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MENTAL FATIGUE

BY

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CONTENTS

MENTAL FATIGUE

CHAPTER I

INTRODUCTION AND HISTORICAL SURVEY*

The facts of fatigue are conveniently divided into muscular fatigue, sensory fatigue, and mental fatigue. That the division is an artificial one does not need any explanation, for the individual is an organic whole and a change in any part of the body is more or less accompanied by a change of the whole. Muscular and sensory activities are, as a rule, connected in various ways with the central nervous system. It is, moreover, very difficult to get mental activity which is entirely free from muscular and sensory accompaniments. Hence the division is made for convenience. When the terms 'mental activity' and 'mental fatigue' are used in this monograph, it does not mean that they are entirely independent of muscular and sensory activities or fatigue.

We have generally used mental multiplication as a type of mental work, for the reason that its process contains hardly any sensory and muscular elements.

Previous investigations of mental fatigue fall into four classes, based on its influence on: Organic processes, motor power and reaction time, sensibility of the skin, and the efficiency of mental functions.

I. *The Investigations of Mental Fatigue Through Its Influence on Organic Processes*

Investigations have hitherto been confined to three processes: namely, pulse, temperature, and metabolism.

*Acknowledgments are due to Professor E. L. Thorndike and Professor R. S. Woodworth for their suggestions as to the general plan of the experiments and to Professor J. McK. Cattell for his advice. The author's gratitude should be expressed to Mr. T. Haraguchi for assistance in connection with the form of presentation of the facts.

1. *Changes in the Pulse Rate*

So far as the knowledge of the writer goes, the first attempt to measure the relation between mental work and changes in the pulse rate was made by John Davy[1] in the paper entitled "On the Temperature of Man," published in 1845. Davy measured his pulse rate by the number of beats per minute on eighteen nights soon after he completed strenuous mental work lasting for from two to five hours and also on nights when no mental work was done. As a result of these experiments, he found that the average pulse rate at midnight after he had done mental work was 57.0 per minute, while it was 54.6 at midnight when none had been done.

In 1881,[2] Gley noted that the radial pulse rate is higher after such mental work as reading and working at geometry than after rest. Mosso[3] concluded that the circulation was not the primary factor in psychological activity. In 1897, Vaschide[4] published the result of his thoroughgoing investigations on the subject. He measured the number of his radial pulse beats per minute on resting days and on days when he devoted fourteen hours to strict mental work. He reported the results of forty resting days and seventy-two working days in spring and four resting days and nine working days in summer. In the first series, the average number of beats per minute was 71.04 on the working days and 76.86 on the resting days. In the second series, the average number of beats was 69.8 on the working days and 74.44 on the resting days. Vaschide gives the full data of the summer observations. By an investigation of these the writer discovered that the average deviation was not so great as the difference between the two averages given above; therefore the difference can not easily be attributed to mere chance.

In 1896, MacDougall[5] found that there is an acceleration of the pulse in the first ten minutes of the attentive state, which is

[1] Phil. Trans., vol. CXXXV, pp. 319-349.
[2] Gley, E., Études de Psychologie, Paris, 1903.
[3] Mosso, A., Fatigue, trans. by Drummond.
[4] Vaschide, N., Influence du travail intellectuel prolongé sur la vitesse du pouls, *L'Année Psychol.*, vol. 4, pp. 356-378.
[5] MacDougall, The Physiological Characteristics of Attention, *Psychol. Rev.*, 1896, pp. 158-180.

followed by a decline. In 1898, Binet[6] and Henri noted that the pulse at the periphery is not necessarily changed by intellectual work and that its change is not always accompanied by a change of the cerebral pulse. In the same year, Larguier des Bancels[7] reported measurements of his own pulse-rate during intellectual work lasting from 8 p. m. to 12 p. m. and during periods of rest covering the same hours of the day. As the results of four days' experiments he found that the pulse-rate during rest fell rapidly to a certain point and remained practically without change for the remaining hours, and that during intellectual work it fell more gradually but lower than the lowest point in the rest period. The average pulse rates in the four successive hours in the work periods were 80.9, 72.2, 67.15, and 62.9. The corresponding figures for the rest period were 80.4, 69.8, 65.75, and 65.25. From two series of experiments lasting from 8 a. m. to 12.20 p. m. he obtained results in which the pulse-rates in successive hours were 68.6, 64.5, 62.5 and 62.8 in the period of mental work, while they were 69.1, 63, 62.8 and 63 in the rest period.

In 1909, Benedict and Carpenter[8] reported the results of measurements of the change in the radial pulse-rate caused by mental work. During four hours of mental work such as taking college examinations, the subjects were asked to count the number of radial pulse beats per minute. As the result of the experiments tried on twenty-two healthy young men, they found that the average number of pulse beats per minute was 79 during the mental work, while it was 74 in the control experiment. They were not inclined to attribute the difference to the mental work itself, and said that it might be due to excitement on the part of the subjects; for it was the first time that they had gone into the respiration-calorimeter chamber. To the writer, these averages seem to be unreliable, for each subject measured his own pulse at any time that he wished during the examination. The result would be that if they measured their pulse oftener in the earlier hours of the mental-work experi-

[6] Binet, A. et Henri, V., La fatigue intellectuelle, Paris, 1898.

[7] J. Larguier des Bancels, Mesure de la fatigue, *L'Année Psychol.*, vol. 5, pp. 191-195.

[8] Benedict, F. G. and Carpenter, B. S., The Influence of Muscular and Mental Work on Metabolism and the Efficiency of the Human Body as a Machine, Washington, General Printing Office, 1909.

ments than they did in the corresponding hours of the control experiments, the average pulse-rate would be reported as relatively higher; for in both mental work and control experiments, the pulse-rate decreased gradually. From the complete reports of these experiments the writer found that seventy-nine measurements were taken in the first half of the experimental period in the mental-work experiment, while only sixty-six measurements were taken during the corresponding time in the control experiment. Since the average number of pulse beats in the earlier half of the experimental period was five and half beats greater than that of the later part, and the number of subjects tested was twenty-two, the difference in the number of measurements in the first half of the experimental period alone would make the average of the mental work test 3.1 beats per minute greater than the pulse rate of that of the control test. To eliminate this source of error, the writer took the average of the pulse-rate at the beginning and again at the end of the mental work experiment and at the beginning and at the end of the control experiment. The average rates are 87.4 and 76.3 respectively for the mental work test while for the control test they are 82.4 and 69.9. Thus, the decrease during the period of work is 11.1; during the period of rest it is 12.5.

In 1910, Billings and Shephard[9] made a careful study of "The Change of Heart Rate with Attention," performing their experiments upon three subjects. They measured the changes in the amplitude and rate of respiration and the pulse wave and rate in connection with the degree of attention, auditory, visual, and central. As the result of their experiments, the following conclusion is reached: "With close visual attention the breathing is uniformly decreased in amplitude. In rate it is sometimes increased, sometimes decreased and sometimes not changed at all. With auditory attention it is nearly always decreased in rate, but changed irregularly in amplitude. The breathing in the kind of central attention that we used is very little changed. These changes are probably adaptive; they remove a source of disturbance. Deep breathing, with its accompanying movements, would interfere with looking; rapid breathing interferes more with listening. With the effect of attention—the strain

[9] Billings, M. L. and Shephard, J. F., *Psychol. Rev.*, vol. XVII, pp. 217-228.

tends to increase the heart rate. Increased breathing, either in rate or amplitude, tends to increase the heart rate. Restricted breathing, either in rate or amplitude, tends to decrease the heart rate. For the latter reason one often finds a decreased heart rate with sensory attention, particularly at first. With central attention the heart rate is regularly increased."

