance signified error in direction and intensity. The S, who was blindfolded for purposes of EEG recording, sat in a semi-reclining chair and performed a simple tracking task in the following manner. He first depressed the foot pedal until it came against a mechanical stop after a movement of eight degrees of arc (see Figure 3). He next allowed the pedal to return to its normal position at the same rate at which the pedal was depressed. If the rate of pedal movement down and up was in exact conformance with that of the function generator, the subject was "on target" and he heard no sound in his earphones. Failure to keep pace with the function generator was signaled to the S by means of a 1000 cps tone in his earphones. The loudness of this tone varied as a function of the S's "distance off target," and direction of error was cued by whether the tone appeared in the right or the left earphone. "Down" errors (i.e., pressing down on the pedal at too fast a rate or lagging behind on the way up) were indicated by the tone appearing in the earphone on the right; conversely, "up" errors were indicated by the tone appearing in the earphone on the left.

The number of up and down errors made per trial and the total distance the subject was off target (DOT) were the measures of performance. Each trial consisted of two complete cycles of the tracking pedal being depressed and released. This required 96 seconds; 96 seconds' rest was also given between each trial. Number of errors were recorded on two electrical impulse counters, and DOT was recorded graphically by means of an electronic integrator with a four-second discharge rate (Davis, 1956, 1959). This latter system was calibrated such that a certain distance off target in degrees produced a given deflection on the ink writer, which was then measured with special scales.

Physiological Recording Apparatus. Three chart drives with ink-writing galvanometers were used for recording physiological tracings and error data. The primary record for electromyograms (EMG) from active and passive muscles, two EEG measures, and the heart rate (EKG), were recorded on a standard Grass IV A electroencephalograph (paper speed 25 mm/sec.). Signals taken from the output of the driver stages of the Grass were led into electronic integrators which summated the muscle potentials over successive four-second periods, and were recorded as deflections on a second chart drive. The EEG was quantified by passing these signals through band-pass filters (Ross and Davis, 1958) with cut-offs to provide bands of 8-12 cycles per second and 18-27 cycles per second. Outputs of the filters were also integrated and recorded on chart drive two (paper speed: 1 mm/sec.).

Chart drive three (paper speed: 2.5 mm/sec.) was used to record respiration (obtained with a Phipps and Bird pneumograph and recording tambour), palmar conductance, DOT, and the output of the strain gauge amplifier. A flow chart of the instrumentation arrangement is shown in Figure 4.

Recording Electrodes. All electrodes except those used for palmar conductance were made of cellulose sponge of one cubic inch. Each had been dipped in normal saline and electrode jelly and attached to the skin of the subject by means of elastic lastonet bands or elastoplast tape. Heart rate was recorded from electrodes placed on the chest wall immediately below the heart, and on the right shoulder.

Electrodes for EMG recording were placed on the extensor muscles of the right and left forearms and the calves of the right and left legs in accordance with Davis' Manual of Surface Electromyography (1959). Two bipolar EEG leads were taken from the nondominant hemisphere from frontal and occipital positions equivalent to placements C2-F2 and P2-02 of the 10/20 system used at the Montreal Neurological Institute (Jasper, 1941).

Palmar conductance (PC) was recorded from the left palm by means of a monopolar method described by Malmo and Davis (1959). Three silver, silver-chloride electrodes were employed: one in the palm and two parallel reference electrodes on the ventral surface of the left forearm.

Other Apparatus. The S's chair and tracking apparatus (shown in Figure 3) were located in a separate room from that of the amplifying and recording devices. It was a relatively soundproof room, entirely shielded with copper screening to reduce electrical interference, and was supplied with an air conditioning plant for the maintenance of constant temperature. Separating the S's room from the experimenter's control room, was a double wall with a screened observation window. Junction boxes and cables provided connection between the S's electrodes and the instrumentation in the control room. A two-way intercommunication system was employed for instructing the Ss and answering questions.

Line voltage for critical instruments such as d-c amplifiers, integrators, and the electroencephalograph, was regulated with a Sorenson Model 3000S regulator. The temperature in the control room was maintained at about 72 degrees Fahrenheit to prevent voltage drifts from excessive heat.

Procedure

All instructions pertaining directly to the experiment were read to each S and are given in the Appendix. When a S first arrived, he was informed that the experiment was designed to study the effects of induced muscular tension on his ability to perform a simple psychomotor task, and that the effects of this tension would be determined by simultaneously measuring certain physiological variables and the muscle tension directly. An assistant then prepared the S by placing the electrodes as discussed above.

S was then instructed by the experimenter in the method of inducing tension and in the method of maintaining a given level of tension. Subjective levels of tension were then determined (see Appendix for details).

A headset with independent earphones for tracking was placed on the S's head and adjusted for comfort. S was then instructed by the experimenter in the tracking procedure (see Appendix). One practice trial was followed by the learning trials to criterion. The criterion was the tracking of three successive trials without improvement, but never less than six nor more than ten.

A ten-minute rest period and a glass of water were given between learning and tension trials. No smoking was allowed. During the rest period, all equipment was again checked to conform with calibration standards.

Five tension conditions of Very Light (VL), Light (L), Medium (M), Heavy (H), and Very Heavy (VH) were given once only to each S in an order determined by a table of random numbers. Two control conditions of No Tension and Exertion (EX) were also randomly presented with the tension conditions. The No Tension control did not differ from any of the learning trials. Its purpose was to gauge the effects of performance with no tension. The Exertion condition was introduced in an attempt to determine the effect of induced tension alone (without tracking) on the various physiological measures. This condition required each of eight Ss to squeeze the dynamometer at a pressure equivalent to his Very Heavy pull, and each of 25 Ss to squeeze the dynamometer at a pressure equivalent to his maximum pull. Five subjects did not have an Exertion condition at all. Besides squeezing the dynamometer, in the Exertion condition each S was required to push the foot pedal down and keep it there for the length of the trial. He also heard a tone in both ears equal in intensity to what he would have heard had he been off target two degrees. Physical exertion was thus at a high level. The primary difference between this and other trials was that there was no actual tracking performance. Instructions and detailed procedure for the tension conditions are given in the Appendix.

To increase the rate of learning during the early part of the experiment, Ss were told their score in terms of time off target at the end of each trial. This was not continued during the tension trials, however, in order to prevent associations of a particular score with a given level of tension and consequent excitement or activation if the score were relatively poor.

The mean tolerance allowed for the maintenance of tension was about 1.5 kilograms. In the pilot experiments and the main study, it was found that after a little practice this tolerance was more than sufficient to enable subjects to maintain tension at quite steady levels over an entire trial.

Treatment of Data

EEG. The raw record of the electroencephalogram was recorded on the Grass chart drive. This record was used primarily to monitor artifacts that might appear in the EEG from movement, muscle, or bad electrodes. Signals from the channel on the Grass recording the occipital EEG were led to an 8-12 cycles-per-second band-pass filter; signals from the channel recording the frontal EEG were led to the 18-27 cps band-pass filter. Outputs from these two instruments were integrated with four-second discharge rates and recorded as deflections on chart drive two. During the 96-second trial, 24 of these deflections were recorded, the height of each one representing the summated potentials of the EEG over that four seconds for the frequencies studied. When artifact was present in a particular portion of the raw record, all of the four-second deflections that included these artifacts were eliminated from analysis of the integrated record. Each of the integrated EEG deflections was measured with special scales calibrated in microvolts. The level of EEG activity for a given trial was then defined as the mean voltage of the 24 integrated deflections.

EKG. EKG was obtained by counting the beats in each successive 12-second period and multiplying by five to get the mean number of beats per minute for that 12-second period. The eight values thus calculated were averaged for the mean number of heart beats per minute for the trial.

EMG. The muscle potentials of the two active and two passive limbs were recorded on the Grass for monitoring purposes, and the four-second integrated deflection recorded on chart drive two for measurement. EMG was not as variable within a trial as EEG so that it was satisfactory to sample only eight peaks during a trial. The measured peaks for the right leg coincided with the deflection occurring approximately midway up and down the rises and falls in muscle tension due to tracking (the 3rd, 4th, 9th, 10th, 15th, 16th, 21st, and 22nd deflections were measured). Like the EEG, these deflections were measured with special scales calibrated in microvolts. The level of muscle activity for a trial was then defined as the mean voltage of the eight measured deflections.

Respiration and Palmar Conductance. These measures were recorded on chart drive three and were obtained by taking a reading every 12 seconds. Respiration rate was found by counting the number of complete inspiration-expiration cycles from one 12 second line to the next, correct to the nearest 1/4 cycles. The mean rate for the trial was obtained by multiplying this value by five to get the number of cycles per minute for that period, and then obtaining the mean of the eight values. Palmar resistance was measured at the 12-second line with a special scale calibrated in ohms. This resistance value was converted to its reciprocal, conductance, as recommended by Woodworth and Schlosberg (1954, p. 140). The average conductance value in micromhos for the trial was obtained by calculating the mean of the eight conductance measures.

<u>DOT and Strain Gauge.</u> The integrated deflections of Distance Off Target and the pull on the Strain Gauge Dynamometer were measured in the same way as the EEG. That is, each of the 24 deflections was measured using a special plastic scale, calibrated in degrees for DOT and kilograms for SG. The average of the 24 deflections was taken as the mean DOT or grip pressure for the trial.

<u>Errors.</u> The number of "up" and "down" errors per trial was obtained directly by means of two electromechanical counters.

Results

Figure 5A presents the graph for continuous rise in force as measured by the strain-gauge dynamometer through the graded series of induced tensions. It will be noted that the rise is approximately linear. Parts B and C of Figure 5 show that the effect of induced tension in this experiment was to impair tracking performance, with the higher tensions having a more detrimental effect than the lower ones. A two-way analysis of variance of these data shows that the between-trials variance of errors as measured by Distance Off Target was significant ($p = .05$) for the induced tension conditions.

Figure 6 presents the EMG data. As in the case of the strain-gauge, the curve for muscle tension in the right arm as a function of the amount of tension induced is approximately linear. The other three curves, for muscles not directly involved in pulling on the dynamometer, likewise show incremental changes corresponding to increasing values of induced tension. In Figure 6B the right leg is designated as active because it was used in tracking, but the load on the leg muscle was constant, of course, from one induced tension condition to the next. The two left limbs (Figure 6C and 6D) were not engaged in any activity, which is why they were designated as passive. Despite this passivity, however, their curves show steady rise through the ascending series of induced tension values up to VH (i.e., through the series of tensions that were induced during tracking). Analysis of variance for all four muscles also showed the between-trials variance to be significant ($p < .01$) over the range of tension conditions with tracking.

