Changes in Muscular Tension in Learning

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CHANGES IN MUSCULAR TENSION IN LEARNING

A Thesis
Presented in Candidacy
for the Degree of
Doctor of Philosophy

by

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Grand Forks
The University of North Dakota
August, 1939

This Thesis, presented by Walter John Swensen, as a partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of North Dakota, is hereby approved by the Committee under whom he has carried on his work.

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ACKNOWLEDGMENTS

Our contributions are seldom, if ever, entirely the results of our own efforts. The writer feels very humble when he considers just how much his instructors, fellow students and friends have actually contributed toward this study. Especially is he grateful to Dr. C. W. Telford for his friendly guidance, encouragement and many helpful suggestions. His sincere appreciation is also extended to Dean Breitwieser for his presentation of psychology as a living and practical science. He is also grateful to Dean Towne, Dr. Hagan, Dr. Cooke and Dr. Talbert who have assisted him so willingly in his preparation for this degree.

Last, but not least, the writer desires to thank those students and fellow workers who acted as subjects through the eight years of this study.

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CHAPTER 1

INTRODUCTION

"Whenever a person says he used his 'brain' or asserts that his 'head' is tired, he implies a theory of mental life which finds little support in current research. Ever since it received official notice in the writings of Gall and Spurzheim, this alleged mental organ has been overworked in the explanation of behaviour." This is the opinion of Dr. Freeman in 1938. (1) We have been very reluctant to scrap our explanations of human behaviour in terms of the independent organs of the body, despite the fact that writers in psychology for the past two decades have considered human behaviour a function of the entire organism.

Methods of instruction in education have seen vast improvements, but some of our teachers still cling to the idea that thinking is solely the function of the brain and the remaining organism serves no facilitating function in this respect. Most teachers have had the general idea that the child should sit erect while studying, but only because they felt, in a vague sort of way, that this posture was the proper one for the class room. The practice may have been handed down by the old school of mental discipline which contributed the pronunciamento that a subject should be accompanied by a feeling of distaste or pain, in order to be truly beneficial. It had been noticed by teachers that more and better work could be accomplished in their own preparation and work, when they assumed a more or less erect posture at the desk as compared to a reclining position in an easy chair. It was also observed that whenever a person had been working half heartedly at a problem, that the posture was relaxed and a decision to "get down to work" was accompanied by a tensing of the muscles of the face and body. This was followed by more productive effort and greater results. Studies of animals also reveal that whenever a dog, for example, is faced by a problem, the same obvious tension accompanies the attempted solution. That there was some basis for these general observations is indicated by Bill's finding that increased muscular tension induced by squeezing a dynamometer facilitated mental activity. (1) Therefore, it seemed to the writer, that there might be a positive correlation between tension and the degree or extent of learning, although the belief was based on criteria which were somewhat qualitative in nature.

On the other hand, coaches of tennis as well as those of other sports and teachers of piano, writing and typewriting urge complete relaxation in order to master the skills in their respective fields. Thus we have two apparently divergent views as to the effect of muscular tension on efficiency and indicates the need for experimentation on the general problem.

In reviewing the literature in this field it was evident that the problem studied has been the influence of increased muscular tension on sensory acuity and on learning. As early as 1899 we find Breese (2) experimenting with tension and retinal rivalry. His procedure was to increase the muscular tension of the subjects by having them press their arms tightly against their sides and look at an object. He found that the increased tension in the arms increased the acuity of the retina of the eye.

In 1912 Jacobson (17) performed a series of experiments on the effects of tensions on distractions. He attempted to neutralize distracting tendencies by increasing muscular tension. His results showed that an increase in tension resulted in an increase in the auditory acuity. Conversely, a decrease in tension reduced the apparent strength of the sensation.

In 1925 Miller (21) found electrical shock to be less severe when accompanied by a relaxation of the involved muscles. Buford Johnson (19) performed a series of experiments at Johns Hopkins University in 1927 on the change in muscular tension in coordinated hand movements. She used the tapping board and recorded the tension on the kymograph. As a result of the experiments, she distinguishes four classes of performances with respect to tension:

1. Slight pressure maintained throughout the performance.
2. Initial rise in tension followed by a decrease in tension.
3. Slight pressure in the beginning followed by a gradual rise.
4. Irregular tension, usually high, throughout the entire performance.

A. G. Bills (1) conducted a series of studies at the University of Minnesota in 1926 on the problem - "Is muscular tension an overflow or does it assist or indicate efficiency of learning". During all tests, he had his subjects squeeze a dynamometer in the unused hand. He utilized four different types of performance, the first being the memorization of non-syllables. The results showed that there was a positive correlation between tension and extent of recall. In the second test, that of paired associates, the results again indicated a positive correlation between increased tension and recall. In the third test, that of adding columns of digits, those who performed under tension showed an average superiority of six percent over the control group.

Bills (1) suggests that the increased mental activity under muscular tension may be through nutritive channels. It might consist in the stimulation of the vital processes through blood supply, glandular secretions etc. On the other hand it might produce its observed effects through neural channels. The sensory-neuro-muscular system is thereby made more active. It is thought that the threshold is possibly lowered to subsequent neural excitation and discharge. Tension may be supplying the activity which sets the latter off. According to Bills, theories of thought favor the inhibiting and facilitating theories. Some think it is irrelevant motor tendencies which are checked or inhibited by the static innervations accompanying strong attention.

In 1932 E. Duffy (4) conducted studies on the relation between muscular tension and quality of performance. The degree of tension correlated -.47 with rate of tapping and -.48 with discrimination reaction. Smoothness of tension correlated .60 with the quality of discrimination and .23 with tapping. The conclusion drawn was that a moderate tension was most advantageous for these performances.

The studies of J. B. Stroud (24) in 1930 showed that in maze learning there is a positive correlation between tension and the difficulty of the task, as measured by errors. He also found that tension increases on easy mazes with each successive trial. There was also a positive correlation between speed and tension. His conclusion is that there is an increase in muscular activity during effortful activity and that these tensions are valuable in activity of the kind involved in learning mazes.

G. L. Freeman has undoubtedly contributed the greatest amount of experimental evidence on the influence of tension in various parts of the human organism in the performance of various purely mental or muscular tasks. One of these studies (6) made in 1932, is entitled "Muscular tension and irritability". The results of this study showed no consistent differences in the amount of tension which accompanied the performance of various tasks of different degrees of difficulty, so long as the subject was unaware of what the difficulty might be. There was, however, consistently greater increases in tension when the subject was notified of the approaching difficulty. The results also showed decreased reaction time under tension. Whenever the tension was localized, there resulted the optimal facilitation in the task to be performed. Finally it was learned that relaxation lengthened the voluntary reaction time, increased the time and decreased the accuracy of discrimination but increased the speed of the non-voluntary reaction.

Further discussions relating to this subject are to be found in "Our muscles and our minds" (8) and "Postural substrate" (10).

Studies in this same field but somewhat more remotely related to the present study are those of Freeman (6), (7), (8), (9). McTeer (20) found that punishment in the form of an electric shock showed a tendency of producing greater tension in the unused hand in the course of a mirror drawing experiment. Ghiselli (14) showed that during the learning of a skill which requires constant application on the part of the subject, the tension remained quite constant. Once the skill was acquired, however, the tension decreased markedly.

In some of the preceding studies, tension was controlled by the squeezing of a dynamometer in the unused hand of the subject. In these instances, the quality of the performance of the task was correlated with the tension exerted on the dynamometer. In other words, in each case, there were varying amounts of additional tension added to that already present in the muscles. In the studies by Stroud (24) a spring stylus was used in maze tracing while Freeman used a pneumatic bag, held in the mouth of the subject.

To summarize, briefly, we find that the studies on the past reveal a positive correlation between tension, either present or imposed, and the quality of performance in mechanical tasks. In such skills as the addition of columns of digits, an increase in muscular tension is accompanied by improved results. Sensory acuity is also improved by an increase in tension as imposed either by the squeezing of the dynamometer or straining with the feet against spring balances.

The problem of muscular tension is one which the educator must face in the class room, shop, and in sports. The role that these tensions play and whether we should attempt to decrease, eliminate or control these tensions in the learning process was a matter which only scientific study could determine. Therefore, in order to better understand the changes in tension and their relation to mental or physical activity, it was decided to make a study of the changes in muscular tension which occur during a typical sensori-motor learning process. In the present study we have measured the changes in muscular tension throughout the entire learning process, while previous studies were concerned with either single or a few performances. These earlier studies have dealt largely with the measurement of improvements in quality and skill with the application of artificial tension, whereas in the present one the subject was left freer to vary tension as he saw fit. Mirror drawing was selected as the learning problem to be studied and the tension measured was that exerted by the subject on the stylus while making the drawing.

CHAPTER 2

APPARATUS

The apparatus used in the principal part of this investigation was developed as the result of considerable earlier preliminary experimentation by the writer. Since the object was to study muscular changes in the learning process, it was necessary to employ some activity not familiar to the subject and still within the limits of the laboratory situation. After some investigation, it was found that most students and adults were naive in the mirror drawing experiment. After preliminary work with members of a class in experimental psychology, it appeared that a tracing pattern consisting of a path, varying from one quarter to one half inch between the lines, with curved and straight sections, changing directions several times and terminating near the starting point, would constitute a satisfactory problem for the purpose of the experiment. At the outset, the tracing pattern was reproduced on sheets of paper, a new sheet being used for each trial. The path was divided into quarter inch squares and each square missed was counted an error. This was done in order to facilitate the scoring, especially in the event of excursions from the path. It was discovered, however, that there was some difficulty in objectively determining errors, particularly when the tracing closely approximated the boundary lines of the path. The solution of this difficulty was the use of a pattern cut in metal and insulated at the base with bakelite. The margins of the metal at either side of the path were notched to prevent following the pattern by keeping in contact with either of the sides. This plate was connected in series with a dry cell, stylus and a recorder so that any error, contact with the edges of the path, would close the electrical circuit and record on the kymograph.

The stylus used in tracing the pattern was of the pneumatic type, seven inches in length by one and one half inches in diameter. This was made of a rubber tube, stoppered at both ends by one-hole rubber stoppers, cemented into place. Through the length of the rubber tube ran a quarter inch brass tube, perforated in eight places to admit air from the rubber tube when it was compressed by the subject. At the lower end, the brass tube was plugged by an L shaped tracing end. A hard rubber tube of small bore connected the upper end of the stylus with the tambour. The stylus was marked in two places, one on either side, in the position commonly assumed by the thumb and index finger in writing or tracing. This was done in order to prevent any differences in tension due to different techniques in holding the stylus. The apparatus, shielded from the view of the subject, was arranged on a well lighted table of suitable writing height. The operator and subject were seated at opposite ends of the table. Conditions of temperature and time of day were held relatively constant over the entire period of the experiment for each subject. Knowledge of the purposes and results of the experiment were withheld from the subject until the completion of the learning.