2. *Change of Temperature*

Claude Barnard[10] reported a development of heat in the nerves caused by mental work. Heidenhein, Helmholtz and Rollenston,[11] according to Benedict and Carpenter, could not demonstrate that heat is generated in the nerves. In 1844, Davy[12] reported the results of eighteen series of experiments, several of them control tests. He found that the average temperature under his tongue at 12 p. m. was 98.4 F. on the mental work days, while it was 97.9 F. on the rest days. The most exhaustive study on the subject is perhaps that of Lombard,[13] published in 1879. Performing his experiments on the same subject, he first investigated the influence of four kinds of mental work on the temperature of the three regions of the head, anterior, middle, and posterior. The result obtained was that the mental work of four kinds caused a rise of temperature in all three regions of the head and that the degree of the rise and the rapidity of its appearance were different according to the kind of work and the region of the head. Lombard's further study of other individuals yielded similar results.

In 1881, Speck[14] reported that the average temperature on three resting days was 35.73 C. and on three mental-work days, 35.77 C. (the work lasting for from two to three hours). In 1884 Gley[15] made two series of experiments on himself. In the first series, the temperature was taken every five minutes during mental work of from one to three hours done between 5 p. m. and 8 p. m. and also during a rest at about the same period of

[10] Vorlesungen über der Thierische Wärme. Cited by Benedict and Carpenter, *loc. cit.*, on their page 46.

[11] *Ibid.*

[12] *Loc. cit.*, page 2.

[13] Experimental Researches on the Regional Temperature of the Head, London, 1879.

[14] Speck, Untersuch. über die Beziehungen der geistigen Thätigkeit zum Stoffwechsels, *Arch. Expt. Path.* u. *Pharmakol.*, vol. 15, pp. 87-88.

[15] Gley, E., Études de psychologie physiologique et pathologique, Paris, 1903, pp. 101-112.

the day. It was found that temperature fell not only during the mental work, but during the rest also. This fall is attributed by the observer to the immobile state which the subject was forced to maintain during the experiment. In the second series, a similar test was made while the subject was in bed, beginning about an hour after awakening in the morning so as to free the subject from the influence due to muscular inactivity. In this test, unlike the results of the other, the temperature rose more than one-half of a degree on the average during mental work of about an hour. Gley concluded from the result of these experiments that mental work raises the temperature. In 1898, Larguier des Bancels[16] noted that the fall of temperature under his tongue after two or three hours of mental work was 0.325 C., while it was only 0.23 C. after a rest for the same length of time. In 1909, Benedict and Carpenter[17] found that, as the result of the experiments tried on twenty-two individuals, the average temperature under the tongue was 98.9 F. before, and 98.4 F. after, about four hours of mental work, such as taking college examination. The average temperature under the tongue was 98.3 F. before, and 98.0 F. after, the same number of hours of rest.

3. *Changes in Metabolism*

The problem of the influence of mental fatigue on metabolism has attracted the attention of such investigators as Hammond, Oppenheim, Speck, Mosler, Luciani, Sherman, Bocker, and Mairet. Their results, however, are of little value to us because they did not report carefully the amount and nature of the mental work done. Some of them compared the waste products of the human body during the day with those during the night both as to quantity and quality. But the method is questionable inasmuch as they fail to take into consideration the fact that more physical work is done in the day time as well as more mental work. The results which are important for us are quoted below.

In 1881, Speck[18] reported the results of experiments tried on himself and one other subject. Using a respiration apparatus,

[16] *Loc. cit.* on page 3.
[17] *Loc. cit.* on page 3.
[18] Speck, *Arch. Exper. Path.* u. *Pharmakol.*, vol. 15, p. 128.

he concluded that mental activity has no influence on metabolism.

In 1899, Atwater, Woods, and Benedict[19] attempted to study this problem by the use of the respiration calorimeter. Their subject led a very quiet life for three days. During the next three days, he spent eight hours per day studying a German treatise on Physics and making mathematical computations. They found that during the twenty-four hours of each mental-work day, the average nitrogen output was 13.1 grams; and the carbon output, 241 grams. The averages were 12.5 grams and 248.4 grams respectively for the rest days.

In 1909, Benedict and Carpenter[20] reported their careful investigations. They determined, by the aid of a respiration calorimeter the amount of water vapor and carbon dioxide eliminated, oxygen absorbed, and heat produced, by each subject during four hours of mental work and during four hours of rest. Their conclusions were: "From the results of the data accumulated in this series of experiments on the effects of mental work on metabolism it would appear that the pulse rate was slightly increased, the body temperature somewhat higher, the water vapor output increased by about 5 per cent, the carbon dioxide production increased by about 2 per cent, the oxygen consumption increased by about 6 per cent, and the heat production increased by about one-half of 1 per cent as a result of sustained mental effort such as obtains during a college examination. Of these factors, those most accurately measured are undoubtedly the carbon dioxide elimination and the heat production. On the whole, however, the increase of both of these factors accompanying the mental exertion is so small and the exceptions are so numerous that it would not be wise to say whether or not the mental activity exercised a positive influence on metabolic processes in general. Indeed, more than half of the subjects studied produced more heat in the control than in the mental work test, which might be considered as negative evidence. This is especially so when it is considered that although every precaution was taken to eliminate all other extraneous influences it still remains a fact that, with many of these subjects, the experiments during the mental work period was their first experience inside of a

[19] U. S. Dept. Agric., Office of Experimental Station, Bull. 44.
[20] *Loc. cit.*, p. 3.

complicated respiration chamber and they were more or less disturbed by the novel experience, and perhaps more restless—that is, made more muscular movements than during the control period. In view of this fact, we are very strongly of the opinion that the results obtained in these experiments do not indicate that the mental effort has a positive influence on metabolic activity."

II. *Investigations of the Influence of Mental Work on Motor Power and Reaction Time*

1. *Motor Efficiency*

Mosso[21] was the first investigator who tried to correlate experimentally mental fatigue with motor efficiency. Using the ergograph he found, with himself as well as others, that mental work resulted in a decrease of efficiency of muscular contraction.

In 1896, Kemsies[22] tested the motor power of school children with Mosso's ergograph at different times during the school day and reported a distinct correlation between the amount of mental work done and decrease of the ability to lift the weights.

In 1900, Thorndike[23] tested various individuals with Cattell's spring ergograph. The subjects made one hundred, two hundred, or three hundred contractions, at the rate of one contraction per second with a rest of one minute after each one hundred contractions. They underwent the test in the morning when no mental work had been done and after a day's class work, study or office work. The comparison between the amount of physical force at these different times indicated that mental work effected no decided decrease in physical power. Thorndike closes his report thus: "To say that mental work does not necessarily decrease one's power to do physical work does not imply that the latter is independent of mental conditions, permanent or temporary, or that in individual cases whose mental make-up is well known, dynamic tests might not be indices of various mental conditions. Among these might be cer-

[21] *Loc. cit.*, p. 2.
[22] Kemsies, *Deutsche Medicinische Wochenschrift*, July 2, 1896.
[23] Thorndike, Mental Fatigue, *Psychol. Rev.*, vol. 7, pp. 576-578.

tain of the phenomena of fatigue. What is asserted is that the difference between a mind before and after it has worked for six or eight hours can not be detected by a record of physical work."

Keller[24] tested a school boy with the ergograph at different intervals during several days, giving him mental work between the tests. The difference in motor power indicated in the ergograph test is attributed to the mental work done. In 1903, Ellis and Shipe[25] tested many persons for their reaction time and their ability to lift a certain weight before and after continuous mental work, and found no uniform change either in motor efficiency or in reaction time as the result of mental work. In 1906, Marsh[26] wrote, "Where my own subjects noted mental depression or even headache on their records, the figures rarely failed to show a high grade of muscular performance at that time. But the younger the individual, the more prone he is to follow his feelings, in the quantity and quality of his work."

2. *Reaction Time*

In 1877, Bernstein[27] found that the general fatigue from a day's work causes loss of speed of reaction. In 1896, Bettmann[28] found that one hour's mental work, such as adding single-place numbers, caused a loss of speed of reaction, but also a decrease of the number of false reactions. The present writer has not found any difference between the reaction time in the morning before the day's mental work and in the afternoon after a considerable amount of mental work has been done.