The drop in the left arm in tension from the VH condition during tracking to the EX condition (no tracking) should be especially noted in Figure 6C. The drop was significant ($p < .01$). It will be recalled that 33 of the 38 Ss were included in the EX condition. Twenty-five of these Ss pulled on the dynamometer their maximum amount during this trial, while eight Ss gripped with the same pressure as they used on the Very Heavy condition. With this amount of exertion, the right leg EMG (Figure 6B) showed a significant rise from VH to EX (the right leg held the tracking pedal all the way down during this condition, exerting the maximum leg tension for a trial). Yet, the right arm EMG, which was squeezing the dynamometer, shows only a slight and very nonsignificant rise. In fact, 48 per cent of the 33 Ss actually showed a fall in the right arm EMG from the VH tracking condition to the EX non-tracking condition. Seventy-five per cent of the 33 Ss showed a fall in the left arm EMG from VH to EX. The slight rise shown in Figure 6D is not significant, of course. A summary of the percentage of Ss whose measures of activation fell for the EX condition, as compared with the VH tracking condition, is shown in Table 1.

Similar curves for palmar conductance, heart rate, and respiration are presented in Figure 7. It is noteworthy that, except for the fall in palmar conductance from VH to EX in Figure 7A ($p < .05$), there are no reversals in the curves which all show a regular progressive rise through the increasing series of induced tensions. Again, a two-way analysis of variance revealed the between-trials variance of all three measures rose to be significant ($p < .01$) over the range of induced tension. The rise in heart rate from the VH to EX was significant ($p < .01$), while the slight change in respiration was not significant.

Finally, Figure 8 presents the EEG data which again shows remarkable correspondence with the increasing levels of induced tension. The two band-pass filters were obviously operating independently of each other. The large reversal between VH and EX is especially to be noted (i.e., falling 8-12 cps amplitude, significant with $p < .01$, compared with rising 18-27 amplitude almost significant at the .05 level). Again, both measures showed significant between-trials variance over the range of tension conditions by a two-way analysis of variance (8-12 cps, $p = .05$; 18-27 cps, $p < .01$).

Another level of analysis suggested from the induced muscle tension literature is the differences between good and poor performers. Figure 9A shows the Distance Off Target for the learning trials for four groups. The groups were divided on the basis of how many trials were necessary to reach criterion (i.e., three successive trials without significant improvement, but never less than six nor more than ten). On this basis, 11 Ss learned to track to criterion in 6 trials, 13 Ss in 7 trials, 8 Ss in 8 trials, and 6 Ss in 9. Note that the level of performance was related to the trials to criterion in that the three groups of slower learners were also the inferior performers. By comparing the curves of the four groups (Table 2 gives critical ratios and p-values for these comparisons[2]), it was found that none of the three inferior groups were significantly different from each other. On the other hand, the three inferior groups were significantly more degrees off target ($p < .01$) than was the group that reached criterion in six trials. On this basis it appeared justified to combine the three inferior groups or "slow" learners and to compare them with the one superior group or "fast" learners in terms of their overall performance and levels of activation.

Amount of pull on the strain gauge for the two groups is shown in Figure 9C. It will be noted that there was virtually no difference between them, even though the performance differences shown in Figure 9B and 9D are significantly different (see Table 3 for critical ratios and p-values).

Figure 10 shows the corresponding comparison of the two groups on muscle output. In Figure 10A there was very little difference between the two groups when they were not pulling on the dynamometer, that is, during the learning trials. But as soon as tension was induced, the right arm EMG of the superior learners increased significantly above that of the inferior learners. It will be recalled that both groups pulled equally on the strain-gauge dynamometer. The other muscle-group comparisons between the two classes of performers did not show this difference as dramatically, though muscle tension during learning in the right leg (Figure 9B) and during the testtrials in the left arm (Figure 9C) were significantly higher for the superior learners (see Table 4). Interestingly, the direction of this difference was reversed in the left leg (Figure 9D).

Figure 11 compares other physiological measures of the two performance groups. Both palmar conductance and heart rate showed the superior learners significantly lower than inferior learners during learning and tension trials (Table 5). Significance was not quite reached between the mean respiration of the two groups, however, probably because of the extreme variability of the slower learners.

Table 6 and Figure 12 compare the EEG of the two performance groups and again show significantly different levels. In Figure 12A, the slower learners have a significantly higher occipital rhythm over both learning and tension trials. In Figure 12B, depicting the frontal EEG, the superior learners are significantly higher. The extreme rise in the EEG 8-12 of the slow learners in Figure 12A, trials 7, 8, and 9, is due to the decreasing N as trials to criterion were reached: the slower the learner, the higher the EEG 8-12.

Discussion

The physiological data were highly consistent in showing regular and continuous rise in level as a function of increments in tension induced in the right arm during tracking. These increments in induced tension were subjectively perceived as only slight ones. In fact, they were only of the order of one to one-and-one-half kilograms on the average. The uniformly high sensitivity of all these physiological measures to change with induced tension is very remarkable.

Freeman's (1938, 1940) and Freeman and Simpson's (1938) results with palmar conductance were thus confirmed, but the additional data from muscle potentials, respiration, heart rate, and especially EEG considerably extend the possibilities of interpretation. The demonstration of such widespread changes, however, would appear to cast strong doubt on any interpretation limited to the skeletal-motor (or somatic) system. From the previous discussion, it appears that Meyer's (1953) interpretation suffers from this limitation.

Let us thoroughly examine Meyer's paper in terms of the results of this experiment. Meyer's avowed purpose was "to account for the effects of induced muscular tension upon learned and unlearned responses" (1953, p. 204). He considers that a pattern of muscular tension, like a pattern of muscular contraction, is a response. Responses interact if they are modified upon simultaneous elicitation. He considered the most parsimonious assumption to be "that interaction depends upon the convergence of simultaneous patterns of neural impulses" and that this interaction "takes place in the nuclei of the motor system" (p. 205).

Meyer then goes on to develop a theory where the effects of induced muscle tension upon performance are attributed exclusively to the interaction of simultaneous responses. An example of his (pp 208, 209), explaining the increase in the amplitude of the knee jerk with induced muscle tension (Courts, 1939a) will best illustrate this concept. He postulates that, when the patellar tendon is tapped, motor neurons in the cortex that subserve flexor and extensor muscles are excited, more extensor neurons than flexor neurons being activated. When the dynamometer is squeezed, another motor channel is activated in the cortex, its extent of activation being proportional to the force of the grip. "Excitation is distributed to the vicinity of the leg channel, and trips off some of the neurons that are near, but not at threshold when hand activity is absent ... Now, it is apparent from the spatial gradient of representation that the fringe regions adjacent to the leg channel are predominantly extensor in function. Similarly, the closer the cells are to the pathway, the more they are changed by the patellar input. Hence, distributed excitation from the hand channel fires more extensor neurons, and the result is an increase in jerk amplitude. Facilitation increases up to the point where as many flexor as extensor neurons are recruited. An inversion of the function takes place if and when distributed excitation fires the relatively remote pools of neurons that are dominated by flexor cells" (p. 209).

Though the above example referred to the influence of induced tension on unlearned responses, Meyer assumes that the same mechanism operates with learned responses but only insofar as the responses require a motor act. That is, Meyer feels that the effects of induced muscle tension, via the mechanism just discussed, act by altering the magnitude or latency of a response, and therefore cannot have any direct effect upon the formation of a habit (p. 209). "By holding that interference is produced by facilitation of irrelevant responses, it is possible to account for the phenomena observed in complex performance situations with the same theory that handles facilitation of the knee jerk" (p. 210).

As previously indicated, some of Meyer's basic assumptions appear entirely undocumented. But perhaps an even more serious weakness of Meyer's theory lies in the arbitrary restriction of neurophysiological mechanisms suggested to mediate the generalized effects of induced tension. The skeletal-motor system does not operate in a vacuum, but interacts constantly with sensory and tonic mechanisms designed to produce co-ordinated movement, balance, and appropriateness of response. In fact, all cortical loci, and not just those in the sensori-motor cortex, exert an important measure of control over voluntary and reflexive somatic motor function (French, 1958). This is thought to be done through the corticifugal control of the reticular formation which is part of the "descending system" discussed in the Introduction. These connections arise from well circumscribed but widely separated cortical loci in the sensori-motor area, frontal occulomotor eyefields, cingulate gyrus, orbitofrontal surface, superior temporal surfaces and tip, the paraoccipital region, and the entorhinal cortex (French, 1958). Stimulation of these loci initiate electrocortical and behavioral arousal in a normally sleeping animal. The influence of the cerebellum, vestibular apparatus, and the basal ganglia also have their effects on the skeletal-motor system via the descending reticular formation, controlling postural reflexes and movements through its intermediary (French, 1960; Rossi and Zanchetti, 1957).

By virtue of the involvement of almost the entire brain with reticular activity to any sensory event, including proprioception, the most logical postulate would have been to suppose that the entire arousal system enters into the determination of any response associated with muscle activity. This would include the musculature, the heart and blood vascular system, the autonomic nervous system, and certainly the brain itself as reflected in the EEG. The results of this experiment definitely encourage the idea that the proprioceptive return from induced muscular tension produces generalized behavioral and physiological effects through increased activity in the reticular activating system. It therefore appears that Malmo (1959) was correct when he suggested that induced tension is merely one of the many ways in which level of activation could be varied.

The EEG data require some special explanation. Generally, the terms "arousal" and "activation" have been used to refer to desynchronization in the EEG tracing in association with stimulation. This is what Lindsley refers to as "activation pattern" (1951, p. 505), whose elicitation by stimulation in the brain stem reticular formation was first discovered by Moruzzi and Magoun (1949). It is well known, however, that this reaction does not inevitably follow an alerting stimulus. The 8-12 cps component of the human EEG may, in fact, be augmented by an alerting stimulus if the <u>S</u> is sufficiently drowsy.

Stennett (1957) and Bartoshuk (1959) have recently systematically investigated the direction of the 8-12 cps change as a function of the S's prior level of activation or state of alertness, showing it to be an inverted-U function.

In the present experiment Stennett's (1957) practice of obtaining average voltage by means of band-pass filters was employed. This method permitted independent measurement of 8-12 cps EEG amplitude and 18-27 cps EEG amplitude. While the overall change in 8-12 cps EEG might have been expected to occur in the downward direction because of the generally activating effects of induced tension, finding a change in the upward direction was by no means unprecedented. In addition to Stennett's results there are recent (unpublished) findings of Malmo showing a significant overall rise in 8-12 cps amplitude in going from a condition of lower, to one of higher, activation level. Malmo and Surwillo (in press) have also shown that under appropriate conditions an overall fall of 8-12 cps EEG can occur with a rise in activation level.

A note of caution should be injected along with the EEG results and interpretation. Under the best conditions of relaxation, even in the clinical situation, some activity from the frontalis muscle of the forehead or the massiters or neck muscles can be seen in the EEG record. In this experiment great care was taken to instruct Ss in how to relax even while tracking, and especially to be aware of instances when they were clenching their teeth, hunching their shoulders, or frowning. Generally, most Ss were fairly good at relaxing these muscles during performance after some practice. As indicated under the section on treatment of the data, the final approach taken to eliminate muscle was to completely monitor every record, and to remove any deflection that contained obvious muscle in the raw-record corresponding to that deflection. While there is certainly no intention to gloss over the difficulties inherent in eliminating all trace of muscle activity from EEG tracings, it seems nonetheless reasonable to claim elimination of muscle artifacts to a satisfactory extent in these experiments.