SUBJECTS

The experiments were first started in the psychological laboratory of the University of North Dakota in the summer of 1933, using graduate students as subjects. Subsequently, members of a city school faculty were used. Finally, students of the high school and middle grades were used to ascertain whether any differences existed in the different age groups. While these latter groups were not large to establish statistically reliable differences between them, they do indicate the possibilities of further investigation along this line. In all, thirty-five individuals were used as subjects in this study. Due to extraneous and subjective factors influencing the subjects in such a way as to nullify the reliability of the results, it was necessary to disregard some of the scores in the final computations. Care was always taken to select subjects of average ability, but some of them failed to cooperate throughout the entire one hundred trials. Five lost interest after the completion of less than one half of the runs, reported at very irregular intervals for their trials and made only desultory attempts to reduce errors, making no sincere effort to learn to trace the pattern. One was a neurotic individual who was confined to an institution before the completion of the experiment. Two were afflicted with poor eyesight and two interrupted the experiment by prolonged sickness. Consequently the data used in this study were obtained from twenty-five subjects. The greater part of seven years were devoted to this study.

PROCEDURE

The subject was shown the apparatus. He was told that the experiment involved the learning of a simple act and that it was in no way a test of intelligence. This was done because many of the subjects were rather reluctant to cooperate in any experiment which they thought would yield information concerning their abilities or intelligence. Following the explanation, the proper method of holding the stylus was demonstrated. The importance of uniformity of procedure was explained and emphasized.

Whenever the stylus came in contact with the side of the path, a click would be made by the recorder. Thus knowledge of ones errors served as a stimulus to improvement. At the end of each run, the stylus was placed on the table in order to release the tension and for checking the apparatus for leaks. The recorder and tambour were started at the same point at the beginning of each trial. This was done in order to permit the discovery of any relationship existing between the making of errors and the resulting tension. The elapsed time for the run was recorded on the kymograph in the space included by tension and errors.

In our preliminary experimentation, records were taken of each of the one hundred trials. The amount of work involved in determining time, errors and tension for each trial in a series of one hundred trials, made the continuation of this seem inadvisable. By a careful examination of the tension and error scores, it had been found that there was no decided change of consequence in any of these in any unit of less than five trials. Consequently with the main group of our subjects we followed the practice of taking kymographic records and making our detailed analysis of every fifth trial.

The kymograph and recorder were kept in operation during each run, whether "practice" or "record" in order to avoid any change in the conditions under which the subject was working. Three records, fifteen trials in all, were taken at each sitting each day. This procedure was continued until one hundred trials had been taken. The number of trials was set at one hundred because it had been found that most of the subjects showed very little improvement after about eighty runs. The additional twenty runs were given to insure complete learning and to take care of any cases in which the learning process consumed more time. The reduction of the number of errors to a low point, usually from three to ten errors, although one subject completed the circuit without any errors, was taken as the principal criterion of learning. The tension record was measured in millimeters, above the base line, separate measurements being made at quarter inch intervals.

Following the one hundredth trial and at the same sitting, an additional hour was spent in making tracings to discover any influence of fatigue on tension and errors. It had previously been found that most subjects were thoroughly fatigued in that time. In addition, several times during the final stages of the learning process, the subject was urged to make a perfect record, the admonition being - "Try hard to make a perfect record", or "Let's see if you can beat all of your former records". At other times, speed was urged. Notes were kept of all of these urgings, together with the tracings. Note was also made of any differences in the emotional, mental or physical states of the subject. Reference will be made to these in a later chapter.

With this experimental technique, an attempt was made to compare the various factors entering into the learning process with the tension of the muscles in the index finger and the thumb. In addition, the influence of urgings and conscious effort on muscular tension was also noted. Obviously, in an experiment of such length, absolute uniformity of the emotional state could not be secured through all trials by all subjects. Thus some incidental information was secured on the influences of different mental or emotional states on tension. This is, however, another subject which will warrant further investigation.

CHAPTER 3

The first and most evident fact in examining the tension curves of the twenty-five subjects in the experiment in mirror drawing is that all of the curves follow the same general trend. A comparison of the three sample curves (Fig. 3) on page eight will make this clear. With each individual, as will be seen from the curves, the tension at the start of the experiment is quite high - from 80 to 125 mm. - followed by a drop and a slow rise in the curve after approximately twenty-five runs, then a levelling off at the end. The exact point of change in degree of muscular tension varies with the different subjects, but all of them follow the same general course.

Below, (Figs. 1 and 2), we have reproduced the kymographic records of two typical subjects, "M" and "N". The figure at the left side of each record indicates the serial number of the trial.

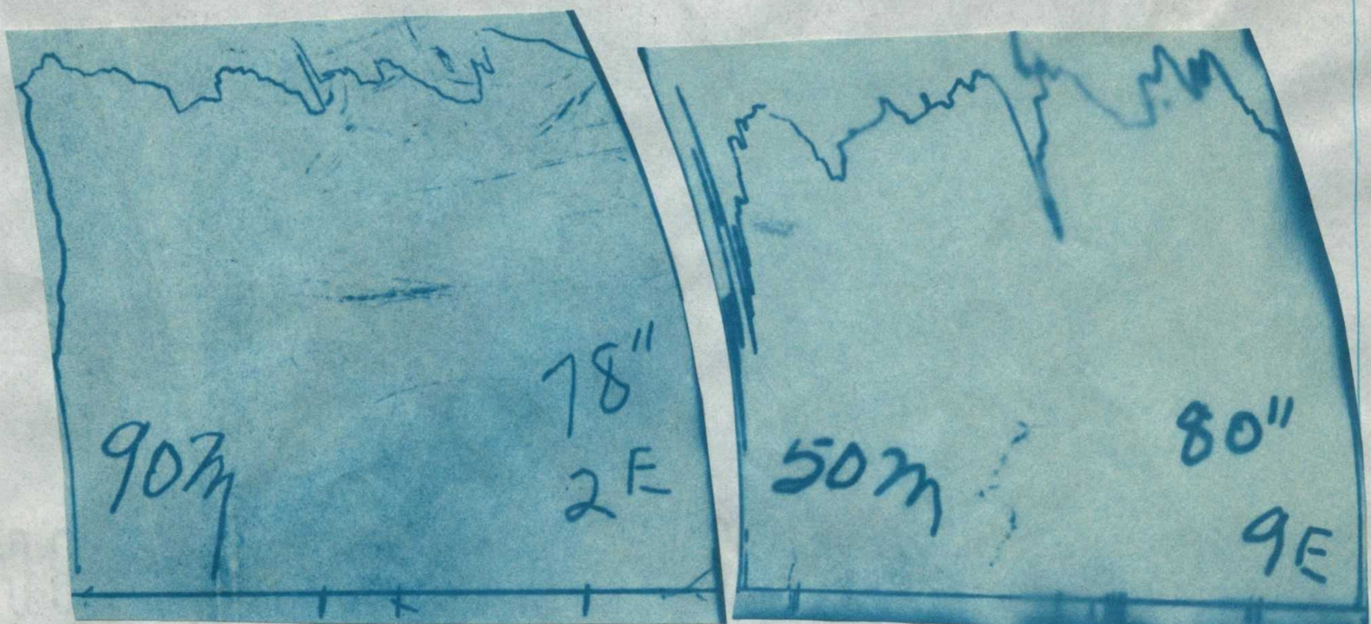


Figure 1

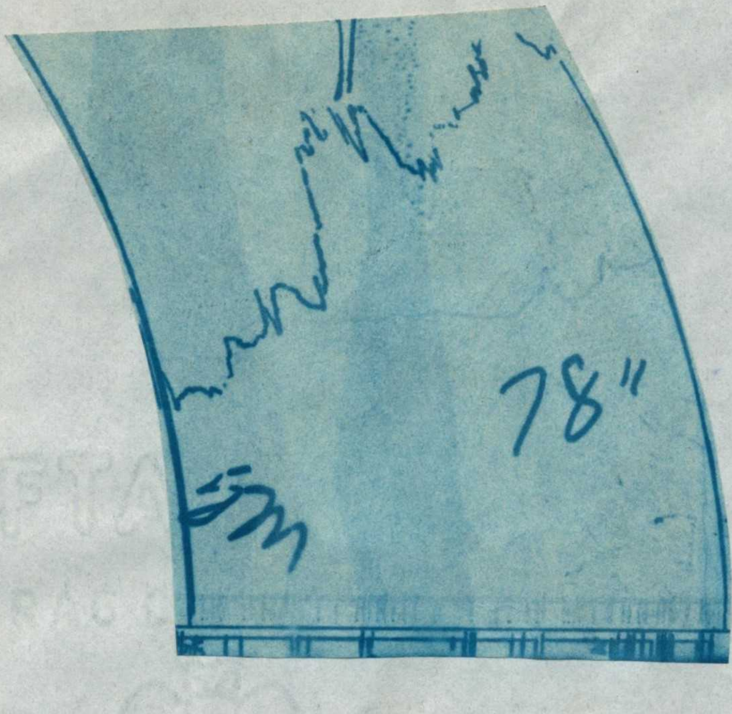


Figure 1 (continued)

Figure 2.

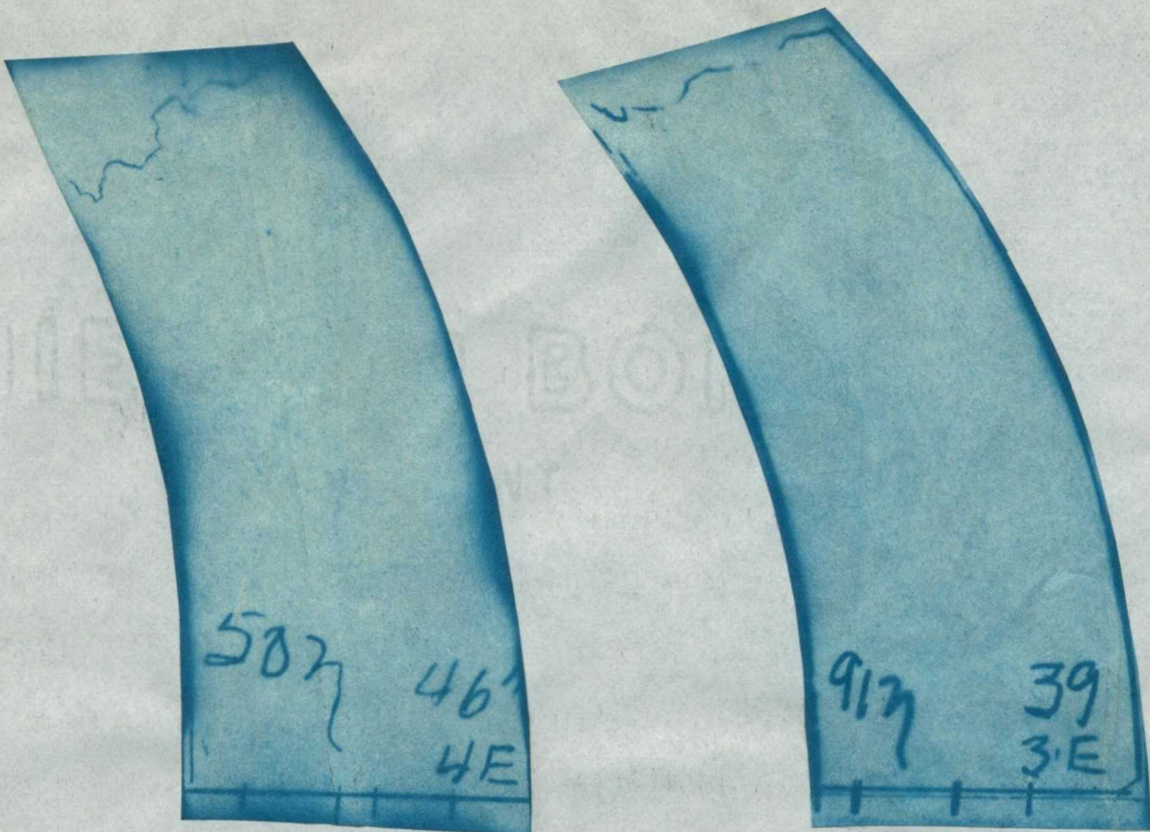


Figure 2 (continued)

The marks on the base line designate errors, and the numbers at the right side give the time and errors (total) for the run. Examination of both of these figures reveals the fact that the tension lines contain a decreasing number of the smaller irregularities as the learning progresses. That is, the tension tends to become more constant or less variable. It will also be seen that the tension at the start of the earlier runs begins low and increases as the run progresses. In the fiftieth trial, the start is a little higher, while in the last ones there is little difference between the tension of the beginning and the end of the run. This characteristic is evident in all of the records obtained.