III. *Investigations of Mental Fatigue Through Its Influence on the Sensibility of the Skin*

The first attempt to measure mental fatigue by changes in the

[24] Keller, *Biologische Centralblatt*, vol. 14, nos. 1, 2, 3. Cited by Ellis and Shipe in *Psychol. Rev.*, vol. 14, p. 506.

[25] Ellis, A. C. and Shipe, M. M., A Study of the Accuracy of the Present Method of Testing Fatigue, *Psychol. Rev.*, vol. 14, pp. 496-509.

[26] Marsh, H. D., The Diurnal Course of Efficiency, *Arch. of Phil. Psychol. and Sci. Method, Columbia Univ. Cont. to Philos. and Psychol.*, vol. XIV, no. 3.

[27] Bernstein, J. A., Ueber die Ermüdung und Erholung der Nerven, 1877, A.g. Phys., vol. 15. pp. 289-327.

[28] Bettman, S., Ueber die Beeinflussung einfacher psychol. Vorgänge durch körperl. und geist. Arbeit., *Psycohl. Arbeit.*, vol. 1, pp. 152-208.

sensibility of the skin was made by Griesbach[29] in 1895. He tested school children and adults with an aesthesiometer at different times and obtained a decided decrease in the sensibility of the skin as the amount of mental work was increased. In 1898, Wagner[30] and Vannod, following Griesbach's method, found that sensibility of the skin was weaker on the days of hard mental labor than on the days of rest. Binet[31] and his collaborators obtained results corresponding to Griesbach's.

In 1899, Leuba[32] published the results of his two series of experiments, one made at Heidelberg with three subjects and the other at Bryn Mawr College with six subjects. The method of investigation was that of Griesbach and Wagner: the threshold for one point was sought by a gradual decrease and that for two by a gradual increase of the distance of the points of the instrument. The results of both of these series agreed in showing that mental work did not decrease the sensibility of the skin and that the aesthesiometric method was not a fit method to measure mental fatigue.

Germann[33] used the aesthesiometer with a distance of a little over two centimeters between the two points. He determined the sensibility of the skin by the number of right judgments. On twenty-seven out of the thirty days covered by the investigation, a total of forty-two tests was made. Of these forty-two tests, twenty occurred in the morning previous to any study, while the remaining tests were made in the evening. The results of these tests showed that the errors were no more frequent in the evening tests than in those made in the morning. Germann concluded thus: "In at least one normal case, the percentage of errors of cutaneous tactile discrimination bears no constant, nor even relative, correspondence to the mental fatigue experienced by the subject."

In 1904, Bolton[34] made a careful study with one subject. He followed closely the method used by Griesbach and measured

[29] Griesbach, H., *Arch. f. Hygiene*, vol. 24, pp. 124-212.

[30] Wagner, L., Unterricht u. Ermüdung, Berlin, 1898.

[31] Binet, A. and Henri, V., La fatigue intellectuelle, Paris, 1898.

[32] Leuba, J. H., On the Validity of the Griesbach Method of Determining Fatigue, *Psychol. Rev.*, vol. 6, pp. 573-598.

[33] Germann, Geo. B., On the Invalidity of the Aesthesiometric Method as a Measure of Mental Fatigue, *Psychol. Rev.*, vol. 6, pp. 599-605.

[34] Bolton, T. L., Ueber die Beziehungen zwischen Ermüdung, Raumsinn der Haut und Muskelleistung., *Psychol. Arb.*, vol. 4, pp. 175-234.

the threshold of discrimination of two points before and after half an hour, an hour, and two hours of addition of one-place numbers, and found no difference in the discrimination before and after the mental work. Neither could he find a gradual decrease in the per cent of right judgments according to the increase of the length of the mental work.

IV. *Investigations of Mental Fatigue Through Its Influence on the Efficiency of Mental Functions*

For our present knowledge in regard to the problem, we are most indebted to Professor Kraepelin and his pupils, and their researches demand our special attention. In the present section, we shall first present a brief account of the previous investigations made outside of Kraepelin's school; and second, general outlines of the results obtained by Kraepelin and his pupils.

1. *A Brief Account of the Investigations Made Outside of Kraepelin's Laboratory*

One of the earliest attempts to study the subject was made by Galton.[35] From the answers given by one hundred and sixteen teachers to the questions respecting the symptoms of fatigue of school children, Galton drew the following conclusions: First, mental fatigue causes worry and excitement. Second, fatigue occurs more often among those who work alone or are impelled to work hard through eagerness to excell.

In 1879, Sikorski[36] made experiments on the influence of mental fatigue on voluntary movements like talking and writing. The results of his investigation showed that errors in these movements increased after certain mental work and the amount of increase was in proportion to the amount of work done. The increase in the number of errors is attributed by him to a decrease in ability to distinguish small psycho-physical differences, weakening of memory and the appearance of mental excitement. The increase of the number of errors in the course of work

[35] Galton, Fr., Remarks on Replies by Teachers to Questions Respecting Mental Fatigue, *Jour. Anthro. Institute,* vol. 18, p. 157.

[36] Sikorski, Sur les effects de lassitude provoquées par les travaux intellectuels chez enfants de l'âge scolaire. *Annales d'hygiene publique,* 1879, vol. 2, pp. 458-467.

was observed by Burgerstein[37] in 1891, Laser[38] in 1894 and Ebbinghaus[39] in 1897.

In 1895, Holmes[40] tested school children in regard to changes in their ability to add as a result of continuous functioning. Comparing the amount of work done and errors made in each of the four successive work periods, each period lasting for nine minutes, this writer found that both errors and the amount of work increased from period to period. When gymnastics was introduced between the two periods, the errors were reduced to a considerable extent, while the amount of work done was unaffected. For this reason the author regards the increase in the number of errors as a result of fatigue; the increase in the amount of work done, as the result of practice. Examination into the nature of the errors revealed that the reproductive process, rather than the perceptual and motor processes, is affected by fatigue. It was also found that the children did no better work in the last period.

In 1900, Thorndike published two articles reporting his two series of investigations. In the beginning of the first article,[41] he gives a brief account of the two theories of mental fatigue. One of these, the mechanical theory, is that mental work causes a gradual decrease of mental efficiency in proportion to the amount of work done. The other, called the by-product theory, is that mental fatigue is not a simple phenomenon. Just as muscle is fatigued because of the fatigue substances produced by its own activity, so mind produces as a result of its own activity, various by-products such as feelings of weariness, headache, and sleepiness. These products tend to weaken the ability to do mental work. The effect of fatigue, according to the theory, appears now and then suddenly in the course of work.

The purpose of these experiments was to determine the relative merits of these two theories. Four subjects underwent the

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[37] Burgerstein, L., Die Arbeitscurve einer Schulstunde, *Zeitsch. f. Schulgesundheitspflege*, vol. 4, pp. 543-563.

[38] Laser, H., Ueber geistige Ermüdung beim Schulunterichte, *Zeitsch. f. Schulgesundheitspflege*, vol. 7, pp. 2-22.

[39] Ebbinghaus, H., Ueber eine neue Methode zur Prüfung geistiger Fähigkeiten und ihre Anwendung bei Schulkindern, *Zeitsch. f. Psychol.*, vol. 13, pp. 401-457.

[40] Holmes, M. E., The Fatigue of the School Hour, *Ped. Sem.*, vol. 3, pp. 213-234.

[41] Thorndike, Mental Fatigue, I, *Psychol. Rev.*, vol. 7, pp. 466-489.

tests in the morning after a night's rest, and in the evening after hard mental work. Tests were also made immediately before and after continuous exercise of special mental functions. The results showed that mental efficiency after mental work is not necessarily less than that before the work, and that in the course of two or three hours of mental work, the effect of fatigue is not strong enough to outweigh the effect of practice. His conclusions are as follows:

(1) "Mental energy, if it means anything, must mean a something which mental work uses up in regular proportion to the work done. But incompetence, mental fatigue, does not come in regular proportion to the work done."