The critical reader may also query another point. This concerns factors other than induced muscle tension that may have been responsible for the variation in physiological measures. It is not claimed, of course, that induced tension was the sole determiner of these variations. In fact, the evidence from the EX condition quite clearly suggests an interaction between tension induction and tracking. That is, if induced tension were the sole factor, the points on the curves for the EX condition should be more continuous with the points for the VH condition than they in fact are. I shall return to this matter of interaction presently. Just here, however, it is important to focus on the comparisons between the EX condition and the conditions with little or no induced tension (those designated N, VL, and L in the figures). These comparisons indicate that induced tension even without tracking had an effect upon the physiological measures. It follows, therefore, that anything associated with tracking (e.g. more errors with induced tension) cannot be adduced as the true determiner of the physiological changes in place of induced tension.

As previously mentioned, the evident interaction between tracking and induced tension in determining the physiological reactions, has important theoretical implications. The evidence for this interaction has already been presented (see Table 1 and accompanying text in the Results). These results support the previous contention of Malmo (1959, p. 373) that activation level is invariably determined by an interaction between internal factors (mainly those affecting the "tonic baseline" activity of the ARAS) and external (cue) factors.

Performance *per se* in this experiment was also affected by induced muscle tension but not in the expected direction. If it is assumed that *Ss* were relatively relaxed at the lower levels of muscle tension, then one would expect performance to be enhanced with induced muscle tension. On the contrary, however, there was a decrement in performance, and error scores rose to pre-learning levels.[3]

There are several possible explanations for this finding. The first is that *Ss* were *overactivated* at even the lowest tension level. This would imply that the situation itself was contributing a significant amount to the level of activation, since the performance and physiological measures were not too dissimilar in the no tension and VL tension conditions. (Incidentally, if Meyer's theory were correct, one would have to assume that first flexor and then extensor neurons dominated the response, since each muscle system was probably used equally in tracking down and up with the pedal).

A second possible explanation is that the necessity of squeezing the dynamometer while tracking represented a sufficiently difficult task to require divided attention. Unpublished data by Malmo (personal communication), showing that divided set is sufficient to significantly impair performance, encourage this idea. For this explanation to be adequate, one must suppose that the difficulty associated with maintaining tension increased with tension level. However, comparisons of the strain gauge integrated output reliably showed amount of tension to be constant over the length of a given trial, regardless of the amount of tension that was induced.

A third, and the most likely possibility, is that the increase in errors with induced muscle tension is due to a combination of factors that involves the complex interaction of set, divided attention, activation, and the like. Freeman (1937, 1940) has shown that the relation between performance and induced muscle tension is affected by such factors as these. Bindra (1959) and Malmo (1959) have reported that level of activation also changes with such parameters. The EX data just discussed also support the possibility of a complex interaction between performance, tension, and level of activation.

Several steps must be taken in future experiments in this area to ascertain the specific effects of muscular tension, performance, and the like on level of activation if these complex relationships are to be understood. Limiting the task to be performed to one that does not involve psychomotor behavior might remove a large contributor to the interaction evident in this study. Secondly, a task should be chosen such that behavioral efficiency is definitely enhanced by low levels of muscle tension over a no-tension condition, but hindered by higher levels of induced tension. A memorization type task, such as Courts (1939b) used, would satisfy both these requirements.

Thirdly, appropriate controls should be employed to insure that other factors that might interact to produce activation are either not present or systematically varied (such as level of motivation, set, etc.). Fourthly, an attempt should be made to vary the muscle tension in some way that would not require divided attention on the part of the S. Finally, some technique should be worked out in which Ss can be combined in a meaningful way in terms of the several measures of activation. This might be approached better after weighting the scores in terms of intra-individual variation, than the usual inter-individual methods (as with T-scores, and the like).

The data shown in the final part of the Results section dealing with the different activation patterns of the superior and inferior learners must be interpreted with extreme caution. It is quite tempting, of course, to suggest that within any group the better learners or performers will show low activation patterns with respect to the poorer learners. Another study performed in this laboratory, relating induced muscle tension to level of activation and performance during learning, tends to support this explanation. However, the groups in that study were too small to give sufficient reliability to this conclusion without additional data. Experiments relating activation to rate, type, and level of learning might be suggested as approaches to the study of these phenomena. Better still, perhaps, would be longitudinal investigations where changes in levels of activation with many types of psychological activity are systematically studied in the same S.

Summary

Induced muscle tension (e.g., by squeezing a hand dynamometer) has been demonstrated to have significant effects in relation to a wide range of behavioral phenomena. In some tasks, such as memorization of nonsense syllables for example, behavioral efficiency has been shown to improve, while in others, such as mirror-star tracing, performance has been impaired. From the behavioral evidence, it appeared reasonable to also consider that tension was one of the many ways in which level of activation can be varied. Since performance is improved or impaired depending upon level of activation, it followed that, in addition to behavioral effects, induced muscle tension should produce regular and consistent changes in the various physiological indicants of activation. The main purpose of the experiment reported in this paper was the investigation of such physiological changes with performance and induced muscle tension.

Thirty-eight male college students were trained in an auditory tracking task. Physiological indicants of activation included heart rate, respiration rate, palmar conductance, and electroencephalograms from the scalp over the frontal and occipital cortex, and muscle action potentials which were taken from the active tracking limb, from the right arm in which tension was induced, and from the passive left arm and left leg.

The first six to nine trials consisted of learning to track without induced tension. Each trial was 96 seconds in duration with 96 seconds' rest between trials. Following learning, Ss were required to track seven additional trials, five of which involved the induction of predetermined tension levels ranging from a subjective Very Light to a subjective Very Heavy. Interaction effects were removed by randomizing the presentations. Two control conditions were interspersed with the tension trials, one consisting of tracking without tension, the other physical exertion by squeezing the dynamometer without tracking.

Results clearly showed close agreement between amount of tension induced and the level of skeletal muscle activity, heart rate, respiration rate, palmar conductance, and amplitude of the EEG. These results were considered in support of a theory that the proprioceptive return from induced muscle tension produces generalized behavioral and physiological effects indirectly by increasing activity in the reticular activating system.

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Footnotes

1. Much of the apparatus used in this experiment was designed and built in this laboratory. Detailed specifications and circuit diagrams of the tracking apparatus, the strain gauge tension induction system, the EEG band-pass filters, and the electronic integrators are on file at the Laboratory for Psychological Studies, Allan Memorial Institute, McGill University, Montreal, Canada.

2. Any two functions that are more or less parallel can be considered constant with respect to each other. It can be shown that a test of significance of the difference between these two functions can be carried out by testing the significance of the difference between the regression coefficients of each function (Edwards, 1960). Curvilinear functions can be reduced to linear functions by the method of least squares (Lewis, 1959), and the same operation employed. A simple method for applying this test (Ferguson, G.A., personal communication), is to obtain a mean value for each function by using the data points as the individual scores and then to test the significance of the difference between each mean by usual non-correlated techniques.

3. Dr. Robert Eason (Naval Electronics Laboratory, San Diego, California) recently confirmed these results on a pursuit rotor tracking task (unpublished, personal communication). An inverse relation was found between performance and level of activation as measured by the EMG. He also found in the

same experiment that tension and performance interacted to increase the level of activation. He stated that "tension level is higher when performance is a factor than when it is not, even though the amount of physical work being done is the same."

Table 1

Per Cent of Subjects with Lower Values for Physiological Recordings Under the Exertion Condition than Under the Very Heavy Tracking Condition

S's Pull on EX	N	Right Arm	Right Leg	Left Arm	Left Leg	Palmar Cond.	Heart Rate	Resp.	EEG 18-12	EEG 18-27
Max.	25	48.00	32.00	72.00	40.00	16.00	0.00	56.00	52.00	60.00
VH*	8	50.00	12.50	87.50	62.50	62.50	62.50	75.00	62.50	12.50
Comb.	33	48.48	27.27	75.75	45.45	27.27	15.15	60.60	54.54	48.48

* This VH condition is not to be confused with the VH condition during tracking. These 8 Ss took their Exertion (i.e. no tracking) condition by pulling the same kgm. value on the dynamometer as they had pulled in the VH tracking condition.

Table 2

Critical Ratios for Differences of Curves

of Four Groups of Learners

Trials to Criterion	6	7	8	9
6		3.39**	2.46*	3.17**
7			2.17 NS	0.73 NS
8				2.00 NS

* $p < .05$)
) Two-tailed test
** $p < .01$)

Table 3

Critical Ratios for Differences of Curves for Performance of Slow and Fast Learners During Learning and Induced Tension with Tracking

	DOT		Up Errors		Down Errors		Strain Gauge	
	L*	IT**	L	IT	L	IT	L	IT
Critical Ratio	2.95	2.26	3.43	2.50	5.42	4.31		0.104
p (two tailed)	$< .05$	$< .05$	$< .01$	$< .05$	$< .001$	$< .01$		NS

* Learning trials

** Induced Tension trials

Table 4

Critical Ratios for Differences of Curves for Active and Passive EMG of Slow and Fast Learners During Learning and Induced Tension with Tracking

	Right Arm		Right Leg		Left Arm		Left Leg	
	L*	IT**	L	IT	L	IT	L	IT
Critical Ratio	1.49	5.04	5.31	2.84	1.69	2.36	1.43	2.91
p (two tailed)	NS	$<.001$	$<.001$	$<.05$	NS	$<.05$	NS	$<.05$

* Learning trials

** Induced Tension trials

Table 5

Critical Ratios for Differences of Curves for Autonomic Functions of Slow and Fast Learners During Learning and Induced Tension with Tracking

	Palmar Conductance		Heart Rate		Respiration Rate	
	L*	IT**	L	IT	L	IT
Critical Ratio	11.84	13.74	8.58	5.85	0.45	1.67
p (two tailed)	$<.001$	$<.001$	$<.001$	$<.001$	NS	NS

* Learning Trials

** Induced Tension Trials

Table 6

Critical Ratios for Differences of Curves for Frontal and Occipital EEG of Slow and Fast Learners During Learning and Induced Tension with Tracking

	Occipital EEG 8-12 cps		Frontal EEG 18-27 cps	
	L*	IT**	L	IT
Critical Ratios	7.70	14.34	9.90	11.40
p (two tailed)	.001	.001	.001	.001