On page 17 we have constructed a composite graph of the

Tension, Errors and Time

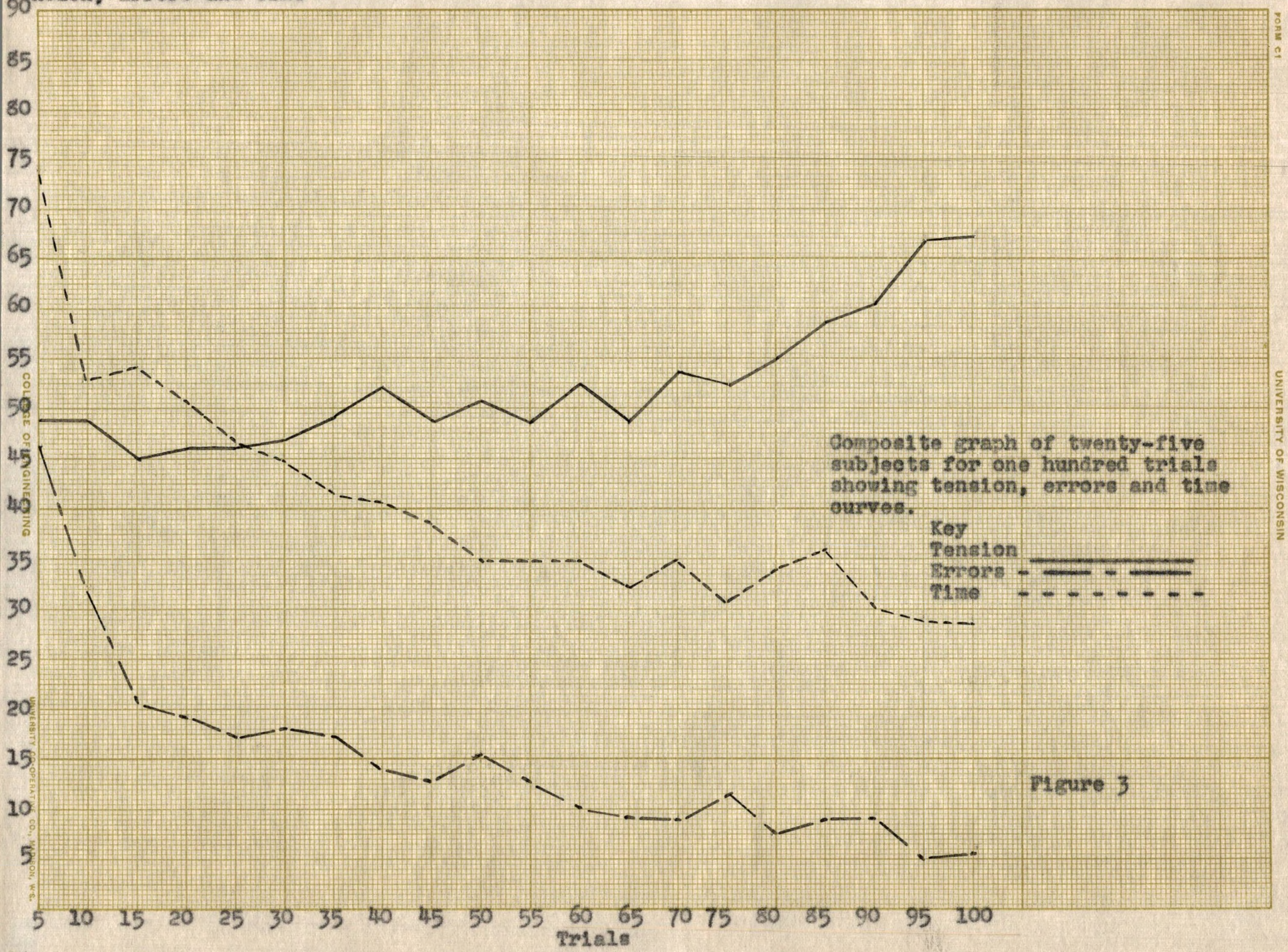


Figure 3

mean scores for each run of both tension and errors. In comparison of the graph for tension with the one for errors, we observe that the initial fall in tension is accompanied by a decided decrease in errors. The low point for tension in the earlier runs is forty-five millimeters in the fifteenth trial. From this point on to the sixty-fifth run, the tension does not vary over three points, while the errors drop from twenty-one to nine. At the seventieth trial, the mean for tension rises to fifty-four, the errors remaining at nine. From this point on, the tension rises gradually to the end of the one hundred runs, while the errors continue their drop to five. Ten of the individual scores show that the tension of these subjects dropped from run ninety-five tc one hundred, while the remaining fifteen either remained stationary or increased. (An explanation of this will be found in the following chapter.) It will also be noticed that the tension and error curves of the composite group is separated at the start by only three points, while at the end the difference is sixty-one.

Table 1

Correlation of Tension and Errors

Subject	One hundred runs	Last fifty runs
RO	-.3112	-.2721
GI	.0892	-.5147
EA	.1730	-.3940
EV	.4283	-.5684
CA	.6911	-.2457
WA	.6942	-.4283
DA	.1316	-.4283
NO	-.0411	-.2118
OP	.0568	-.6483
M	-.1436	-.6027
Y	-.0789	.6850
ED	-.7493	-.5632
MI	.6743	-.6304
HA	.0130	-.2359
HU	.8098	-.8843
MU	.3499	-.2231
VI	-.5932	-.6395
NO	.3106	-.3549
JE	.8996	-.4165
AV	.3556	-.1576
BE	.1079	-.1642
BI	-.5625	-.4880
LW	-.1696	-.3031
AL	.1110	-.0348
HE	.7542	-.4543
Average (Fisher method)	.46	-.48

In examining the coefficients of correlation of the one hundred trials in the above table, we find that out of twenty-five cases, only eight are negative while seventeen are positive. When the correlation is computed for the last half of the one hundred runs, twenty-four are negative, twelve of them significantly so, and only one is positive. The reason for this is apparent if we examine the composite graph of the errors and

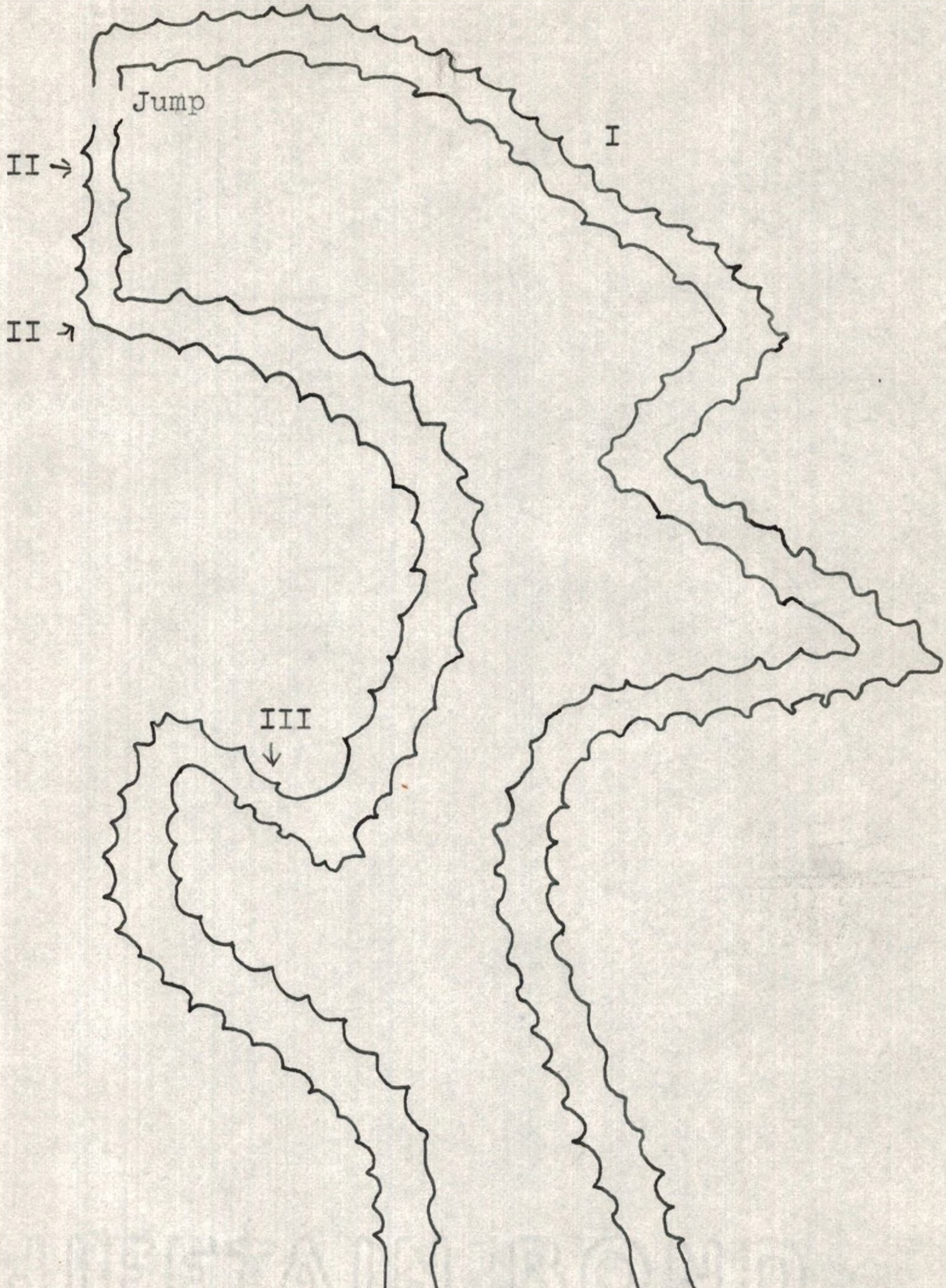


Figure 4

tension (Fig. 4). The initial high tension accompanied by the high errors was more than sufficient to outweigh the negative aspects of the second half of each series of runs.

RELATION OF POINTS OF DIFFICULTY IN THE PATTERN TO TENSION

In constructing the pattern for the maze, curves and lines in various directions were used in order to present a learning problem of considerable difficulty. Although we possessed no objective data on the relative difficulty of the different sections, our earlier experimentation indicated that three places offered greater difficulty than any of the others. These are designated on Figure 4 as I, II and III. Evidence of this increased difficulty was secured from the record of errors and the comments of the subjects while the pattern was being traced. After approximately thirty trials, when the subject had become aware of his improvement, as measured by the reduction of errors, he normally set for himself the goal of continuing the learning and of finally making a run with no errors at all. Consequently, knowing the difficulty of these places, he used every precaution to keep from making contact with the margins of the pattern. Invariably when such effort was made, it was accompanied by a rather adrupt rise in tension. This is illustrated by Figure 5. The tension resulting from the difficulties are indicated on the graph by the numerals 1, 2 and 3, corresponding to places I, II and III in the pattern.