(2) According to introspection, there is no feeling of general mental incompetence.

(3) The feeling of fatigue can not be a measure of mental inability. On the whole, the results of the first series strongly favor the by-product theory.

The second series of experiment, recorded in his second article,[42] was made on school children, in order to determine the influence of school work on their mental efficiency. The functions tested were written multiplication of four-place numbers by four-place numbers, marking misspelled words, drawing certain figures from memory, writing certain numbers, nonsense syllables and letters from memory, and also counting the number of dots on a chart which was exposed five minutes. Every precaution was taken to guard against such errors as would come from testing a group of children specially selected, or with a different degree of practice, etc. The children met all the tests just as well after as before a day's school work except one: i.e., memorizing nonsense syllables. In this experiment, their records in the late test were slightly inferior to those made in the early test. "A fair claim to make on the basis of the results obtained," says Thorndike in conclusion, "is that a regular day's work in the grammar school does not decrease the ability of the child to do mental work. . . . The chief responsibility for mental exhaustion in scholars falls, I should be inclined to think, not on a creator who made our minds so that work hurt them, nor on the public opinion which demands

[42] Thorndike, Mental Fatigue, II, *Psychol. Rev.*, vol. 7, pp. 547-579.

that children shall do a given amount of work, but upon the unwise choice of material for study, the unwise direction of effort, the unwise inhibition of pleasurable activities, the unwise abuse of sense-organs and unattractiveness of teachers and teaching."

The results of tests made on an adult subject, W, agree with the foregoing. In the first experiment, W marked every word containing both *e* and *t* on one hundred and fifty-one pages of a book, each page containing about seven hundred and twenty-five words of text. He worked for eight hours without rest. The number of words correctly marked was only a little less in the later part than in the earlier part of the test. In the second experiment in three hours of estimating the areas of small parallelograms of paper, the accuracy of W's judgment was constant for the first two hours, but fell off seven per cent in the last hour. In the third test, the results showed that fatigue, if present, did not outweigh the practice effect. In the fourth test, W measured the time it took him to correct examination papers for about six hours, and observed no sign of fatigue. In the fifth experiment, W tested the change in the time it took to go over three hundred and fifty cards, on which were written titles of foreign books and articles, to decide in each case to insert it in a certain bibliography. Here, too, no fatigue effect was observable. The author asserts that the results do not at all disprove the existence of fatigue. On the contrary, mental incompetency is a fact. His conclusion is that the causes of fatigue are not mere decrease of energy, but highly complex by-products of mental work.

In 1903, Ellis and Shipe[43] investigated fatigue in special mental functions resulting from general mental work. The mental functions tested were (1) addition of numbers, (2) writing the cubes of numbers up to nine, and (3) memorizing nonsense syllables. Five advanced students and a professor took part in the first experiment. The subjects worked on adding, cubing and memorizing for two minutes, each at about 8:30 a.m. and at 5:30 p.m. after severe, unremitting mental work with rest for luncheon only. The results were divergent with different individuals and on different days, but they utterly failed

[43] *Loc. cit.*

to show a difference in the amount of mental work done in the two tests. The same kind of tests, made on the children between the ages of eleven and sixteen, yielded somewhat uniform results tending to show that mental efficiency was much greater after the mental work.

In 1903, Pillsbury[44] studied the relation between the attention wave and mental fatigue. The efficiency of attention was measured by the ratio of the visibility to the invisibility of a gray ring on a slightly different background. The number of subjects was five, including the experimenter himself. He found that the ratio was smallest after hard mental work, while it was greatest after rest. It was also found that the efficiency of attention corresponded to the total length of the wave, and it underwent diurnal periodicity like the Traube-Hering waves of blood pressure. He gave the following explanation for the cause of the inefficiency of attention: "We can explain our results if we consider the fluctuations of the attention a resultant of two physiological processes, of the degree of efficiency of the cortical cells, on the one hand, and of the state of excitation of the vasomotor center on the other. The reinforcement from the medullary center would have its effect in decreasing and increasing the response of the cells, and would determine the ratio of fluctuation, but the proportion of the cycle in which they would be sufficiently effective to give rise to a sensation, would depend primarily upon the freshness of the cells themselves. The degree of efficiency of the cells, then, would be measured directly by the ratio of the period of visibility to the period of invisibility of our minimal stimuli, while the length of the total wave would be a measure of the Traube-Hering wave."

In 1910, Winch[45] published his experimental study of mental fatigue in the evening schools. He took three classes which had homogeneous groups of students, and divided each homogeneous group into two equal groups, A and B, according to the results of the previous tests. The group A did the given fatigue tests at 8 p. m. and the group B at 9 p. m. The results of the tests made on those classes showed that the work done by the group

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[44] Pillsbury, W. B., Attention Waves as Means of Measuring Fatigue, *Amer. Jour. of Psychol.*, 1903, vol. 14, pp. 541-552.

[45] Winch, W. H., Some Measurements of Mental Fatigue in Adolescent Pupils, *Jour. of Ed. Psychol.*, vol. 1, no. 2, pp. 5-12 and 83-100.

B was much worse than the group A. He concluded that evening school is of comparatively little profit and that a short period of work after a day's labor is enough to produce low efficiency of mental functions.

In 1911, Thorndike[46] reported the results of an experiment made on eighteen college students. The mental function tested was mental multiplication of three-place numbers by three-place numbers. The subjects worked for from two to twelve hours, each choosing a convenient time, and again for a short time next day. Efficiency was measured by the time taken to do each example. The amount of fatigue was measured by the difference between the time taken at the end of the continuous work period and that at the beginning of the test made next day. The average ratio between the average time per example at the end of the long work period and at the beginning of the brief test on the following day, expressed as a percentage, was about 61 per cent for the group. He found that the number of errors varied inversely as the degree of efficiency, and that the feeling of fatigue bore little or no relation to mental efficiency.

2. *The Important Investigations Made by Kraepelin and His Pupils*

It was by Axel Oehrn[47] in 1889 that the first attempt to determine and analyse the work-curves of certain mental functions was made, so far as the writer has been able to discover. He measured the efficiency (1) of perception through ability to count letters, to search for given letters, and to read proof; (2) of memory through ability to memorize nonsense syllables and lists of numbers; (3) of association through ability to add one-place numbers; (4) of motor functions through writing sentences from dictation and reading aloud. Each subject marked his place on the stroke of a bell at the end of five-minute periods so that the amount of work in each such period might be computed. Ten professors and graduate students took part in the tests, which yielded the following results:

[46] Thorndike, Mental Fatigue, *Jour. of Ed. Psychol.*, vol. 2, no. 2, pp. 61-80.

[47] Experimentelle Studien zur Individualpsychologie, *Psychol. Arbeit.*, vol. 1, pp. 92-151.

(I) The predominant factors which determine the course of efficiency of mental work lasting for one hour are practice and fatigue.

(II) This course of efficiency is represented by a curve, which rises at first, and falls toward the end of the test (showing an increase of efficiency, followed by a falling off). The effect of practice and fatigue on efficiency are matters of common experience. Both are undoubtedly present throughout the tests. The length and the height of the rise vary in different individuals and with different functions.

(III) Individual curves are subject to other minor fluctuations. Many of them show a sudden rise in the first ten or twenty minutes followed by a sharp fall before they reach the point of maximum efficiency. This sudden rise is explained by Oehrn as resulting from strain of attention.

(IV) The point of maximum efficiency, or the point where the fatigue effect begins to outweigh the effect of practice, comes sooner in the curve of the function which is more automatic than in that which is more purely mental. The average time at which the maximum point is reached is as follows: At the 24th minute, in learning nonsense syllables; at the 26th minute, in writing from dictation; at the 28th minute, in addition; at the 38th minute, in reading; at the 39th minute, in counting letters one by one; at the 59th minute, in counting letters three by three; and at the 60th minute, in learning numbers.