* Learning Trials

** Induced Tension Trials

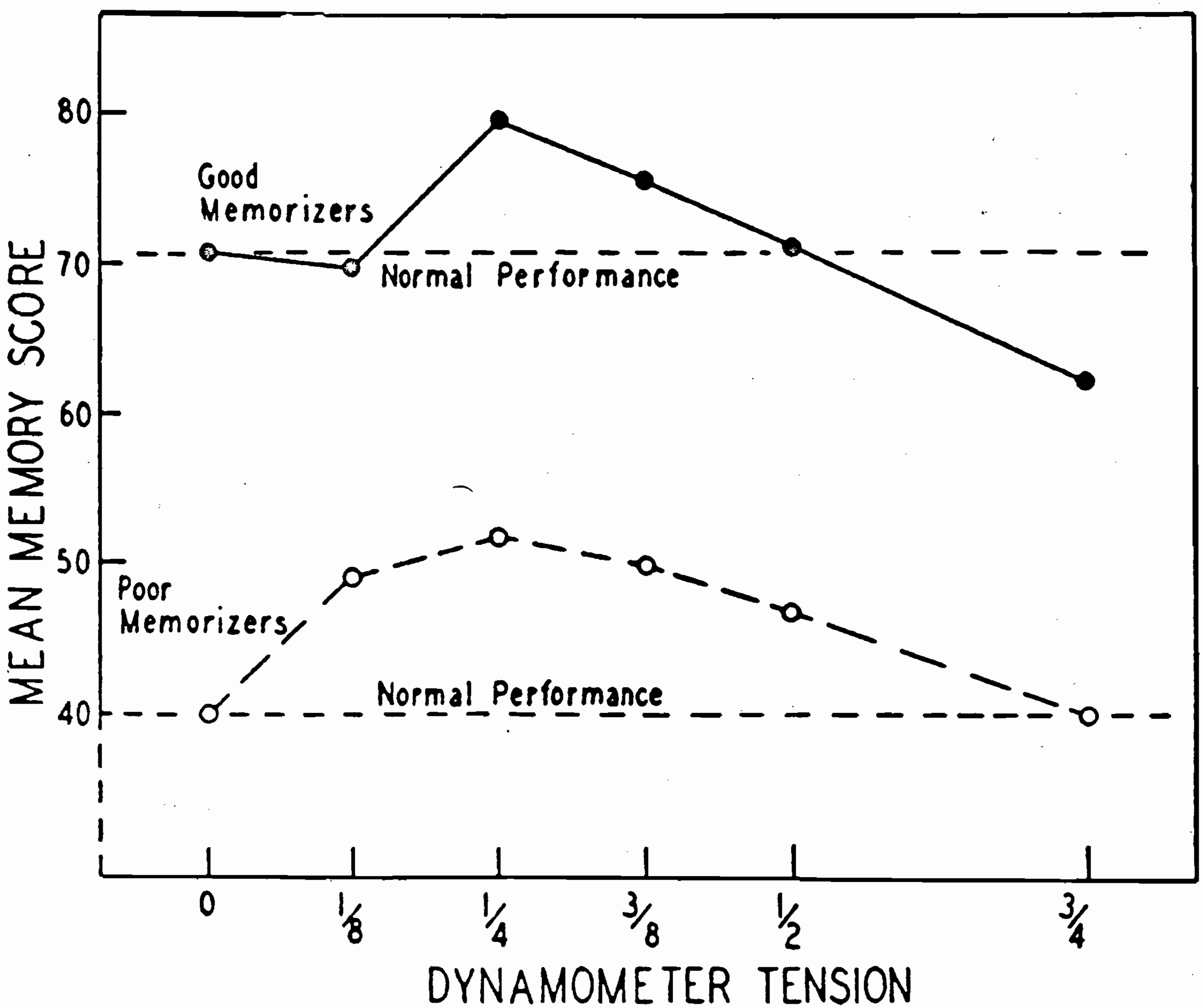

Figure 1. Mean memory score on nonsense syllables for good and poor memorizers under several conditions of induced muscle tension (Courts, 1939b)

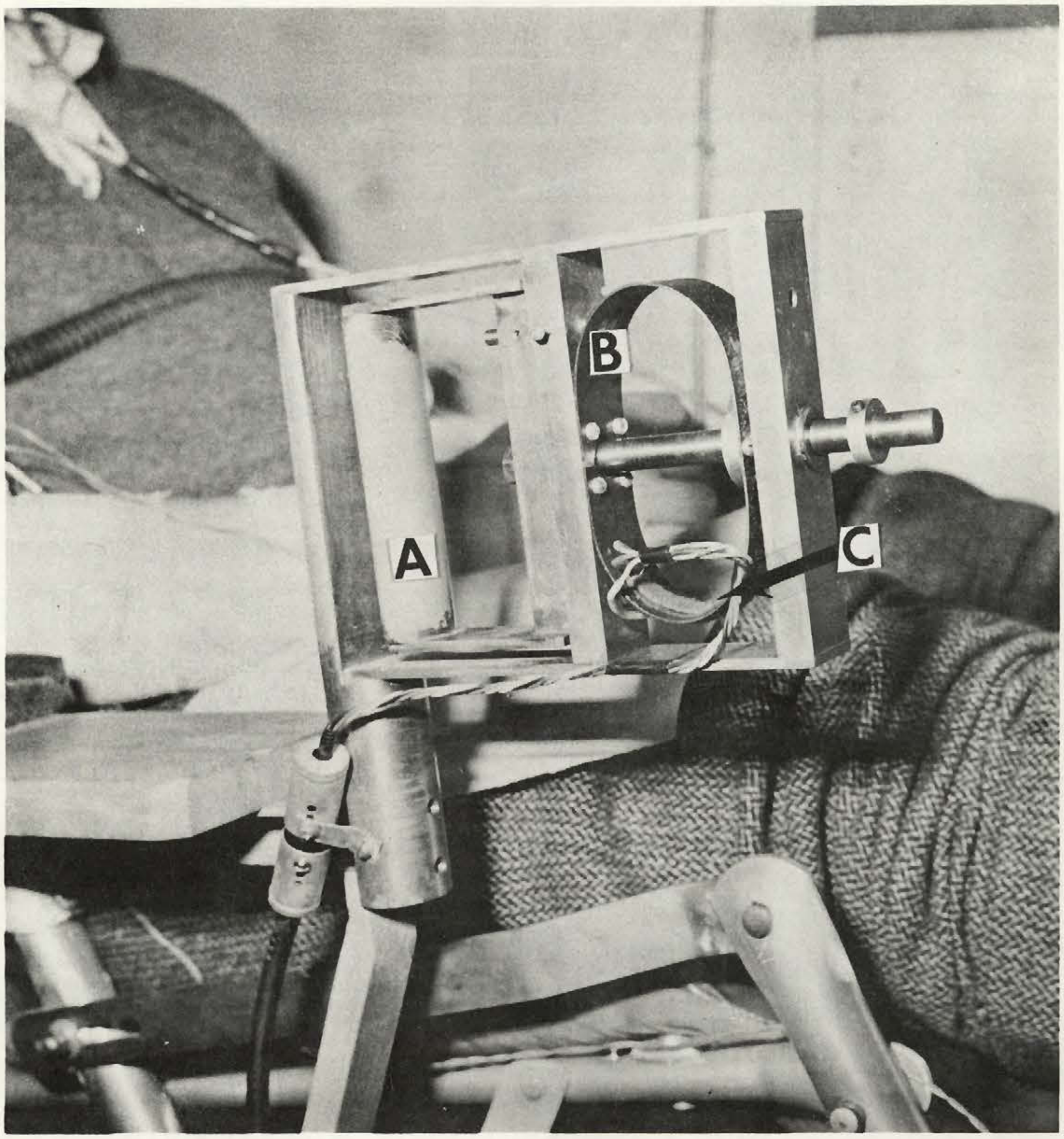

Figure 2. Strain gauge dynamometer for inducing muscle tension.

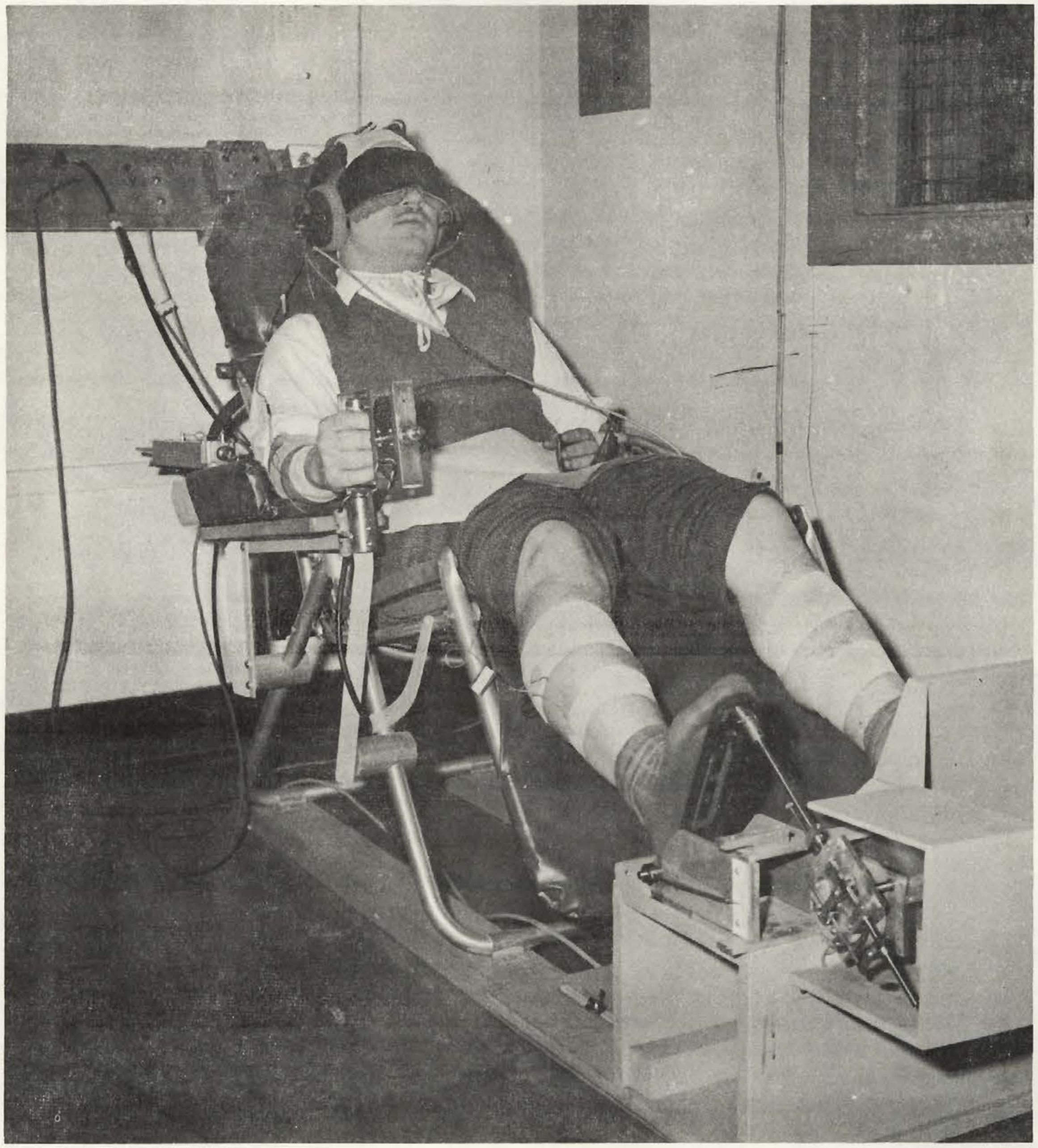

Figure 3. Subject in chair with all electrodes attached, earphones and mask in place, preparing to track with induced muscle tension.