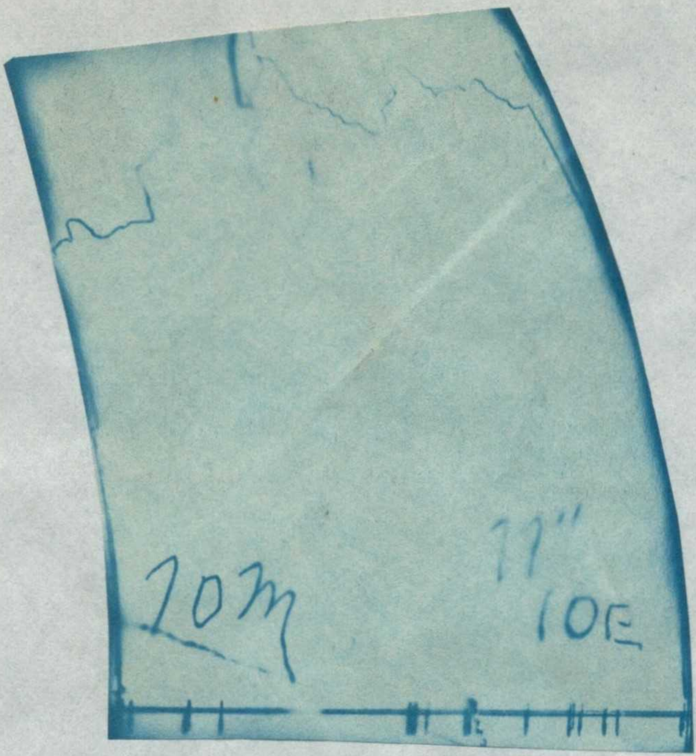


Figure 5

The graph for the figure above is taken from the record of subject MU. It shows the relation between difficulties of the pattern and the resulting tension.

Difficulties I and II in the pattern (Fig. 4) are quite close together, in fact it is doubtful if difficulty I ended before number II was encountered. In the great majority of tracings, however, the tension shows a drop, because of the necessity of removing the stylus from the pattern in making the jump. This is indicated by a vertical line in several of the tracings included in this work. Following II, however, there is a distinct drop in tension until in the proximity of number III. Here, again, the tension increases as the problem is met and remains high in the majority of cases. This is especially true where very few errors had been made, as indicated in

Figure 6. Here, only one error was made early in the run. While the remaining inches of the pattern were not as difficult

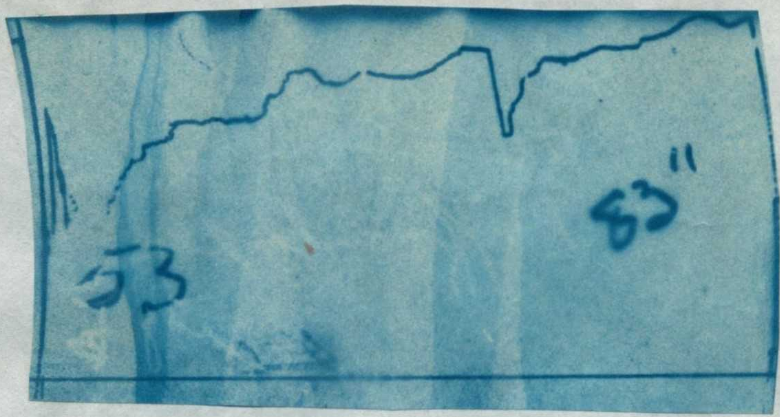


Figure 6

Showing increasing tension to the goal.

as section III, from comments of the subjects, who had made good records up to that point, it was discovered that they were continuing their extreme care to the end in order not to spoil their record. In those records which contained several errors and which did not promise a very good score, the tension at the end showed a gradual decrease. This is only true, of course, after the ordinary mechanics of the experiment had been learned. This can be seen in Figure 6, 50 N and 91 N of Figure 2. It must be emphasized, however, that in those cases where there was no conscious effort to make a good score, there was no rise in tension towards the end of the run.

Figure 7 illustrates several instances of irregular tension due to a large number of errors and the consequent loss of interest.

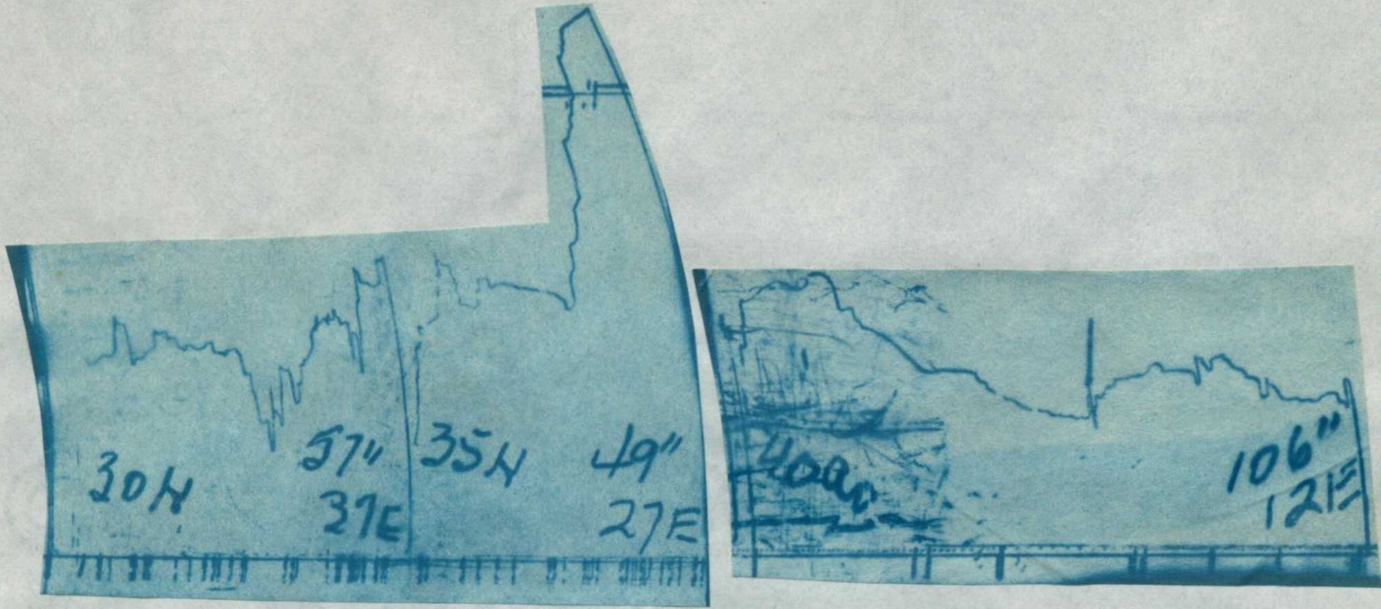


Figure 7

When the subject made a number of errors early in the run, after having set out with the determination to do well, there is a drop in tension, following the errors, decreasing to the end. The decrease in tension is accompanied by a further increase in errors. This is illustrated by the tracings in Figure 8.

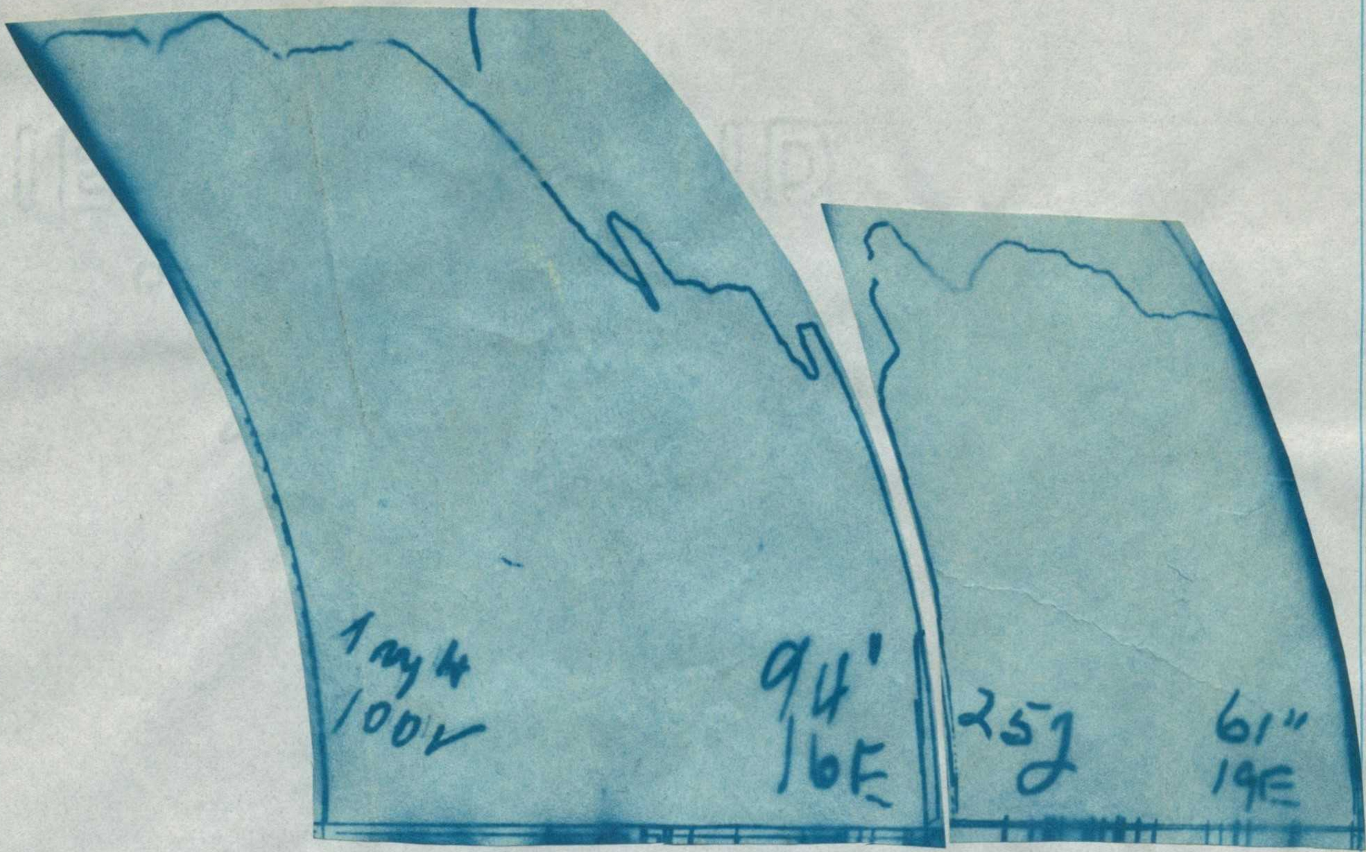


Figure 6

Decrease in tension as a result of errors.

Tracing 100V is the one hundredth run of Subject VI. She was instructed to try hard to make a better record than she had done previously. If a curved line is drawn up from the base line and parallel to the starting line at the right, it will be seen that nine of the errors preceeded the drop in tension and that each succeeding error resulted in a further decrease.