(V) In measuring the effect of fatigue and practice, Oehrn used the following formulae:

$$\text{Practice} = \frac{(M - m^1) \times 100}{M},$$

$$\text{Fatigue} = \frac{(M - m^2) \times 100}{M},$$

M stands for the point of maximum efficiency, m^1 stands for the first and m^2 stands for the second point of minimum efficiency. The average amount of practice thus obtained in each function is as follows: Writing, 1.8; reading, 5.7; memory of nonsense syllables, 6.2; counting letters one by one, 6.9; counting letters three by three, 11.1; memory of numbers, 28.0.

The average amount of fatigue is as follows: Reading, 5.9; counting letters one by one, 6.2; counting letters three by three, 6.9; writing, 8.4; addition, 15.4; memory of numbers, 22.3; memory of nonsense syllables, 38.5.

The effects of both practice and fatigue, in general, are less in the less intellectual functions. The ability to memorize nonsense syllables is an apparent exception. Oehrn holds that the smaller net effect of practice is due to the far greater effect of fatigue.

In 1892, Bettmann[48] studied in himself the influences of physical and mental work on certain psychological functions. To produce physical fatigue, he walked for two hours; for mental work, he added numbers for one hour. The influence on psychological functions was measured in the first series by 50 reactions, 30 minutes' work at memorizing numbers, 30 minutes' work at addition, and by 300 choice reactions (in the second series only). In both series of experiments, a day on which the tests were taken after mental work was followed by a day of physical work, then by a normal day when the tests were taken after a period of rest, then by another day of mental work, and so on in rotation. The first series covered twelve days; the second, nine. The mental work was done from 7 to 8 a. m.; the walking, from 6 to 8 a. m.; and the testing, from 8 to 9:10 a. m. in the first series. In the second series, the mental work was done from 7:30 to 8:30 a. m., the walking from 6:30 to 8:30 a. m., and the testing from 8:30 to 9:55 a. m.

The results obtained were as follows: The reaction time was decidedly affected by the work of both kinds. In the second actions in each experiment was (in thousandths of a second) as follows:

	1	2	3	4	5	Average
Normal day	312	381	284	285	299	292
Mental work day	376	391	386	388	377	384
Physical work day	296	254	246	234	254	257

The percentage of false reactions was: 1 per cent on normal days, 2.9 per cent on mental work days, and 26.9 per cent on physical work days.

[48] Bettmann, S., Ueber die Beeinflussung einfacher psychologischen Vorgänge durch körperlische und geistige Arbeit, *Psychol. Arbeit.*, vol. 1, pp. 152-208.

The results of the choice reaction-time test in the first series were about the same. The average reaction time was 389σ with no false reactions on the mental work days, 309 with 3.6 per cent false reactions on the normal days and 340 σ with 19.5 per cent false reactions on the physical work days. The influence of both mental and physical fatigue increases the time of choice. The quick reaction-time after the physical work is the result of excitement which makes one react before the choice is made intellectually. This is indicated by the large number of false reactions.

The tests of word reactions yielded the following results: The average word reaction-time was 317σ on normal days, 391σ on mental work days and 357σ on physical work days. Thus continuous work of both mental and physical functions results in increasing the time of word reaction.

The effect of practice is very great in memorizing lists of numbers. The excess in the amount of work done on the last normal day over that done on the first normal day was 38.5 per cent of that done on the last normal day; on the last physical-work day it was 21.9 per cent; on the last mental-work day, 11.2 per cent. These figures indicate also that the fatigue resulting from both physical and mental work has an unfavorable effect on the influence of practice. The average number of digits remembered in the first and second halves of the thirty-minute period was:

	First half	Second half
Mental work day	237	236
Normal work day	321	302
Physical work day	237	221

In the addition test, the average number of digits done in the first and second halves of the thirty-minute periods was as follows:

	First half	Second half
Mental work day	794	778
Normal work day	911	882
Physical work day	800	771

The two hours of walking and the one hour of adding, then, result in reducing efficiency, both in the function of memorizing and in that of adding.

The conclusions which Bettmann gives are, in substance, as follows:

(I) Intellectual work of one hour and physical work of two hours have an unfavorable influence on the efficiency of mental functions.

(II) Decrease in mental efficiency after work of either sort shows itself in the increased time taken for apprehension, choice, and association, in the weakening of memory and in reducing the effect of practice.

(III) Decrease in mental efficiency is as great after physical work as after intellectual work. Therefore, gymnastics, walking, and many other forms of physical exercise are not suitable recreation after mental work.

(IV) Motor inefficiency appears after mental work, and excitement of the motor centers after physical work.

(V) Excitement in motor centers disappears sooner than mental inability. Its disappearance is hastened by taking up intellectual work.

(VI) The influence of fatigue such as results from the tests described above disappears very soon, while that resulting from work such as research throughout the night lasts for many days.

Amberg[49] investigated the influence of periods of rest and work of various length on mental ability and its variation with different individuals. The mental functions tested were ability to add to one-place numbers and to memorize lists of numbers. The addition research was of two kinds, a one-hour test and a two-hour test. The one-hour test was made on the subject A, (1) with a five-minute rest between two thirty-minute work periods; (2) with five minutes' work and five minutes' rest coming one after another; and (3) with fifteen minutes' rest between two thirty-minute work periods. The latter test was made also on the subject B. The two-hour test was made on the subject A and several others with a fifteen-minute rest between two one-hour work periods. The test of memory was

[49] Amberg, E., Ueber den Einfluss von Arbeitspausen auf die geistige Leistungsfähigkeit. *Psychol. Arbeit.*, vol. 1, pp. 300-377.

made on two individuals, A and C, with a fifteen-minute rest between two thirty-minute work periods.

The influence of rest was studied by noting the difference in the amount of work done in the test with rest and that done in the control test, in which the subject worked without rest. Eight days were devoted to the experiment, with periods of work and rest of varying length, the control test coming on the first day, the rest test on the second day, and so forth on alternate days.

Since the results of each rest test were affected by the practice gained in the control test of the preceding day, the following method was used to make comparison possible. In the one-hour test, half the average percentile gain in the amount of work done in each control test over that done in the preceding test two days before, was taken as a coefficient of daily practice gain. A coefficient was likewise obtained in the two-hour test. The influence of rest was measured by the difference between the amount of work done in each rest test and that done in the control test of the day before multiplied by one plus this coefficient. By dividing the sum of these differences by four, the average influence of a certain length of rest was gained.

The results thus obtained were:

(I) Different lengths of rest exercise different influences on mental efficiency after rest.

(II) Favorable lengths of rest are determined by the duration of work preceding it. For instance, a fifteen-minute rest was unfavorable after a half-hour of work, but it was favorable after an hour of work. A five-minute rest is better after a fifteen-minute work period than after a five-minute work period. After thirty minutes of work, a five-minute rest was better than a rest of longer duration. This is explained by the fact that, during five minutes, the effect of "warming up" is retained, while the effect of fatigue is largely offset. If the rest is longer the effect of "warming up" is also lost.

(III) Favorable lengths of rest are determined by the kind of work preceding it. For example, after a thirty-minute work period, a fifteen-minute rest was reported favorably in the memory test, while it was unfavorable in the case of the addition test.

Rivers and Kraepelin[50] attempted to find the influence of different rest periods after the same length of work. The mental work used was addition of one-place numbers and only one subject was observed. There were two series of experiments. In the first series, there was a half-hour rest after each half-hour of work; in the second there was an hour of rest between half-hour work periods. In both series of experiments, 'long' and 'short' days alternated, the 'long' preceding. Eight days were devoted to the first series, six to the second. On the long days there were four work periods; on the short days, but one.