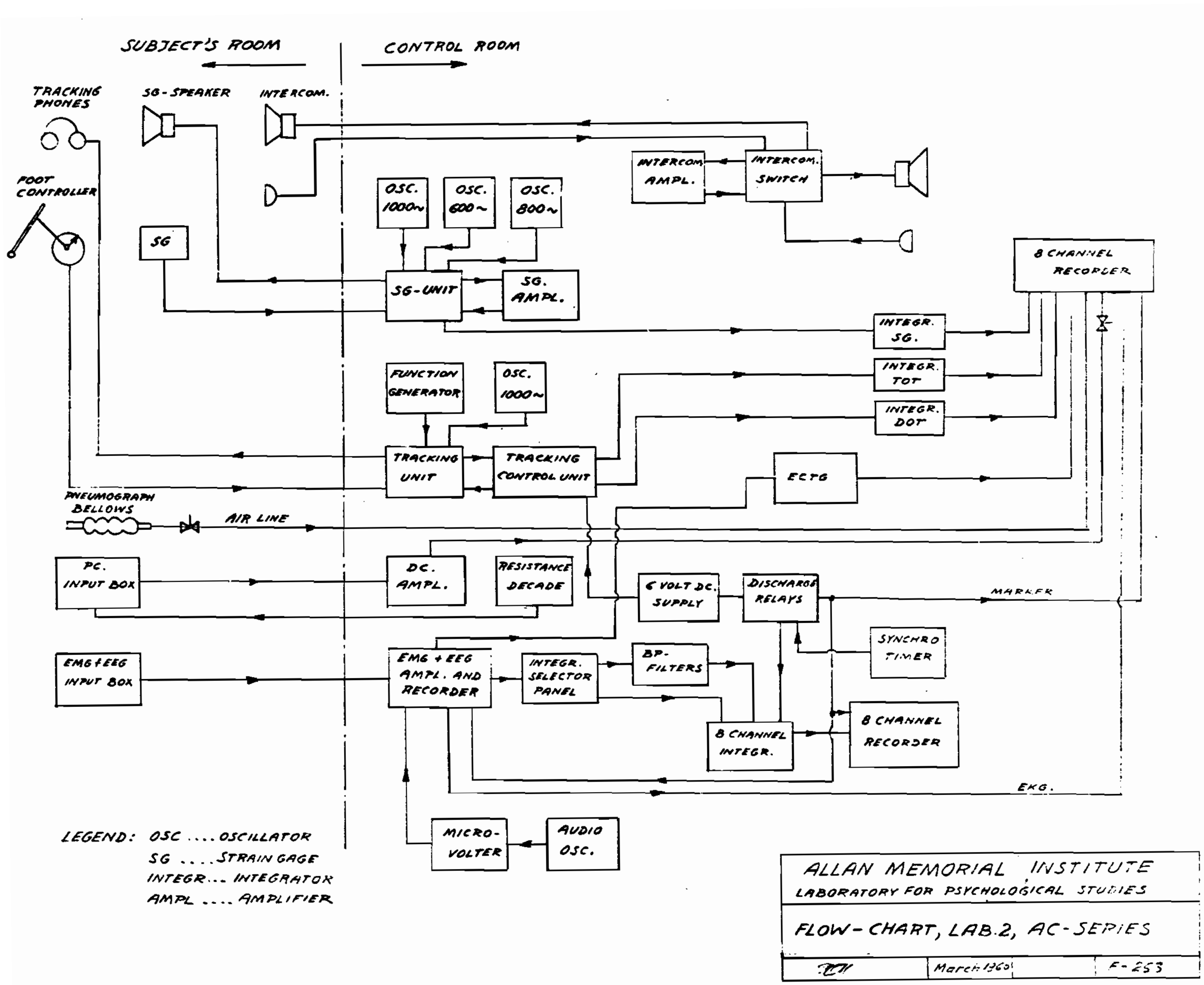

Figure 4. Flow-chart of the instrumentation arrangement used in this experiment.

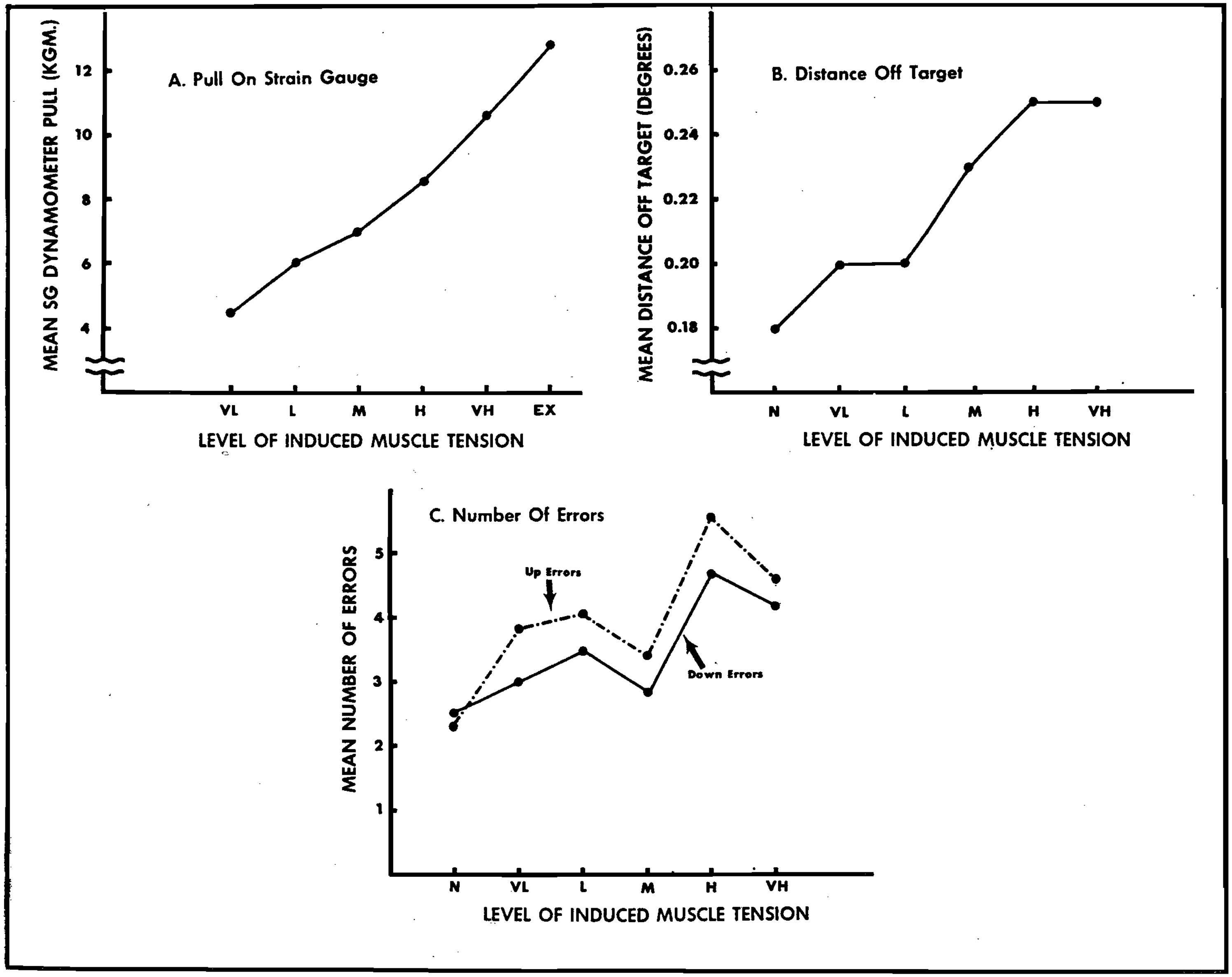

Figure 5. Performance measures as a function of induced muscle tension.

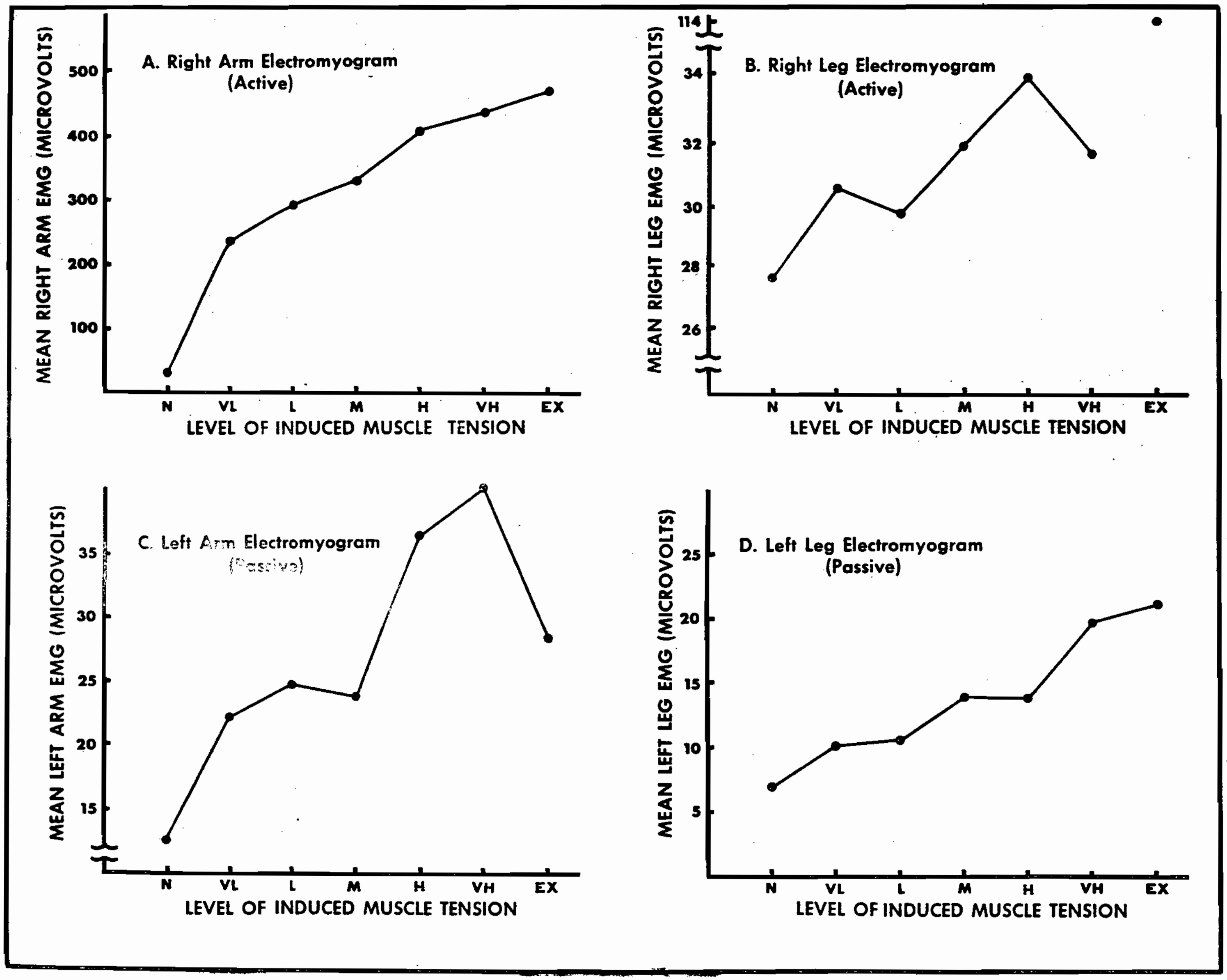

Figure 6. Muscle tension of active and passive limbs as a function of induced muscle tension.