In the regular runs in which progress was being made - that is, only a few errors were being made, there is an increase in tension subsequent to the making of each error. This can readily be seen in Figure 5 and 91N and 50N of Figure 2. In determining the relationship between the errors and tension in these tracings, the method employed with 100V must be used.

INFLUENCE OF EMOTIONS ON TENSION.

Over the long period of time required to get data on this experiment, it was to be expected that the emotional states would not be uniform at all times. We have selected a few runs which were made during a period of anger or disgust. The cause of the emotional disturbance was outside of the laboratory, but the individuals were still in an unstable mood at the time of their trials. As stated previously, any evident physical or emotional condition was recorded on the daily note sheets accompanying the tension curves. The most obvious characteristic of the tension curve obtained at such a time (Figure 9) was the irregularity, changing degree of tension with no relation to the comparative difficulty of the different parts of the path. The normal influence of errors on tension was also strangely absent from the curve. In fact there seemed to be an inverse relationship in some cases.

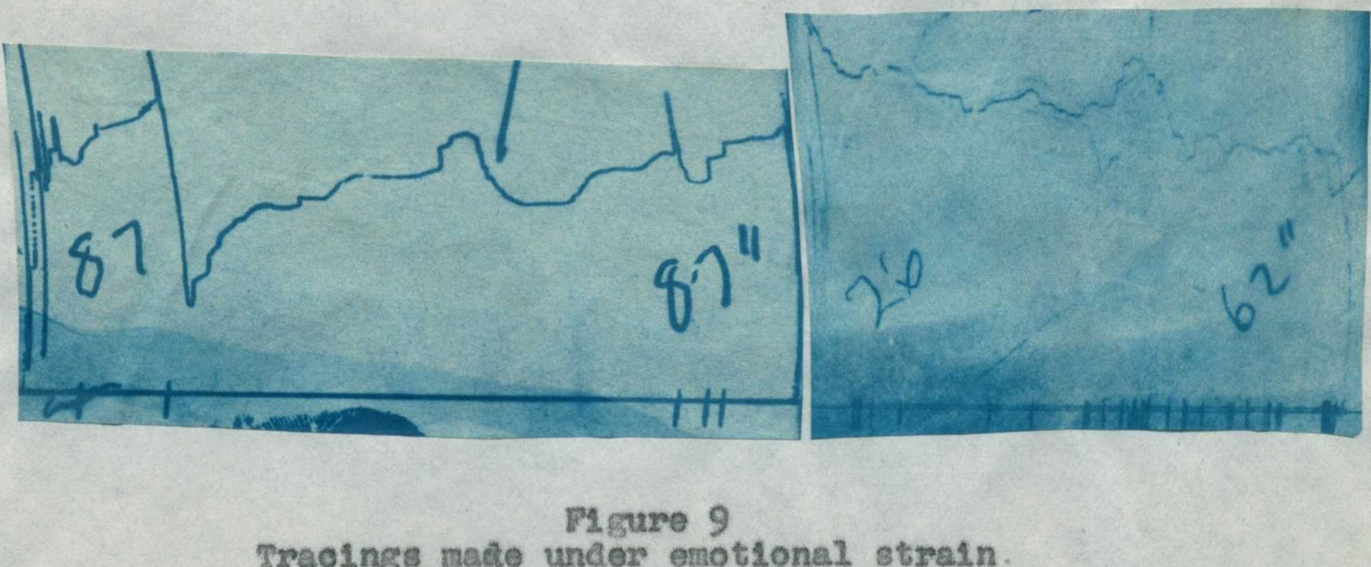


Figure 9
Tracings made under emotional strain.

Both subjects were angry at the time these tracings were made. In and of themselves, they do not have a great deal of significance, but when compared with a typical run of the same subject (Figure 10) the difference is quite obvious. In 26 and 37 there is a falling, irregular tension. Number 81 is typical of the other tracings of this subject.

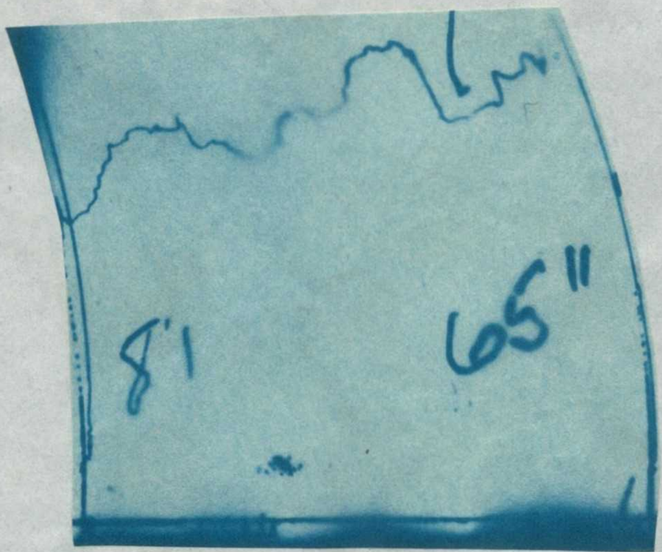


Figure 10
Normal run of subject in Figure 9.

The other emotion noticed and on which notes were taken was that of joy. The curves made at the time of this emotion were irregular, but the tension was at a higher level. Here too, we noticed that there was relatively little change following errors, or if there was any change, it might be either up or down, the rule of the normal runs not being followed. No other emotions were recognized or identified in the course of the experiment.

INFLUENCE OF URGINGS ON TENSION.

While the knowledge of errors is, of itself, an urge to do better work, we added to that commendations and encouragement at various times during the trials. Each trial where these have been given is so marked on the tension records. Specific encouragement and the urge was given before the run. The usual comment was "Mr. Blank made a run with only five errors today. I want you to see if you can improve on that record". We have selected two records of such runs. For comparison, we have taken another run from the same individual where such stimulus was not given. Upon examination it will be seen that the essential difference between these two groups of curves is the height and regularity. The tension curve of the encouraged is also less irregular and shows a constant rise from the beginning to the end. The effect of errors on the tension is also exaggerated in these cases. While we have included only two graphs, Figures 11 and 12, illustrating these characteristics, the same is true of all of the subjects in the "urge" runs.

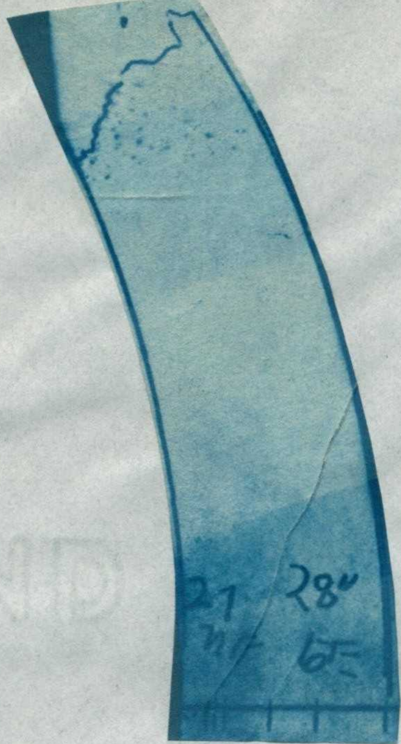


Figure 11　　　　　　　　Figure 12

Graphs of encouraged runs.

RELATION OF TIME TO TENSION.

In correlating time and tension of each run, we find about the same general results as when we compared tension with errors for the entire one hundred trials. These are shown in Table 1, page 19 . The coefficient is positive in every case but one. In this case, JE, there is a large negative correlation. The reason for this is to be found in those same factors which influenced the scores in the correlation of errors with tension. The time for each run was fairly consistently reduced from the first runs of about three minutes to the last which consumed as little as thirty seconds. The reason for the positive correlation can be attributed to the excessively long time and high tension found in the earlier trials. In those trials, however, in which accuracy had been urged, the time consumed was usually increased by about fifty percent above that of the normal runs. In those trials in which speed was urged, the curves uniformly showed a rising tension line to the very end, with less apparent influence of errors on tension.

In comparing time and tension for the last fifty trials of each subject, as was done with tension and errors, we find a significant negative correlation. The correlation for the entire group is -.24. The figure for the last half of the runs for the entire group is -.63.

RELATION OF FATIGUE AND TENSION.

Nine of the subjects completing the learning experiment were used in the fatigue runs. It will be recalled that these consisted of about one hour of runs following the completion of the one hundred runs. Of these, the correlations between tension and errors were negative with only one exception. (Table 2) The average correlation for the entire group was -.57.

Table 2

Fatigue runs

Correlation of Tension and Errors

Subject	
EA	.3706
EV	-.6482
HA	-.6100
HU	-.7834
VI	-.7246
AV	-.4864
MU	-.2676
NO	-.4828
HE	-.5642
Speed after 100.	
Z	-.5072

In examining the tension graphs of these, samples of which are found in Figure 14, several characteristics seem to be common to all. The tension begins relatively high and increases to the end. The tension line for each trial also shows a characteristic peculiar to fatigue runs - it increased from beginning to the end of each trial. The influence of errors on the tension curve in the fatigue runs, is less evident. A comparison of the fatigue with the regular runs will show that in trials of an equal number of errors, the tension in the fatigue runs is distinctly higher. In other words, there is a direct positive correlation between muscular fatigue and the amount of muscular tension involved in the performance of the act.

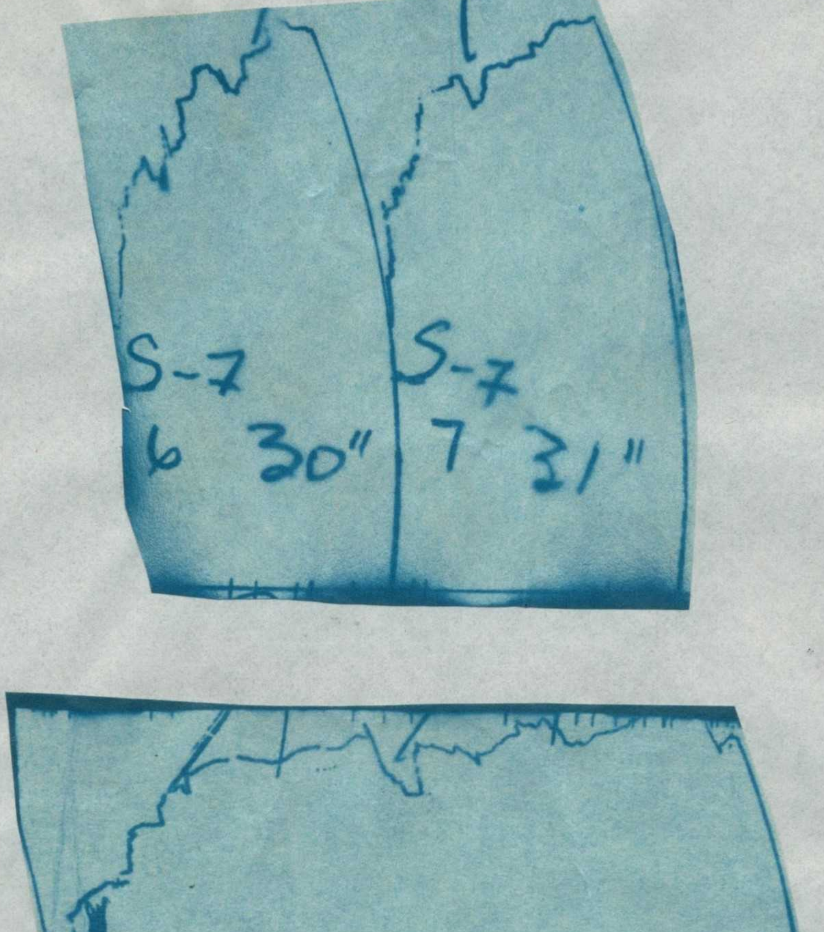


Figure 13

Fatigue runs.