The authors studied the four main factors which influence the efficiency of mental function; "warming up" (Anregung), spurts (Antrieb), practice (Uebung) and fatigue (Ermüdung). The existence of "warming up" effect was indicated by its loss after the one-hour rest. Comparing the amount of work done in the second half of each work period with that done in the first half of the following period, it was found that the gain was greater in the first series with the half-hour rest period; a phenomenon attributed to the fact that the rest period of a full hour in the second series caused a greater loss of "warming up" effect. This is even more significant, since fatigue would be more completely offset by the longer rest period. In comparing the amount of work done in each successive five minutes, it was discovered that there was a sudden increase here and there in the amount done, which lasted but a few minutes. This was attributed to the influence of spurts, which are defined by the authors as follows: "We designate these brief periods of greater accomplishment as 'spurts' in order to distinguish the special effort of the will from such ordinary influences as practice, fatigue, and 'warming up' effect." The average amount of practice effect resulting from thirty minutes of work, called, for convenience, the *average daily practice gain,* was determined as follows: The amount of work done in the first work period of each long day was subtracted from that done on the succeeding short day, and the difference, divided by four (the number of the work periods on a long day), was assumed to represent

[50] Rivers, W. H. R. and Kraepelin, E., Ueber Ermüdung und Erholung, *Psychol. Arbeit.,* vol. 1, pp. 627-678.

the practice effect of a thirty-minute work period of a long day. That of a short day was measured by the gross excess in the amount of work done in the work period of the succeeding long day over that done on the short day. These results were averaged.

The amount of fatigue in each thirty-minute work period was determined as follows: To the amount of work done in a given period were added the "daily practice gain" as computed above, and the "daily practice loss," also previously determined; from this sum was subtracted the amount of work done in the period immediately succeeding it. The average amount of fatigue is given below expressed as a per cent of the reckoned amount.

Fatigue effect	30 minutes' rest	60 minutes' rest
First work period	0.8%	......
Second work period	4.6%	4.9%
Third work period	14.8%	10.3%

The fatigue effect in the third period is smaller after the one-hour rest than after the thirty-minute rest. The experimenters conclude that the thirty-minute rest was not long enough to eliminate all the fatigue effect which resulted from an equal length of work.

The aim of the research by Weygandt[51] was to investigate the relative influence of various changes of work on the recovery of efficiency lost through fatigue. The method used was as follows. The experimental days were of two kinds; namely, change-of-work days and control days. During a test of an hour and fifteen minutes, the subject did a certain kind of work during the first thirty minutes, changed it to another kind in the next thirty minutes and resumed the first kind for the last fifteen minutes. On the control day, the subject did the same kind of work as that done during the first thirty minutes on the change-of-work day, for an hour and fifteen minutes without change. The comparison was made between efficiency in the last fifteen minutes on the change-of-work day, and on the control day. In comparing the two, Weygandt used the same method as that

[51] Weygandt, W., Ueber den Einfluss des Arbeitswechsels auf forlaufende geistige Arbeit., *Psychol. Arbeit.*, vol. 2, pp. 118-202.

of Amberg, to eliminate errors resulting from the order of the test. The tests were varied by using the different kinds of work in various combinations. Six subjects took part.

The results obtained were, in substance, as follows:

(I) Change of work has a different influence according to the degree of difficulty of the work introduced for change. If the work introduced is more difficult, its influence is unfavorable, and *vice versa*

(II) Whether any given work is considered hard or easy, depends on the individual and the degree of practice in the work assigned.

(III) Fatigue in one function is transferable to another.

(IV) The insertion of a different kind of work has very often a favorable influence in the form of a spurt due to the change (Wechselsantrieb) which amounts to very little and disappears soon.

(V) A favorable influence due to spurts comes very often in the state of fatigue; it depends on the motor excitement caused by change of work.

Voss[52] studied the minor fluctuations of a work curve in order to determine their causes. The author investigated the problem by finding: first, the time taken for adding each two succeeding figures; then, the extent of deviation of each single addition time from the average; and finally, the frequency of the occurrence of fluctuations of different lengths. Special apparatus was arranged so that a record of the time could be taken for each addition. The mental work employed was an hour of addition. The number of subjects was three, including the experimenter himself. The results thus obtained were:

(I) The time taken for a single addition ranged, as a rule, from 0.4 sec. to 1.2 sec., but there were a few cases in which it took more than 1.2 sec. A majority of the single addition times fell between 0.6 sec. and 0.8 sec.

(II) In all the subjects, the effect of practice increased the frequency of occurrence of a single addition time of 0.6 sec. and decreased the average deviation from it. It did not, however, increase the frequency of occurrence of the shortest addition time of 0.4 sec.

[52] Georg von Voss, Ueber die Schwankungen der geistugen Arbeitsleistung, *Psychol. Arbeit.*, vol. 2, pp. 399-449.

(III) The effect of fatigue, on the contrary, decreased the frequency of occurrence of an addition time of 0.6 sec. and increased that of 1.0 sec.

(IV) The effect of the spurts tended to decrease the addition time to the minimum and made it very irregular.

(V) The fluctuations were most frequent at lengths of from 2 sec. to 2 3/5 sec. This duration, according to other researches made by the same author, was found to be about the same as that of fluctuations of attention. Therefore he thinks that the fluctuation of the addition time is probably due also to the same change in the central nervous system.

A very brief description of the investigation made by Lindley[53] will be sufficient, as his methods are described in full in Chapter V. The aim of the investigation was to find factors entering into the work curve, such as: period of maximum rest, gain by practice, persistency of practice effect, susceptibility to fatigue (Ermüdbarkeit), "warming up" effect, spurts, and individual variation.

The subjects were three in number, including the experimenter. The mental function tested was the addition of one-place numbers. Experimental days of five kinds followed each other in rotation for twenty-six days, as follows: a day on which one hour's continuous work was done; four days on each of which there were two thirty-minute work periods separated respectively by rests of five, fifteen, thirty, and sixty minutes; the one continuous hour work day again, and so forth.

The following conclusions were reached from the series of experiments thus arranged:

(I) The influence of rest is threefold; elimination of fatigue effect, loss of "warming up" effect, and loss of practice effect.

(II) The best period of rest varies with individuals. With the three subjects tested, it lies between fifteen minutes and sixty minutes or more, but, in case the "warming up" effect is great while fatigue is slight, work without rest amounts to fully as much as work done after the period of maximum rest. The absolute excess and the percentile excess of work done in the work period before, over that done after, the different rest periods with the three individuals are given below.

[53] Lindley, E. H., Ueber Arbeit und Ruhe, *Psychol. Arbeit.*, vol. 3, pp. 482-534.

Rest	Subject A		Subject B		Subject C	
	Absolute	%	Absolute	%	Absolute	%
0	47	1.8	96	4.2	186	11.3
5 minutes	23	0.8	29	1.2	118	7.0
15 minutes	135	4.8	63	2.7	109	6.4
30 minutes	132	4.6	72	3.1	69	3.9
60 minutes	103	3.5	62	2.5	10	0.5

(III) Capacity to gain by practice seems to go hand in hand with weaker persistency of practice effect and greater susceptibility to fatigue.

(IV) The greater part of the practice effect disappears within twenty-four hours after the cessation of work.

Miesemer[54] investigated the same problem as Bettmann, namely, the influence of physical and mental work on certain simple mental and motor functions, using for physical work, one hour's walking; for mental work, one hour's addition. Their influence on mental functions was measured by the ability to perceive nine letters exposed for .017 sec. and to reproduce them after a half minute. A record was made of the number of letters perceived and reproduced; of those rightly perceived and reproduced; of those wrongly perceived and reproduced. Their influence on motor functions was measured by the ability to write numbers from one to ten and from ten to one. Eighteen days were spent on the investigation in the case of mental functions; twenty-one days on the investigation in the case of motor functions. The physical-work test, the control test and the mental-work test came in rotation on successive days in the order named. In the physical-work test, mental and motor efficiencies were measured immediately after the walking; before the control test, no work was done; and in the mental-work test, measurements were made immediately after the hour of adding.