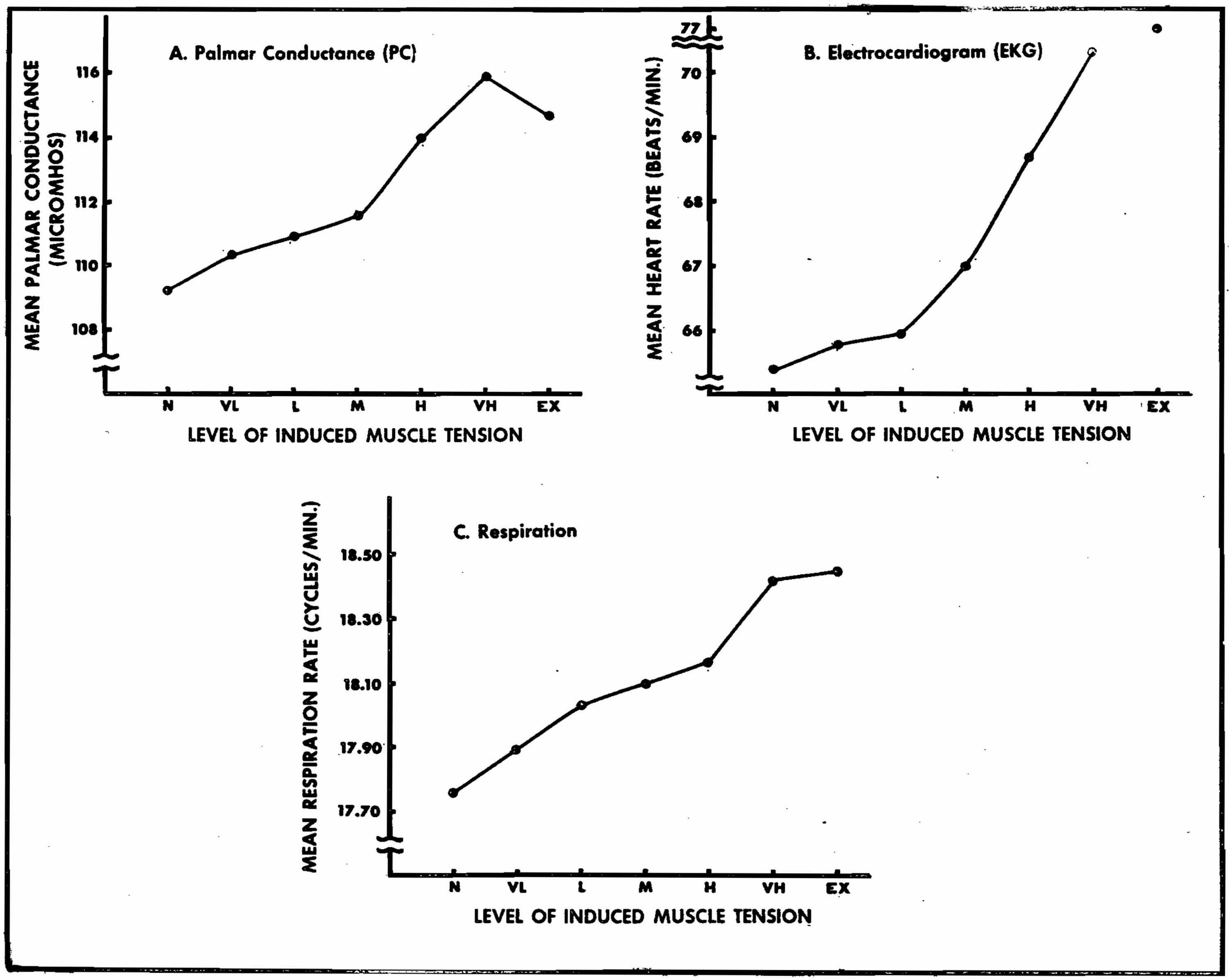

Figure 7. Autonomic nervous system measures as a function of induced muscle tension.

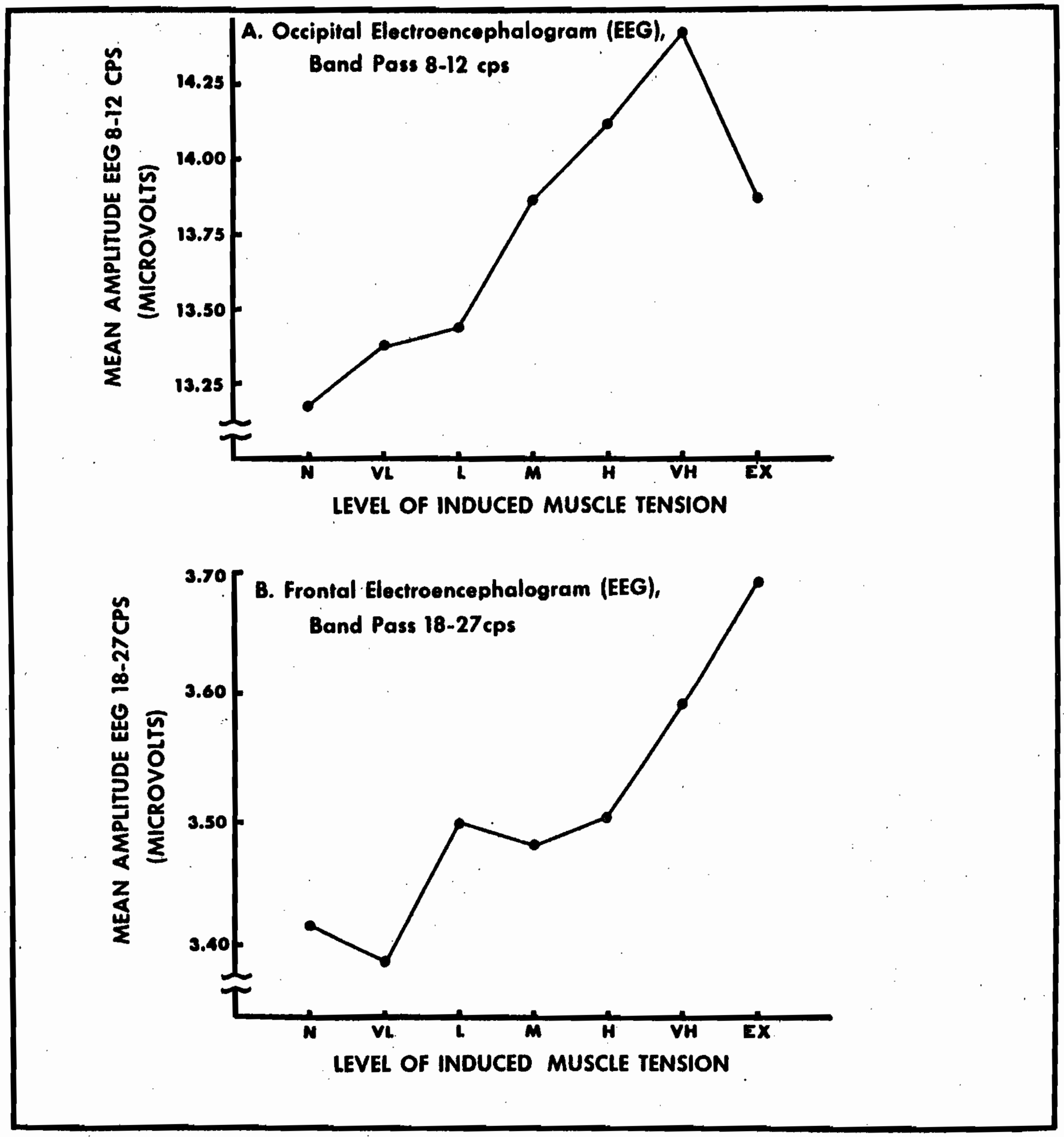

Figure 8. EEG measures as a function of induced muscle tension.

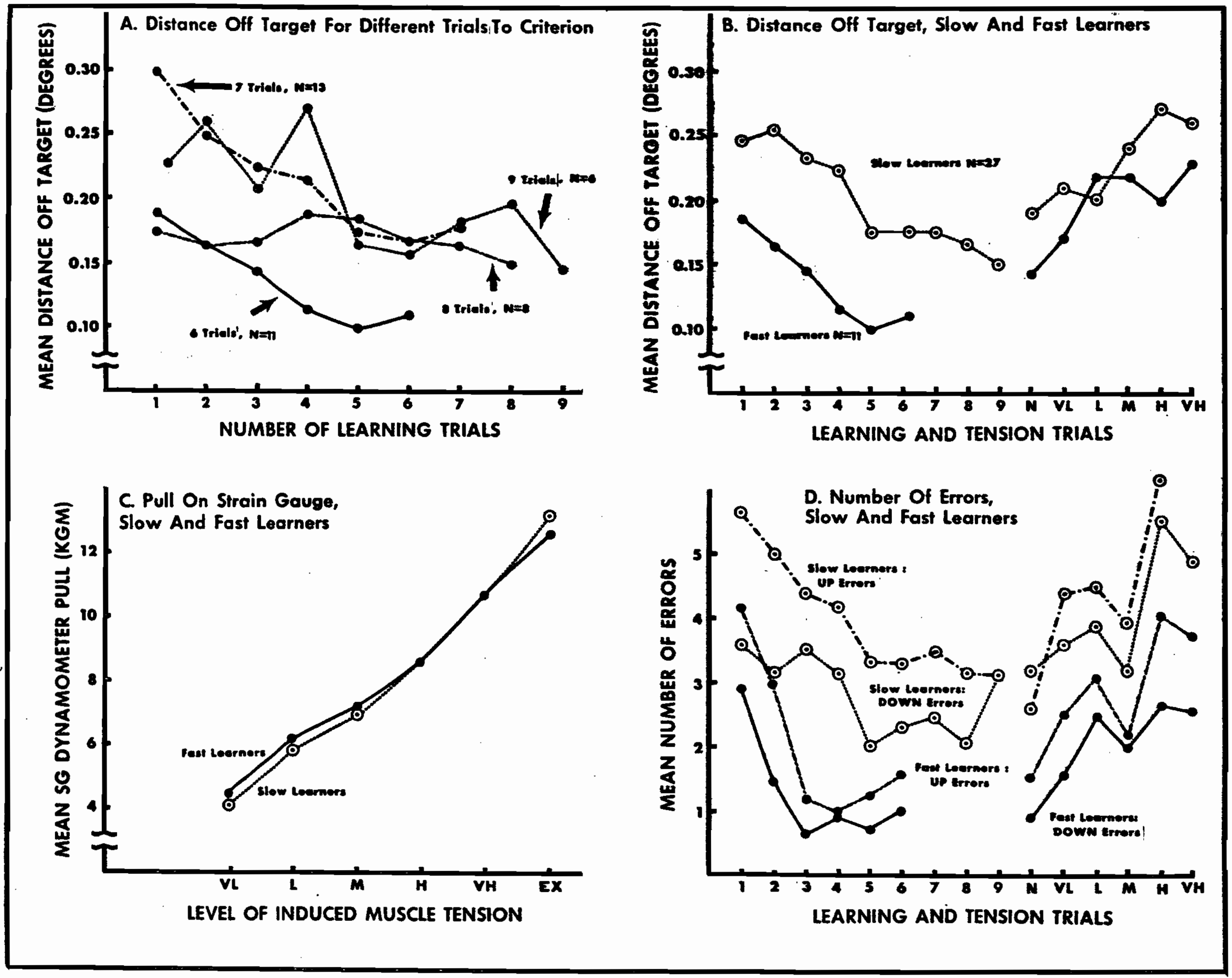

Figure 9. Performance measures as a function of learning and level of performance