If we take a few concrete examples for comparison, the point will be made clear. In the regular runs near the end of the learning, the tension and error scores were as follows:

Tension	Errors
78	5
82	3
94	3
72	10

In the fatigue runs, the tension and error scores near the end of the run were as follows:

Tension	Errors
96	2
74	10
82	7
88	6
83	7

Table 3

Following the fatigue trials, we tried two runs urging the best possible scores, perfection if possible. This resulted in an increase in errors and a very irregular tension curve.

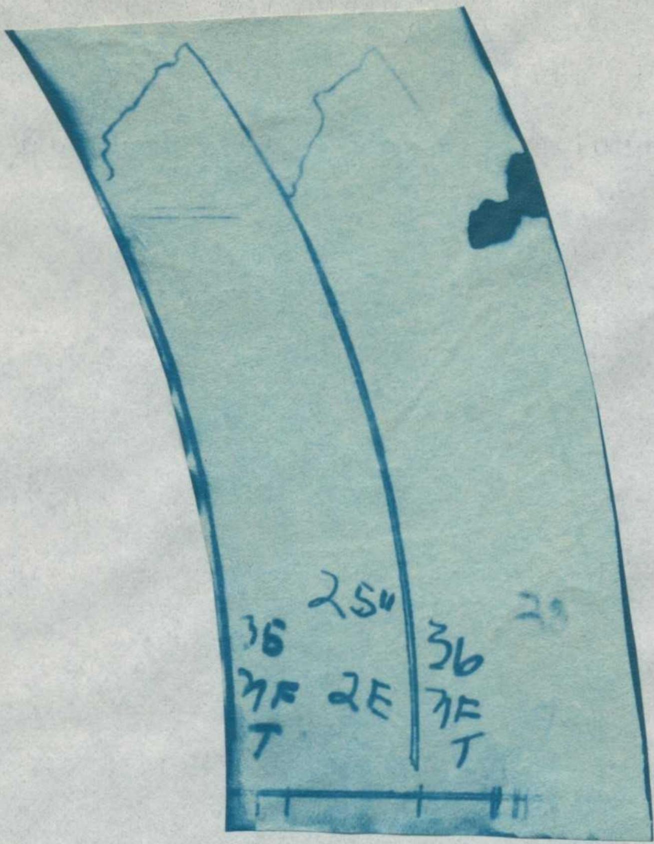


Figure 14

Fatigue runs

RELATION OF AGE AND GENERAL TENSION CURVE.

Out of the entire group of subjects, three were students in the grade department, the others being high school students and adults. The tension, as a rule, was higher for the younger subjects as compared with the adults. This, however, was not a large enough group. Among the adults, however, it was discovered that the tension of those who had learned to write by the Palmer Method was very noticably lower than the tension of those who had been taught by some other system. The tension, while low, followed the same general characteristics in regard to errors as did that of the other group, the essential difference being the magnitude.

CHAPTER 4

INTERPRETATION AND CONCLUSION.

In order to secure a complete picture of all the muscular changes accompanying the learning process, it was necessary to observe any evidence of tension in other parts of the body. The specific criteria by which tensions other than those of the writing level were judged were posture, facial expression and respiration. Notes were made of any apparent change in these factors at each trial and were considered together with the kymographic records.

While we desired to select a muscular activity in which there was only one learning problem involved, we soon discovered that two problems faced the subject. The first of these was that presented by the general mirror drawing situation and the second was that of tracing the pattern without coming in contact with the sides, i. e. without errors.

In mirror drawing, the movements from left to right and conversely were normal situations, but the up and down movements as well as combinations of these were distinctly foreign to all subjects. The problem which received primary consideration of the subject was that of tracing the pattern in the new situation provided by the mirror drawing equipment. This fact was discovered from comments of the subjects, one of the most frequent ones being "I'll have to be able to get around this path before I can try to reduce errors". Being faced with this difficulty, the entire organism responded by a rise in tension. Evidence of this was found in the posture and evident tension of the facial and arm muscles. In addition, we found further objective evidence in the tension of the fingers on the stylus. It was gripped so hard at times, that the tambour was forced to its limit.

In from ten to fifteen trials, the difficulty of the pattern was at least partially solved. At this point, the tension dropped. From here on, the subject faced only the one major problem, that of making the tracing without coming in contact with the sides of the pattern. Since the degree of success in solving this problem was measured by the number of errors in each tracing, it was not difficult to objectify the results.

After the initial difficulty of the mirror drawing had been reduced, it was noticed that the general, diffused tension was also less pronounced. The jaw was not so set and the breathing was more regular. From this point on, it was evident that the tension involved primarily the muscles of the fingers and arm. This fact together with the very nature of a tambour indicates that all of our measures of tension should be considered as relative rather than absolute. In other words, the general, diffused, bodily tension had been reduced to a specific tension of the muscles used in operating the stylus. (The high tension can be seen in Figure 3). Following the high initial tension, the graph shows a significant negative correlation between tension and errors, i. e. as the tension increases, the errors decrease. In the majority of cases, this tension increase continues on to the end of the series of runs, at which point there is a levelling off. With three subjects, GA, WA and LW, there is a decline in tension with errors remaining the same for the last five trials.

The results presented point clearly to several considerations. In the first place, with four subjects - AV, VI, ED and N, the tension at the beginning of the experiment, while relatively high, shows a gradual increase for about ten runs, whereas the other subjects begin high and show a drop at the fifteenth or twentieth trial. From questions asked by these four subjects at the time of the early runs, it is evident that they had failed to center their attention upon only one general problem. They were attempting to solve both of them simultaneously and only confusion resulted. In the case of ED, there seemed to be no interest in the problem at the start. Our records show that at the point where the subject had analyzed the problem, the tension was at its highest point for the earlier runs. All of our subjects were entirely naive in mirror drawing procedures. Therefore, until the general mechanics of the situation were understood, no solution could be attempted. Consequently, in the early trials of those subjects who had difficulty in assimilating the details of the procedure and synthesizing them into a unified problem, there was in reality no clear goal and consequently no solution of the process could be formulated. With the other subjects who discovered the problem before the first recorded run, (at the end of the first four practice trials) the tension started at its highest point of the first series and declined for the next fifteen trials. These findings substantiate the results of Freeman's experiment (6) in 1932, in which he discovered that the tension of the subject rose in anticipation of a known difficulty. Conversely, when the subject was unaware of the difficulties, the tension showed no consistent differences in amount.

It was only a matter of five trials for the majority of subjects before the tension declined to its lowest point. It seems probable, therefore, that the first fall in tension came as a result of having solved the first general problem offered by the mirror drawing situation. Further evidence is presented in the cases of LW and NO. In these instances, the tension dropped from trial eighty to the end of the experiment. This probably came as the result of having solved the second problem of tracing. In runs following one hundred (not a part of the regular or fatigue trials) the tension of these subjects remained constant at a figure 5mm under that at eighty.

F urther agreement with Freeman's study (6) is found in the runs subsequent to the initial drop in tension. As stated previously, there were three places in the pattern which uniformly offered particular difficulty to all subjects. As soon as the subject discovered where these difficulties were, the tension would invariably rise in anticipation of each difficulty. However, before such difficulties were discovered and segregated from the rest of the pattern, there was no consistent increase in muscular tension.

Tension tracings of the fatigue runs present another phase of this investigation. It will be noticed that the tension for these runs (Table 2) is increasingly high for the trials of about the same number of errors in the runs prior to one hundred. In the fatigue trials, the difficulty of tracing the pattern increased with each run and the increase in specific tension came as a result of the additional difficulty presented by the muscular fatigue. It was also noticed that as these runs progressed, there were sporadic increases in tension as evidenced in the muscles of the face and body. This was further shown when the subject was urged to "try hard". This resulted in a tension similar to that displayed in the early trials of the regular one hundred runs. The subject sat erect, the jaw was set and the respiration was short and irregular. When we compare the graph of the urge runs of the regular series with those of fatigue, the difference is quite evident. The tension is higher in the latter and the difficult places result in greater increases in specific muscular tension. It is therefore patent, that with increasing fatigue more of the entire organism is called upon in order to produce a score comparable to that of the earlier and more successful trials. Toward the end of the fatigue runs, when the subject was urged, "for the last time", in an attempt to produce a perfect run, the tension increased still more and was accompanied by more irregularity of the tension curve. Further, there was more evidence of tension in the face and body. We believe that the irregularity of the tension curve indicates the difficulty of the task under the conditions imposed by fatigue.

It must be noted that the two problems of this experiment were different in nature. The one required but a short space of time for its solution. It was simply a matter of understanding that the up and down directions were reversed in the mirror drawing situation, while the movements to the left and right remained as in normal situations. The second problem required more practice in order to negotiate the various difficult sections of the pattern without making contact with the sides. This accounts for the difference in time needed for the learning of each.

Another consideration which comes to our attention at this point is the individual differences in regard to amount of muscular tension. All subjects did not show the same amount of tension in those runs in which their scores were the same. Neither did each individual consistently maintain the same general level of tension throughout the entire series of runs. Physiological conditions served to modify these at different times, the result being either general increases or decreases in the level. It is therefore evident that each individual possesses the capability of muscular tension gradations from the lowest which is characteristic of sleep to the highest found in hysteria and flight of ideas. Just what the optimal level is must be determined for each individual and for each act. Some activities for some individuals, for example, are highly energy consuming, while others can be engaged in for longer periods without any apparent decrease in efficiency.

In the studies made by Bills (1) there was a positive correlation between the quality of performance and tension. In his experiment, however, the increase in tension resulted from a loading of the muscles of the unused hand by squeezing a dynamometer. In our study, a problem in learning was assigned the subject and the tension accompanying the process was measured at each trial. The first study revealed a positive correlation between quality of performance and tension while the latter shows the same for learning, if we take the reduction of errors as the index of learning. In the third study made by Bills (1) in which the subjects added columns of digits while squeezing the dynamometer, the task would commonly be termed a mental one. In the same manner, in this study the activity might be termed both mental and muscular, since certain problems in the mirror drawing situation required considerable thinking. It seems evident, therefore, that the organism responds as a whole to any problem, whether mental or physical, by an increase in muscular tension when a solution of that problem is attempted, and that the accompanying increase in muscular tension is essential to the learning of the act or the performance of the task.

Perhaps the above conclusion holds in it the solution for another problem which has been puzzeling the educators for some time. In the preparation of lessons and in drill work, it has been found that better results are obtained when a student works under pressure of time. In any of the reading subjects, more of the subject matter is learned and retained when the student is working against time than when he is setting his own pace. The same is true of the drills in column addition, multiplication, subtraction and division. From the time scores obtained in our study, three of the twenty-two correlations for the one hundred runs between time and tension are negative, while the remainder are positive. These three negative correlations vary from -.14 to -.38. Again, if we consider only the last fifty runs of each series of trials, as was done with the correlations between tension and errors, the correlation between tension and time is significantly negative. (-.63) In other words, the increases in tension are accompanied by decreases in time. Therefore, in the same way that we were able to improve our learning by loading the muscles, it seems that we are able to increase the efficiency of our learning by again loading our muscular system and consequently increasing the efficiency of learning by limiting our time. In other words, we believe that it is not the decreased time, in and of itself, which improves the learning, but it is the resulting increase in tension accompanying the decrease in time, which is beneficial.