The experiments yielded the following results:

(I) The number of letters perceived and the number rightly perceived increased after both kinds of work, but more after the mental work. The number of letters wrongly perceived was

[54] Miesemer, K., Ueber Psychische Wirkungen körperlicher und geistiger Arbeit., *Psychol. Arbeit.*, vol. 4, pp. 375-434.

greatest after the physical work. This was attributed to excitement of the motor centers by the physical work.

(II) On the other hand, both walking and adding caused a decrease of efficiency in reproducing letters perceived after a half minute, and the decrease was greater after the adding. The number of letters reproduced wrongly also increased after work of both kinds and this decrease in efficiency was again greater after the mental work.

(III) Speed in writing and the size of the figures written increased after the physical work, and decreased after the mental work. This corresponds with the result obtained by Bettmann in which the speed of reaction and the number of the false reactions increased after the physical work. This was explained by assuming that mental work exerts an inhibiting influence on the motor centers, while the physical work excites them.

The aim of the investigation made by Hylan and Kraepelin[55] was to ascertain the effect of practice and fatigue. Long periods of work and rest have hitherto been used by such investigators as Amberg, Rivers and Lindley. Hylan and Kraepelin made a new departure, by adopting short periods. An advantage of using shorter periods is, in their opinion, that not only can experiments be made on a greater number of individuals, but also a greater number of measurements can be obtained from the same individuals. A disadvantage is that the effect of work and rest is sometimes so slight that it is not measurable.

The mental function used was the ability to add one-place numbers. On each experimental day, there were four five-minute work periods in groups of two, separated by a thirty-minute rest. On the first day, the two periods of the former group were separated by no pause; in the latter a twenty-minute pause intervened between the two periods. On the second day, the pauses were respectively one minute and fifteen minutes; on the third day five and ten minutes. Three subjects underwent the tests.

The results of the experiments were:

(I) Mental work lasting only for five minutes produced an appreciable amount of practice and fatigue. The ratio of these

[55] Hylan, J. P. and Kraepelin, E., Ueber die Wirkung kurzer Arbeitszeiten., *Psychol. Arbeit.*, vol. 4, pp. 454-495.

products determined efficiency. The amount differed with different individuals. For instance, W's practice gain was 9.6 per cent and H's was 3.5 per cent of his own average amount of work, while K made progress only in the beginning and his average daily gain was very small.

(II) The fact that the amount of work done on one day was greater than that done on the day before in spite of the fact that efficiency at the end of one continuous work period was lower than at the beginning, indicates that the effect of practice outlasted that of fatigue.

(III) The influence of rest was favorable or unfavorable. It eliminated, on the one hand, the effect of fatigue so that the amount of work after rest was greater. But, on the other, it tended to destroy the effect of "warming up" and practice. "Warming up' effect was lost sooner than practice effect. The most favorable length of rest was that which resulted in the greatest ratio of favorable to unfavorable influence. The five-minute rest was best after five-minute's work in all the individuals tested. There lay an unfavorable length of rest between five minutes and a certain period longer than five minutes, differing with different individuals. For instance, with H the rests of fifteen minutes and of twenty minutes were unfavorable, while the thirty-minute rest was again favorable. With W, the unfavorable length of rest lay between five minutes and twenty minutes. With K, the longer the rest, the better the effect.

CHAPTER II

PROBLEMS AND EXPERIMENTS OF THE PRESENT INVESTIGATION

To make the aim of the investigation clear, it is important that we should define the term mental fatigue. By mental fatigue, we mean the unfavorable and destructive effect which continuous mental work produces on mental functions. In a complete investigation, we should have to study at least its influence on the four large classes of mental and physical processes mentioned in Chapter I. Lack of time for a more thoroughgoing examination of each problem, however, limits the scope of the present investigation to its influence on (1) certain physical processes; (2) the feelings of fatigue; (3) intellectual efficiency. We shall, in the following pages, state more specific phases of each problem and their relations to the results of the previous investigations.

(I) In regard to the influence of mental fatigue on physiological processes, we recorded the pulse and the body temperature. In the matter of the influence of fatigue on the pulse, previous investigators are not agreed. Davy, Gley, and Billings and Shephard, for instance, found that mental work increased the pulse rate, Vaschide and Larguier des Bancels have found that it decreased it, while Benedict and Carpenter found no change at all. These contradictory results may be due to the difference in the subjects used, or in the duration of mental work. We have no data on which to judge whether or not there was a difference between their subjects, but in regard to the different lengths of the work period, we do know that all of the investigators who reported an increase of the pulse rate employed a working period of less than one hour while those who obtained opposite results had a working period of more than four hours. Consequently, if, as MacDougall states, mental work increases the pulse rate at first but lowers it during the later part of a work period, their obtaining contradictory results is perfectly natural. If the shorter period of work is used, it is possibly only mental excitement that raises the pulse rate. These considerations lead us to direct our labors to the investigation of the following subjects:

1. The direction and amount of change in pulse rate during continuous mental work lasting long enough to produce enough fatigue to decrease intellectual efficiency.

2. The correlation between the change in the pulse rate and that in mental efficiency.

In regard to the bodily temperature, all the investigators agree that mental work raises it. Here, again, a possible error may come in from the effect of excitement. Therefore, we have taken the same precautions as in the case of the pulse rate.

(II) In regard to the relation of mental fatigue to the feeling of fatigue, Kraepelin, Thorndike and some others agree that feelings of fatigue are not in any definite way related to decrease of mental efficiency. We have investigated the problem by ascertaining:

1. The direction and the amount of the change in the feeling of fatigue during continuous mental work.

2. The correlation between the state of this feeling and mental efficiency.

3. The correlations between the change in the feeling and the change in mental efficiency during continuous mental work.

(III) The problem of the relation of mental fatigue to the change in mental efficiency is divided into three parts. 1. The first concerns the factors having influence on the efficiency of mental functions. The results of the previous investigations are not uniform. Kraepelin and his pupils, for instance, found that mental efficiency depends on practice, fatigue, "warming up," Gewöhnung, and spurts. But Thorndike found only the first two of these factors playing important parts. It is, therefore, necessary that a more careful investigation of the problem be made before we can know how far the change in mental efficiency is really due to fatigue itself. 2. The second concerns the effect of mental fatigue on the efficiency of the special mental function exercised. Kraepelin, Amberg and others discovered that the longer the work lasts, the longer it takes to eliminate the effect of fatigue resulting from the work. This they interpret as showing that decrease of mental efficiency is in proportion to the increase of the duration of mental work. But Thorndike, and Ellis and Shipe found that efficiency of mental functions was not less after certain hours of mental work. In the attempt to solve this problem, we have endeavored to determine:

a. The amount of fatigue caused by continuous work.

b. The course of the change in efficiency during continuous work.

3. The third concerns the transfer of fatigue. Kraepelin states that the greatest difference between mental fatigue and muscular fatigue is that mental fatigue has its effect on the whole field of mental activity, while muscular fatigue affects only the special muscles exercised. In short, Kraepelin holds that fatigue is transferred almost *in toto*. Thorndike, on the contrary, maintains that the effect of mental work is very largely restricted to the special function exercised. Our investigation of this problem was along the following lines:

a. The influence of such mental work as that of a school day for a student upon the special mental functions, such as adding or memorizing.

b. The influence of the exercise of the special mental functions on other functions.

c. The correlations between the fatigue in one function and that in the other, both being affected by the same mental work.

d. Individual differences.

Experiment I

The first experiment was made during February and March, 1909, at Teachers College, Columbia University. The purpose of the experiment was to ascertain: (1) the amount, rate and the change of the rate of fatigue in the special mental function exercised, and (2) the amount of the fatigue transferred to certain other functions.

The particular function tested was that exercised in mental multiplication of pairs of numbers like

2645	8324	7954	5438
5784,	7384,	3528 and	2347.