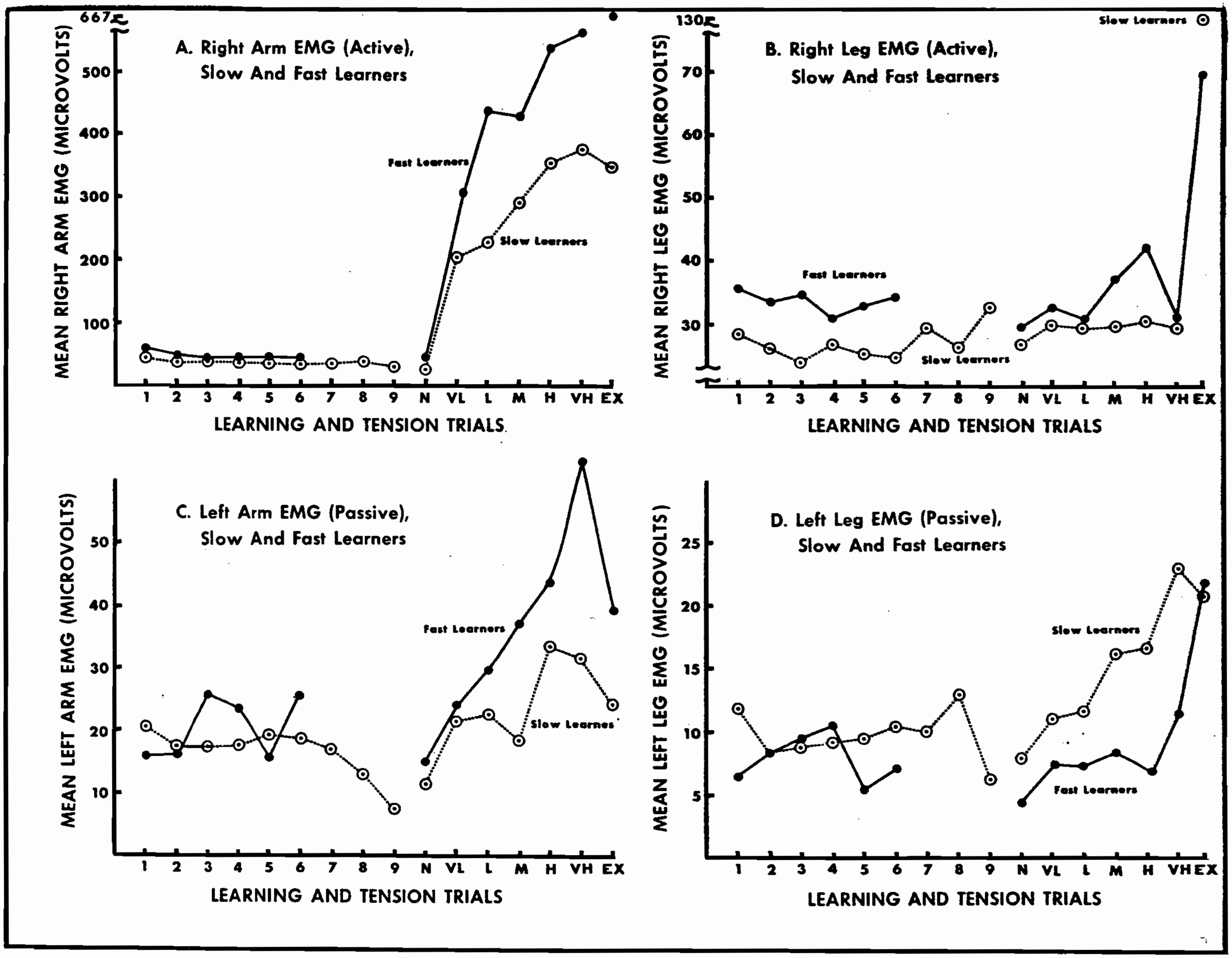

Figure 10. Muscle Tension as a function of learning and level of performance.

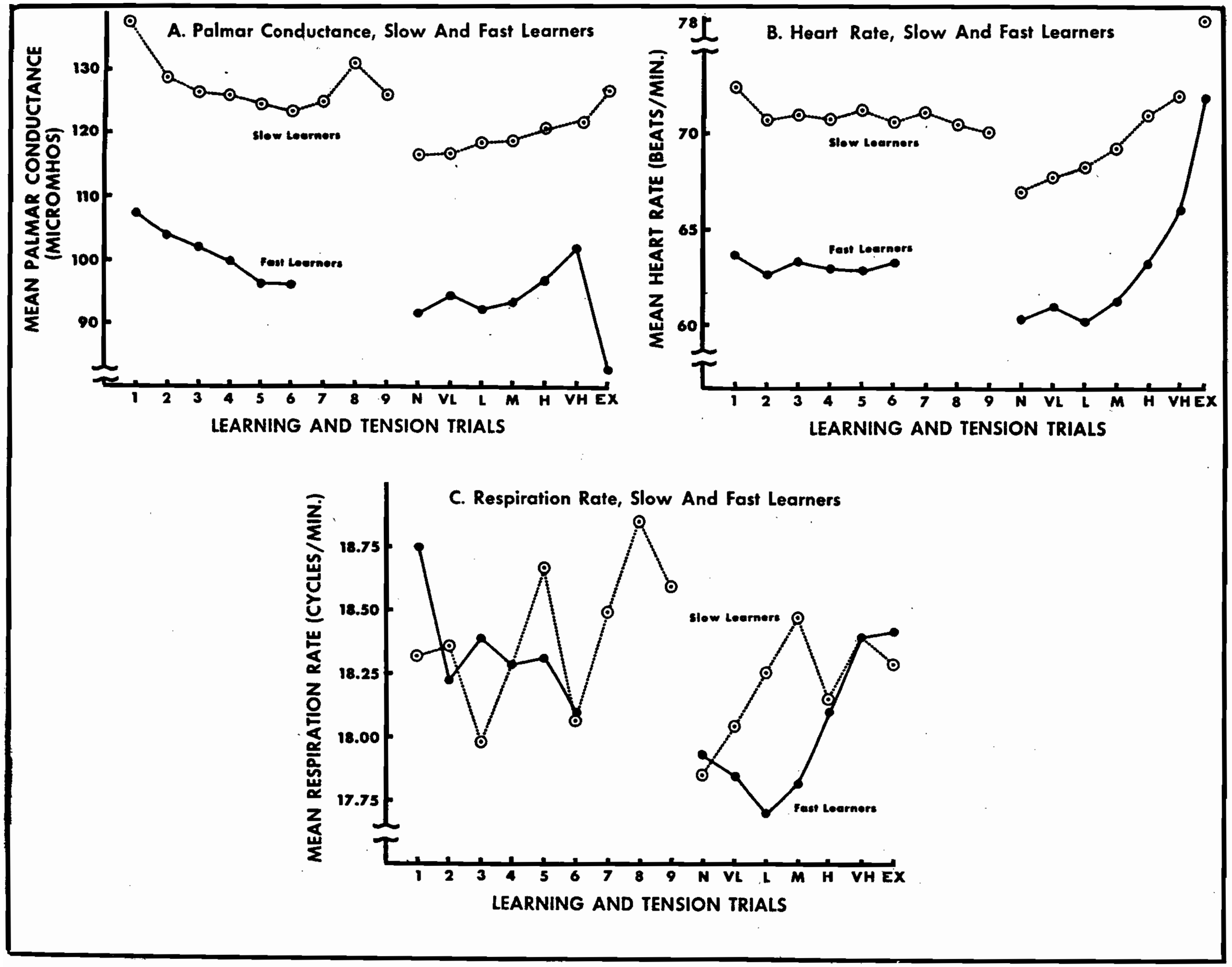

Figure 11. Autonomic nervous system measures as a function of learning and level of performance.

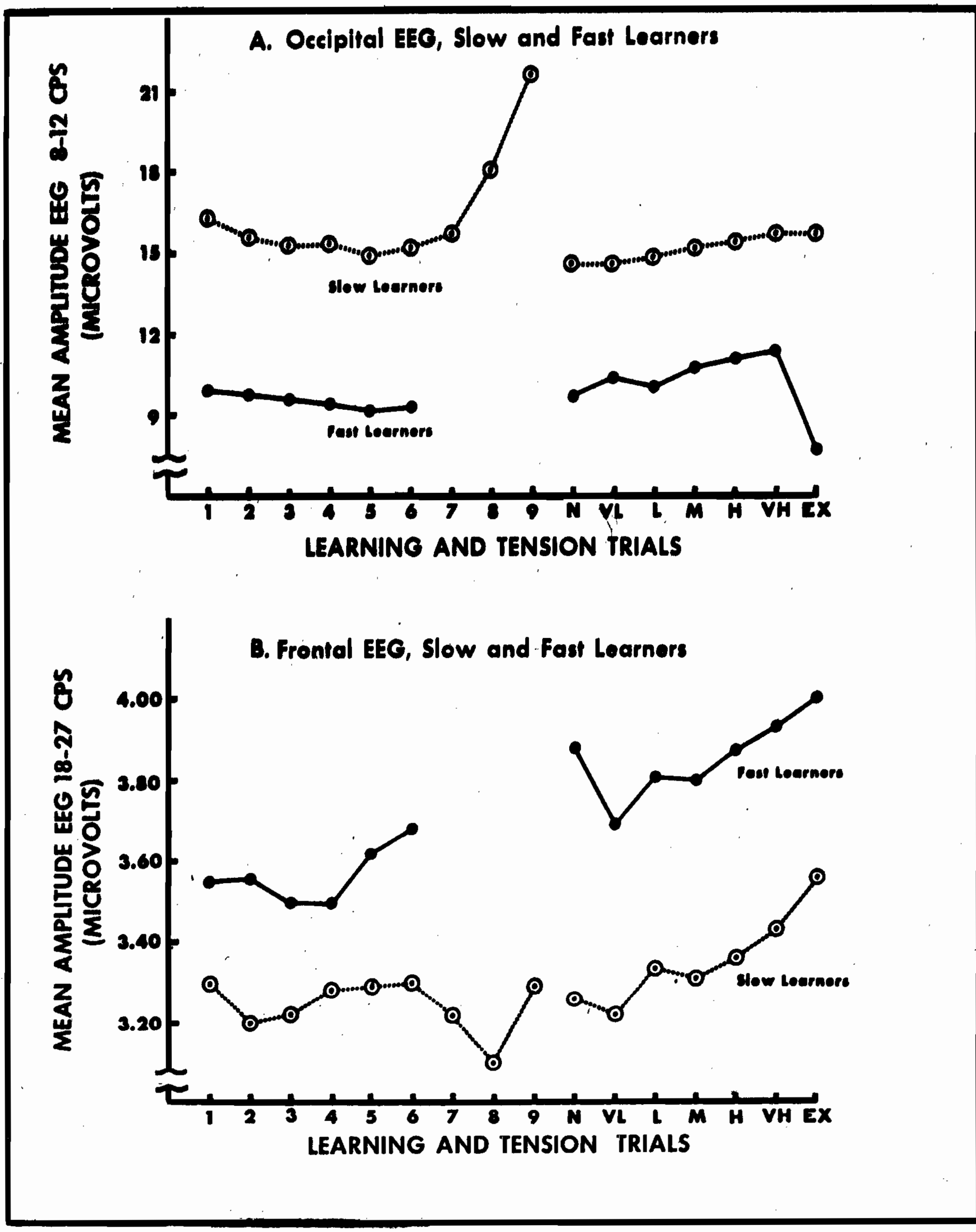

Figure 12. EEG measures as a function of learning and level of performance.