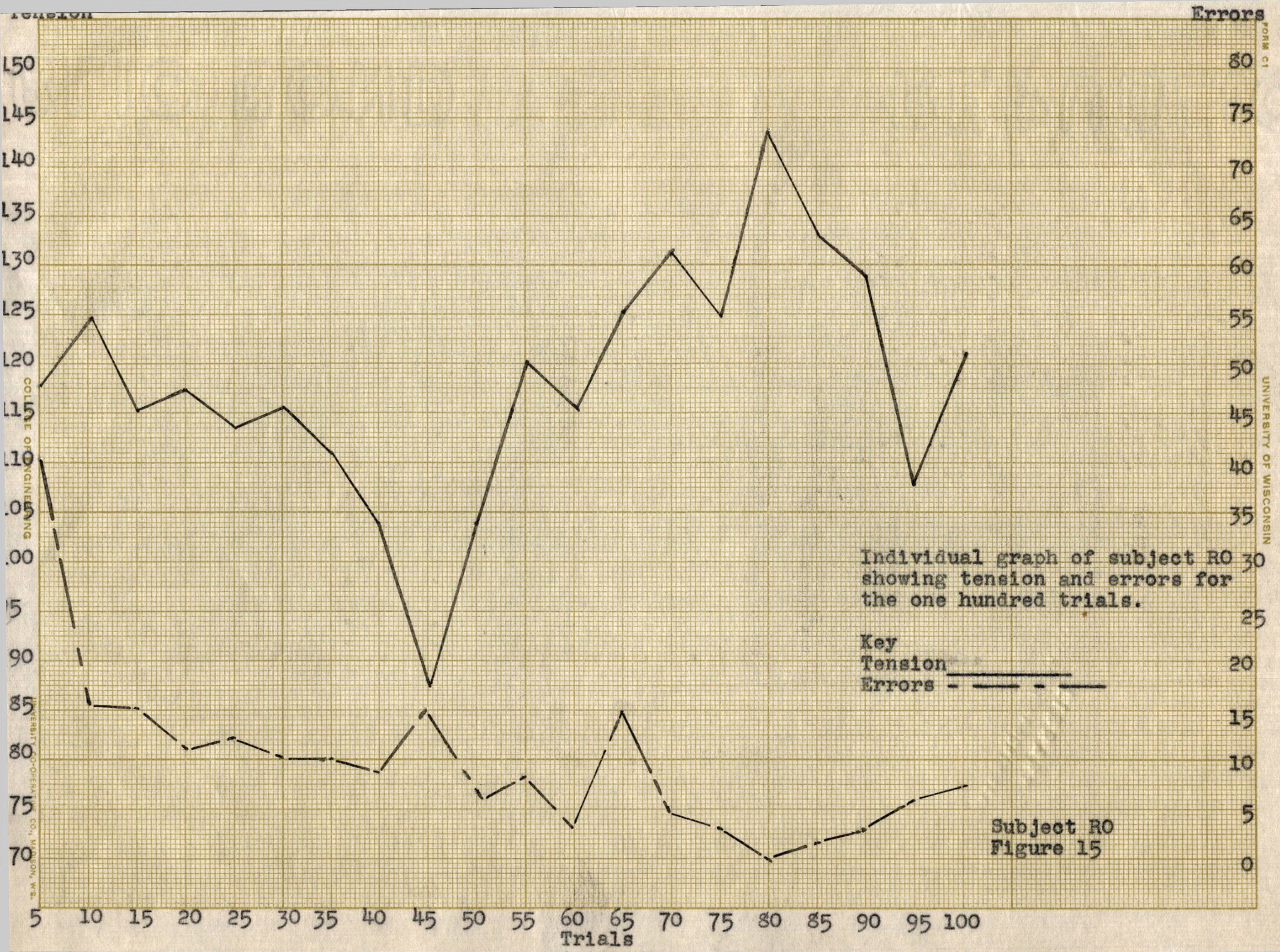
From the results of the experiment, it seems justifiable to draw the following conclusions. Whenever the organism is faced by a clearly defined problem and which he attempts to solve, the activity is accompanied by an increase in tension. The success, as measured by the reduction in errors, bears a negative correlation to the tension. If, however, the subject makes only desultory attempts to solve the problem, there is no increase in tension. As soon as the difficulty is overcome, there is a slight decrease in tension but at no time following the learning of the act, is it ever as low as it is in the earlier runs following the initial fall. However, any great reduction in tension was accompanied by a decided increase in errors.

Our inference in regard to the general diffused tension was gathered from our observation of the subject while attempting the solution of the problem and were somewhat qualitative in nature. It is our belief that these factors could be made more quantitative by an exact measurement of the tensions of the muscles of the leg, for example, during the performance of the act used in this experiment.

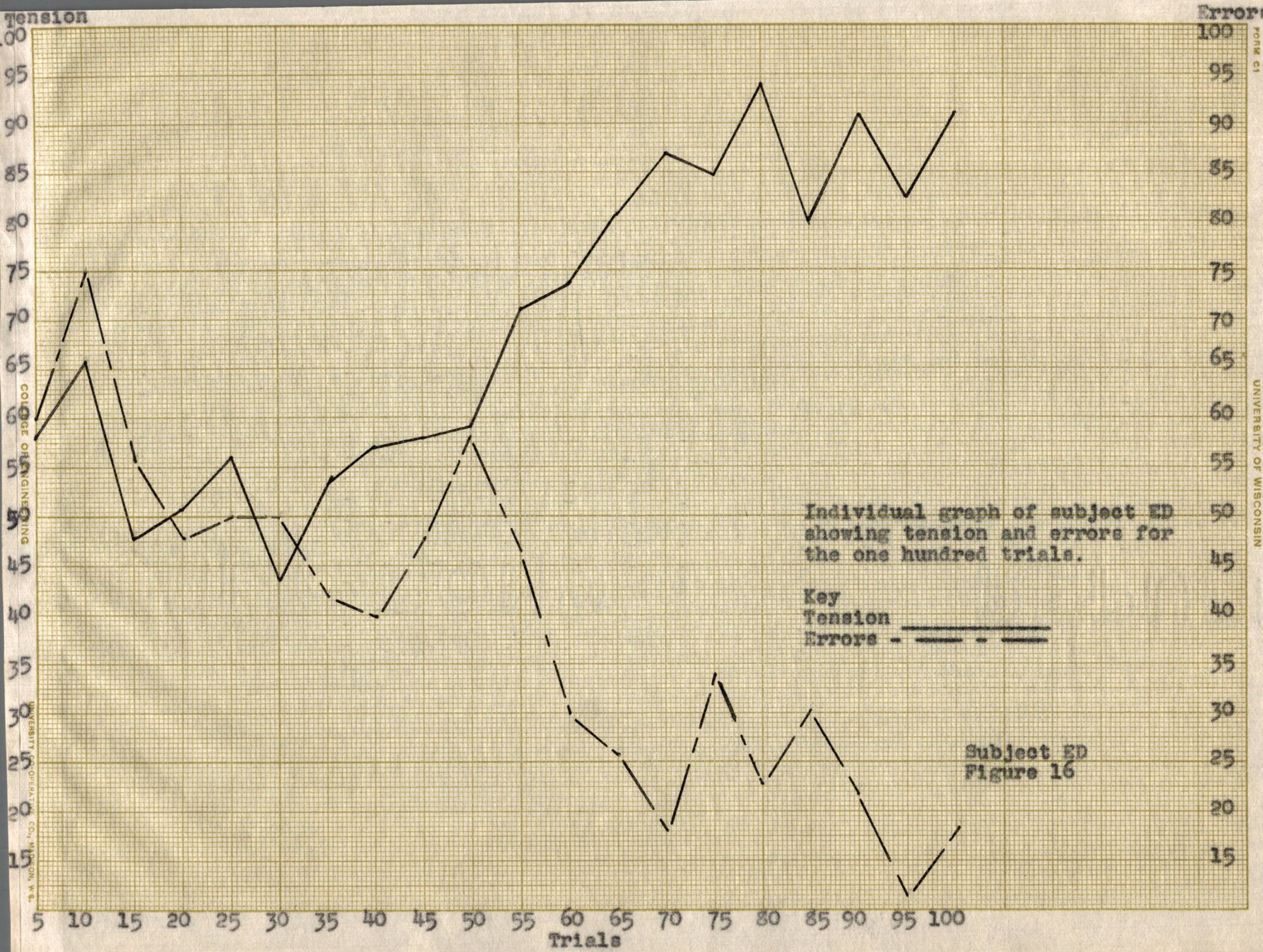
A great deal has been said and written concerning the necessity for complete relaxation in performing a muscular feat. Thus relaxation of the musculature was advocated for the athlete in golf, tennis, basketball and numerous other forms of the sports. In the class room, the student was urged to attain complete relaxation in order to be able to write well. The pianist and the typist were given the same advice. It seems, however, that what actually takes place in a typical learning process is not complete relaxation, but rather a differential relaxation and an increase in the tension of the specialized muscles used in performing the act. In the final analysis, the only reason for complete relaxation is to prevent the inhibitory action on the part of the antagonistic muscles. If we begin by concentrating our attention on the act to be performed, an increase in tension will follow as a natural consequence.