Instructions and Method for Inducing Muscle Tension

"Now, as I said before, we are going to study the effects of muscular tension on your ability to perform a simple task. To induce the muscular tension, we have you squeeze this hand dynamometer. To maintain a given level of tension, we provide you with two tones (the higher 800 cycle tone and the lower 600 cycle tone were demonstrated). When you hear the low tone, it means that you are not squeezing hard enough and must squeeze harder; when you hear the higher tone, it means you are squeezing too hard and must relax your grip a little. Thus, you are to squeeze the dynamometer such that you hear no tone at all."

The S was asked to practice squeezing the dynamometer at about 6 kilograms tension, using the tones to maintain a constant pressure. "Now I am going to establish several of your tension levels that we will use in the experiment with rest periods in between. During the rest periods, you are to try and relax as much as possible, as we will be testing electrodes." The experimenter then showed the subject how to relax all muscle groups, including the neck and frontalis muscles.

The instructions that now follow were given to the subject in order to establish his subjective level of the various tension categories. While he was resting for one to two minutes between dynamometer pulls, all EEG and EMG electrodes were checked for artifact or interference. If any trouble was found, it was repaired at the end of the tension determinations.

"I now want you to squeeze the dynamometer very, very lightly, and hold it until you are instructed to relax, please."

After 30 seconds the reading on the dynamometer meter was noted and the subject told to relax. In one minute, he was asked to do the same thing again. This procedure was repeated for a total of three readings. The mean value was taken as the Very Light condition.

"Now I would like you to squeeze the dynamometer as tightly as you can and hold it until you are told to relax, please."

A reading was again taken after 30 seconds; however, this level was not repeated in order to prevent fatigue. The reading was recorded as Maximum.

After a few minutes' rest, the subject was told: "Now I want you to perform a small task; I want you to squeeze the dynamometer at a pull that seems to you to be half-way between the very light pull you did at first and the maximum pull you did a moment ago. That is, try to bisect that pull and hold it until you are told to relax."

At the end of 30 seconds, a reading was taken on the dynamometer meter. The mean of a total of three such readings was recorded as that subject's Very Heavy condition. This condition is equivalent to Courts' (1939b) 1/2 pull. The three final pulls were made by instructing the subject:

"Now I would like you to further bisect that pull. That is, I want you to squeeze the dynamometer at a pull of what seems to you to be half-way between the very light squeeze and the three you just completed, or -- you might say -- one fourth the pull of the very best you can do. Please hold it again until asked to relax."

The mean of three readings following 30 seconds of pull was recorded as the Medium condition of tension. The Light and Heavy tensions were then arbitrarily chosen as the physical midpoints between the Very Light and Medium, and the Medium and Very Heavy, respectively.

Tracking Instructions

"The task we want you to perform is a simple one. All you are to do is to push this pedal down and let it back up, twice per trial, at a certain rate. To help you determine this rate, we provide you with one of three conditions: either a tone in your right ear, a tone in your left ear, or no tone at all. We call the condition where you hear no tone the target. This target, or point of no tone, moves continuously up and down at a constant rate. It is very similar to what you had with the wheel and your right hand in the other laboratory. If you move your pedal up and down at the same rate, you will never hear the tone. This we call "tracking," or following the target. If, however, you do hear a tone, it means you are not tracking properly. That is, you are not moving the pedal up or down at the same rate the target is moving."

The tracking switch was put on at this point and the function generator allowed to revolve. With the pedal in the up position, as the function generator moved, the S heard the error tone in the left ear, signifying an up error. The experimenter was wearing a duplicate set of earphones for this procedure and, as he explained the relationship of tone and pedal movement, he also manipulated the foot pedal to illustrate the points made.

"If you hear a tone in your left ear, it means that you are making an up error, and you must push the pedal down to correct the error. If, however, you hear a tone in your right ear, it means you are making a down error and must let the pedal up to correct it. The louder the tone, the greater the error; therefore, if you hear a tone and you move the pedal either down or up and the tone gets louder, it means you are moving in the wrong direction.

"Now place your right foot on the pedal, and I will show you what I mean. (The experimenter guided the S's foot through two tracking trials, pointing out certain features as indicated). Note that if the pedal is left all the way up, the tone increases in the left ear as the target moves away. On the other hand, if the pedal is now pushed quickly all the way down, the tone moves into the right ear and decreases as the target approaches the bottom. When the target reaches the bottom and begins up again, the tone in the right ear becomes louder. If, however, you let up on the pedal, the tone decreases, and if you let up at the correct rate (demonstrated) you will not hear the tone at all. Actually, you are given half a degree of pedal movement on each side of zero, or one whole degree where you make no error. This is your tracking tolerance. You may now practice tracking" (two trials).

"Normally you will sit with your right foot here (indicating the resting position) and your right hand relaxed in your lap. When I give you the instruction to 'prepare to track,' you are to put your right foot on the pedal and your right hand on the dynamometer. You are not to squeeze the dynamometer unless told to do so -- just keep your hand relaxed holding the dynamometer. (This procedure of holding the dynamometer relaxed while learning was carried out to control for position effects). In about 8 or 10 seconds I will say 'track when you hear the beep;' about two seconds later you will hear this: (A short beep is produced in the earphones by changing a control switch. When it was moved to a particular position all integrators discharged and a new trial began). At the very end of that beep, the target is at the top of the pedal and just beginning down. Therefore, at the beginning of each trial your pedal must be up. Also, since the target is just starting down, do not be too hasty and push the pedal down rapidly. Wait a moment and push slowly. Many people make the mistake of pushing too hard right at the beginning instead of waiting just a moment, and therefore start each trial with a large error. Another thing some people do is to try to track using some sort of a 'gimmick.' That is, they try to track just a little ahead or behind the tone. You should not do this, because you may be outside your tracking tolerance and will record an error continuously. So, always try to track the target, or the point of no tone.

"As I said before, one trial consists of the target going down and up twice. This takes 96 seconds. When it reaches the top the second time, you will hear the beep again (demonstrated). This means the trial is over and you are to relax; so, at the end of each trial, put your right hand back in your lap and your right foot in the resting position.

"We will run several learning trials first, during which you will not squeeze the dynamometer. Between each trial, you will have a 96 second rest period. Any questions?

"Now I will give you one practice trial tracking. (From the operator's room): This first trial is only a practice trial. Track with your head relaxed against the back of the chair."

At the end of the trial, the S's mask was put on and made comfortable. He was then instructed: "During the trials in which you are learning to track, I will keep you informed of your scores. I will tell you how many up and down errors you made and the total time you have been off target. For example, this practice trial you were off target ... seconds. You made ... down errors, and ... up errors. Once you have learned to track, however, and we are running the test trials, I will not be able to tell you your score."

From the operator's room: "The following trials are the learning trials. Please do not move during these trials except to track. In between trials you may scratch, stretch, or what not, so long as you are careful not to pull any electrodes. At the signal 'prepare to track,' place your right hand on the dynamometer, but do not squeeze, and place your right foot on the pedal. Remember, do not push the pedal down at first, but wait for just a moment. At the end of the trial, take your foot off the pedal and place your right hand in your lap." (These last instructions were to force the S to move both his right arm and leg so that they did not become fatigued from keeping them in the same position).

Between each trial the S was told his score in terms of time off target and the number of up and down errors he had made. He was also advised during the first four trials that he should try to improve his score, though no indication was ever given that his performance was either poor or good.

At the end of the learning trials: "This concludes the learning trials. We will now take a ten-minute rest period." The mask and headset were removed during the rest period and the subject was offered a glass of water. He was not allowed to smoke nor, of course, to leave the tracking chair. Calibrations were made on the equipment during the rest period. Following ten minutes, the mask and headset were replaced.

Instructions For Tension Trials

"The following trials are with tension. Now you will have to squeeze the dynamometer while you are tracking. For these trials, when I say 'prepare to track,' you will hear the dynamometer tone; you will have about 6 to 8 seconds to squeeze the dynamometer until you hear no sound. Hold the dynamometer in that position throughout the tracking trial. During a given trial, the tension will remain the same, but it will vary from trial to trial. At the end of each trial, put your right hand in your lap and take your foot off the pedal. The first two trials with tension will be practice trials only." (For practice, either the Heavy or Light tension was given since neither of these had been experienced before by the S. The other level was given in the second practice trial. This also served to give the subject experience of two different tensions in succession).

After the first practice trial: "The next practice trial will be with a different tension level from the last."

Following the practice trials: "The following trials will be the test trials with different levels of tension. You will not be told your score these trials. Do you have any questions before we start?"

The trials were then given in an order predetermined by a table of random numbers, as noted in the text. Before the No Tension condition, the Ss were told: "This trial I want you to hold your hand on the dynamometer just as you did during the learning trials. That is, do not squeeze the dynamometer."

Before the Exertion condition, Ss were told: "This trial when I say 'prepare to track' I want you to put your foot on the pedal and adjust the dynamometer for no tone, as usual. However, when the beep comes on to begin tracking, instead of tracking you are to hold the foot pedal down to the stop. And, of course, you must maintain the dynamometer tension. During the trial you will hear a steady tone in both ears; when the tone ceases, the trial is over and you may relax. Do you understand?"

If any other trials occurred after the No Tension or Exertion condition (that is, any regular tension trials), the Ss were told before the trial: "During the next trial you are to squeeze the dynamometer again while tracking, as usual."

At the end of the tension trials, the Ss were informed: "This concludes the experiment. We will now take off your electrodes. Before we do, however, we must check your PC resistance again; so please do not move until this test is complete. Also, please do not try to help us remove the electrodes; we can get them off easier and quicker if you just remain still and let us do the work. The mask and headset will now be removed. Do not open your eyes for a few moments because the room will seem quite bright."

After the electrodes were removed and the S's skin under the electrodes was cleaned with alcohol, he was paid and allowed to go.