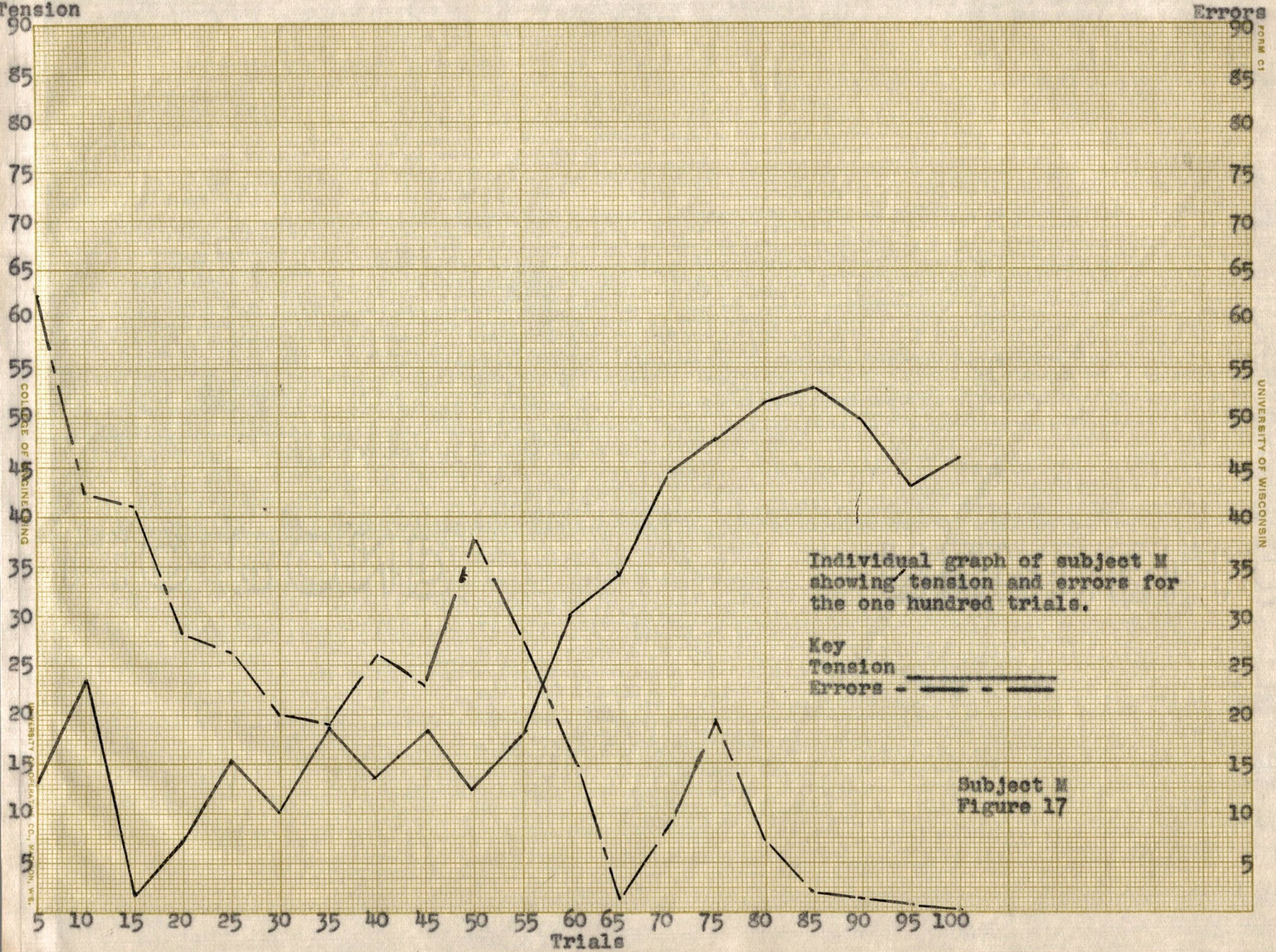
In the teaching of a certain type of penmanship commonly used in our schools, complete relaxation is urged. In fact, a test of the correct method is that the pen or pencil must be held so loosely that it can be slipped out of the fingers of the writer without encountering any resistance. Several subjects who had been taught to write by this method were used in this experiment. Their tension records bear striking resemblances to each other, but they all conform to the composite curves for the entire group. While their tension is generally lower than that of others, the same gradual increase in tension prevails near the end of the one hundred trials. In addition, the individual tension curves of these subjects conform to the curves of the other subjects, but the tension increases are not so great.

The logical follow-up for this study is a study of the same type wherein tensions is experimentally increased in some subjects and diminished in others and the effects on rate of learning determined.



Individual graph of subject RO showing tension and errors for the one hundred trials.


Tension
Errors
Individual graph of subject ED showing tension and errors for the one hundred trials.
Key
Tension
Errors
Subject ED
Figure 16
Trials
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100



Individual graph of subject M showing tension and errors for the one hundred trials.

Subject M
Figure 17

Subject

Trials	1	2	3	4	5	6	7	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	-10	90	8	22	100	98	21	21	114	120	75	90	78	67	120	43	99	105	110	65	90	110
10	6	23	6	21	19	70	23	18	88	80	69	74	60	44	105	55	96	90	90	63	72	90
15	7	15	13	21	-3	72	12	16	118	85	78	59	60	29	80	24	93	92	80	61	101	80
20	33	10	9	20	1	70	25	18	66	75	64	66	57	25	84	28	72	85	78	60	83	80
25	11	8	11	20	4	76	21	14	67	80	65	57	60	-2	85	11	90	86	76	60	60	76
30	21	5	9	18	4	60	19	13	45	70	57	72	60	17	83	10	81	86	76	62	48	74
35	23	1	19	18	20	52	21	12	39	70	55	49	60	6	53	3	82	88	72	75	-47	70
40	13	2	8	16	7	48	22	14	44	65	66	40	60	7	50	0	106	82	73	70	-47	68
45	-3	6	8	17	0	50	15	9	37	67	61	52	67	-3	56	14	105	82	68	60	40	70
50	1	0	11	14	-10	40	20	11	22	60	63	41	80	6	42	10	52	78	67	52	61	65
55	-4	0	11	13	-14	42	20	11	28	62	50	47	68	13	40	11	50	80	73	50	61	68
60	-2	0	6	10	2	42	22	12	60	63	55	37	63	-5	36	-9	45	82	74	50	63	64
65	0	-2	9	11	-20	43	12	9	58	65	48	31	73	-6	42	-8	50	70	58	58	60	66
70	4	-2	7	8	-23	40	16	5	51	58	52	54	67	-9	68	-12	47	76	57	55	68	60
75	-1	-1	7	7	-11	35	18	3	53	55	48	50	75	-2	40	-3	53	72	58	35	51	61
80	0	-6	6	6	-13	37	18	4	41	63	49	52	78	-7	49	5	55	72	58	70	56	58
85	-2	6	5	6	-20	42	18	3	48	60	45	47	80	28	40	6	40	78	65	72	73	57
90	-13	6	4	4	-13	30	15	4	45	52	51	45	30	24		-1	42	60	66	74	72	55
95	-13	-1	3	2	-12	22	14	2	49	48	46	40	51	30	42	10	55	62	50	30	69	52
100	-5	-3	1	-6	-10	26	18	4	41	50	48	40	43	34	40	11	38	63	51	35	72	60

Time in seconds

Time record of Subjects 8, 9 and 10 not available.
The time for subjects 1, 2, 3, 5, 17, 19 and 24 have been reduced to permit scaling.

Table 4

	Subject																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Trials																	
5	117	73	9	53	110	108	15	-9	8	-7	2	58	108	68	42	55	60
10	125	67	8	54	86	84	16	-5	5	3	4	66	84	52	34	57	73
15	115	69	8	55	66	64	13	-8	4	-18	7	47	64	44	36	51	85
20	117	69	6	55	75	70	12	-1	0	-13	6	51	73	43	24	55	94
25	114	58	7	55	64	60	12	4	2	-5	7	56	62	78	45	66	89
30	115	62	9	56	52	75	15	6	6	-10	8	44	80	25	27	69	85
35	111	65	7	57	83	78	19	8	6	-2	10	53	81	26	41	70	83
40	104	70	8	59	90	85	13	8	13	-7	8	57	88	15	83	70	83
45	88	72	7	61	84	80	8	7	10	-2	9	58	82	30	38	78	80
50	104	70	9	65	87	83	21	4	-10	-8	8	59	85	19	28	61	93
55	120	47	8	66	84	19	16	-4	-11	-3	8	71	82	28	27	67	85
60	116	49	9	68	77	72	17	-7	-16	9	7	74	75	15	35	76	84
65	125	44	11	69	67	62	15	-7	-10	14	8	81	65	16	38	59	80
70	131	52	13	70	74	69	12	6	2	24	6	87	72	17	38	72	89
75	125	66	11	70	75	70	12	8	-8	27	8	85	73	26	65	54	84
80	144	52	13	72	66	61	12	7	-10	31	7	94	64	16	44	44	102
85	133	68	14	76	47	52	13	3	8	33	8	80	65	22	86	41	95
90	129	58	15	78	62	57	14	4	2	30	7	91	60	17	115	68	97
95	108	57	15	80	70	65	12	2	-2	23	5	83	70	16	140	37	88
100	121	67	16	104	62	57	17	1	4	26	7	91	62	31	140	53	83

Tension in millimeters

Table 5

Table 5 (continued)

Subjects							
18	19	20	21	22	23	24	25
91	30	10	18	24	30	108	49
86	22	19	21	24	17	123	49
102	64	22	19	25	14	129	45
91	40	13	15	25	31	117	45
79	74	25	11	26	33	122	46
75	75	36	11	26	19	124	47
80	93	36	9	26	18	133	49
87	105	24	10	26	23	126	52
84	98	21	10	32	29	131	49
85	108	27	12	32	34	118	51
88	85	46	11	25	38	117	49
98	99	52	8	25	55	110	52
93	108	30	13	34	49	122	49
85	108	42	7	34	51	92	54
84	96	37	9	32	59	118	53
93	113	35	9	32	60	114	55
94	103	53	8	28	57	114	59
	101	50	12	28	34	101	61
72	110	28	10	32	53	117	67
81	105	52	9	32	49	103	54

Subject

Trials	1	2	3	4	6	5	7	8	9	10	11	12	13	14	15	16	17
5	30	66	14	35	15	55	39	51	19	38	32	20	52	48	6	26	60
10	6	32	12	37	15	21	55	14	13	22	30	35	20	32	-2	28	21
15	5	34	16	30	12	0	17	11	7	20	17	16	2	24	-11	25	19
20	1	22	9	25	11	-2	39	13	6	7	25	8	0	28	-8	13	8
25	2	25	8	27	12	-4	23	-1	11	6	26	10	-2	8	-15	23	8
30	0	41	11	24	9	-4	35	2	2	0	20	10	-2	5	-13	9	2
35	0	15	31	22	8	2	30	-8	5	-1	17	2	0	6	-23	17	0
40	-1	14	11	19	6	-3	29	-11	-1	5	18	0	-1	-5	-24	12	1
45	5	10	8	17	4	-1	12	-3	-2	3	19	8	1	10	-21	11	-2
50	-3	13	16	18	0	-9	26	-5	-1	18	17	18	-7	-1	-28	9	-5
55	-2	15	17	18	-1	-10	23	-4	2	8	15	7	-8	8	-25	5	-8
60	-7	18	9	13	1	-6	20	-3	5	-4	13	-10	-4	-5	-31	2	-5
65	5	19	10	11	-3	-8	18	-8	4	-18	14	-14	-6	-4		10	-7
70	-5	20	7	12	-2	-9	32	-8	-4	-11	12	-22	-7	-3	-31	10	2
75	-7	7	10	10	-1	-13	32	-10	6	-1	25	-6	-11	6	-34	15	-1
80	-10	23	8	8	0	-9	32	-5	4	-13	0	-17	-9	-4	-34	5	0
85	-8	17	8	9	-1	-13	30	2	2	-17	9	-10	-3	2	-29	5	-5
90	-7	17	7	6	-2	-15	27	-9	2	-18	6	-18	-8	-3	-39	10	-2
95	-4	16	6	3	-5	-15	23	-8	-2	-19	15	-28	-15	-4	-39	6	-2
100	-2	8	5	5	-6	-16	20	3	-3	-21	9	-22	-10	11	-40	3	5

Errors

The scores for subjects 1, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, and 17 have been reduced to permit scaling.

Table 6

Table 6 (continued)

Subjects

18	19	20	21	22	23	24	25
23	28	36	15	165	9	32	41
-4	30	15	20	165	6	12	27
8	4	14	17	108	0	6	16
-7	-1	12	19	108	6	11	14
-3	3	6	10	76	2	2	12
-12	3	4	6	76	6	6	13
-11	0	6	9	76	4	5	12
-14	1	2	6	76	1	-3	9
-16	5	-3	6	41	3	2	8
-16	-1	5	6	41	3	0	10
-15	0	1	2	47	5	8	8
-10	-7	-5	12	47	6	7	5
-15	-12	-1	-12	46	3	-5	4
-15	0	-2	6	46	4	0	4
-14	6	-1	-3	44	4	-1	6
-9	-8	-1	-4	44	3	-1	3
-15	-8	-3	-2	46	2	-2	4
	2	-7	-8	46	4	-4	4
-10	-3	-2	-14	23	3	-5	0
-13	-3	-1	-12	23	2	-2	1

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