About one thousand different combinations of figures were used.

The order of the examples being made by chance, the distribution of difficult and easy examples is random. The subject of the experiment was the writer herself. But the danger that her presuppositions affected the results was precluded by the fact that the writer's knowledge of mental fatigue at that time was not enough to enable her to form any expectation of what form the fatigue curve in mental work would take.

The experiment is divided into two parts by a slight difference of method: each part consisting of two series, the practice series and the fatigue series.

Experiment I, Part 1

Practice series.—On February 2nd, the subject made the first test in the following manner. Using an ordinary watch the subject set a time for starting. When the hand of the watch reached the point set, the subject looked at the first example and multiplied mentally but with the original numbers in sight. The answer was written down as soon as it was obtained and the time recorded. Then the subject immediately took up the second example and repeated the same procedure. Thus she worked from 9:30 a. m. to 3:18 p. m. with a rest of forty-eight minutes for luncheon, and obtained the answers of twenty-four examples.

From the recorded results of the first test, the subject found notable fluctuations in the time taken for doing an example, and that these fluctuations were not due to the fatigue produced by continuous exercise of the function, but were rather due to the lack of training for this work. This is probably correct, for as the subject became used to the experiment, the extraordinary irregularity in time disappeared and the curve became smoother. Also the fluctuations appeared more in the first part of a period of continuous work in the first days of observation, while during the latter days the fluctuations became greater in the latter part of the continuous work, indicating that the former fluctuation was due to lack of practice and adaptiveness, while the latter was the result of continuous mental work. For this reason, it is important that when fluctuations resulting from fatigue are to be studied, the subject should be tested at or near the limit of practice and should be required to cooperate fully by always achieving his maximum. Therefore, before any attempt to determine changes in the rate of fatigue was made, the subject practiced on mental multiplication until the daily effect of practice became very slight. The amount of work done in the practice series is given in Table I.

TABLE I

Time and errors in each successive mental multiplication of a four-place number by a four-place number. both numbers being presented to perception. Feb. 2–15. Subject T. A. Times are in minutes and seconds.

Feb. 2, '09			Feb. 4, '09			Feb. 7, '09			Feb. 15, '09		
9:30 A. M.– 2:13 P. M.			9:30 A. M.– 1:40, 30 P. M.			10:40, 39, A. M.– 12:14, 10 P. M.			8:22 A. M.– 12:15 P. M.		
No.	Time	Er.	No.	Time	Er.	No.	Time	Er.	No.	Time	Er.
1	9.00	4	1	3.55	4	1	2.16	3	1	4.30	5
2	18.08	3	2	5.30	3	2	5.50	2	2	7.20	0
3	8.20	0	3	6.30	3	3	5.55	0	3	2.45	2
4	8.25	5	4	6.50	5	4	3.55	0	4	6.45	0
5	10.30	2	5	4.55	1	5	6.10	1	5	7.45	0
6	7.15	2	6	7.20	2	6	4.20	5	6	5.45	4
7	7.30	4	7	6.05	2	7	4.40	3	7	4.50	4
8	9.00	1	8	2.55	4	8	18.50	3	8	5.00	3
9	9.30	1	9	14.00	3	9	9.15	1	9	6.00	1
10	18.10	5	10	16.10	5	10	9.50	0	10	6.20	1
11	9.30	2	11	5.00	4	11	10.55	4	11	12.20	0
12	13.20	2	12	5.00	3	12	12.00	0	12	8.25	0
13	9.30	4	13	9.35	3				13	9.20	0
14	9.55	1	14	4.08	5				14	6.55	5
An hr. rest, lunch			15	9.00	0				15	10.10	3
15	5.00	1	16	12.15	0				16	5.25	3
16	3.55	2	17	5.20	2				17	7.05	4
17	8.10	3	18	10.10	2				18	6.50	0
18	7.20	1	34 m. rest, lunch						19	5.50	0
19	7.50	1	19	10.05	2				20	4.30	1
20	6.05	5	20	6.55	5				21	11.20	5
21	4.30	2	21	6.10	2				22	9.25	2
22	14.30	1	22	7.54	5				23	8.25	1
23	3.50	5	23	13.07	0				24	8.00	0
24	16.00	4	24	5.05	5				25	13.55	3
			25	11.40	1				26	6.55	0
			26	14.15	0				27	4.45	3
									28	11.20	2
									29	17.30	0
									30	10.45	3

Fatigue series. After the practice series described above the subject made the experiment lasting from 1:45,40 p. m. to 10:07,30 p. m. with a stop for dinner, the results of which are given in Table II.

TABLE II

Time and errors in each successive mental multiplication of a four-place number by a four-place number, both numbers being presented to perception. Feb. 22. Subject T. A. Times are in minutes and seconds.

Feb. 22, 1:45 P. M.–10:07 P. M.

Example	Time	Error	Example	Time	Error	Example	Time	Error
No. 1	2.25	2	No. 22	6.10	2	After dinner		
2	4.55	0	23	8.30	0	No. 41	6.00	2
3	6.05	3	24	6.00	0	42	8.00	2
4	4.55	2	25	9.30	2	43	7.00	3
5	6.00	3	26	5.10	2	44	5.25	5
6	5.20	2	27	6.20	4	45	5.40	2
7	3.35	6	28	5.50	3	46	4.20	3
8	4.15	3	29	5.10	3	47	6.40	1
9	4.30	4	30	7.00	3	48	6.10	2
10	8.10	5	31	7.30	2	49	7.20	4
11	5.30	2	32	5.00	2	50	6.00	0
12	5.40	2	33	8.00	3	51	5.30	5
13	4.20	3	34	5.40	3	52	5.35	0
14	5.10	4	35	5.50	2	53	6.15	2
15	4.40	5	36	12.45	1	54	9.50	3
16	5.20	4	37	8.30	4	55	9.00	4
17	5.40	3	38	8.30	3	56	8.05	4
18	5.50	3	39	8.30	1	57	7.20	3
19	7.35	1	40	8.30	2	58	7.20	4
20	4.15	2				59	5.40	1
21	2.50	2	Dinner, 6:32–7:41 P. M.			60	6.45	3

The introspection recorded after the experiment is as follows: "I have no feeling of fatigue but a little feeling of weariness caused by the monotonous work. My consciousness is clear and mood quiet. I was always guided by the hope of obtaining a true result."

Pulse record:

At the beginning of the experiment	79
Immediately before the rest for dinner	82
Immediately after the rest for dinner	91
At the end of the experiment	78

Experiment I, Part 2

Practice series. From the experiment described above it was discovered that the work was not difficult enough to produce sufficient fatigue. In order to make the task harder, a new condition was introduced; instead of multiplying with the original figures in sight, the subject relied on memory for the figures and multiplied them mentally with closed eyes. The method was better than the earlier one, for it not only made the task more difficult, but it helped to eliminate sensory fatigue. When the subject forgot the original figures, she looked at them again, but as the time was made longer on this account, the loss of the original figures was counted against her. But this seldom occurred as the subject was careful to commit the numbers to memory. With this new method, six practice experiments were performed. The results are given in Table III.

The introspections recorded by the subject after the experiment were: Feb. 24, "The task is extraordinarily difficult. To multiply mentally with the new method is many times more difficult than it was by the other method." Feb. 25, "I do not feel well to-day; I studied hard all day before the experiment and have great difficulty in concentrating my mind on the figures. The work is very difficult." Feb. 26, "No feeling of fatigue after the hours of mental work." Feb. 27, Lacking. Feb. 28, "The work was so interesting that I forgot meals. No feeling of fatigue."

Fatigue series. Before going into the description of the experiments in this series, a word is needed in reference to the state of the subject's mind. By this time, the subject was accustomed to the concentration of attention upon the work and was little affected by fluctuations of feeling. She could do her utmost in each example. The writer is more and more impressed by the importance of this state of mind in the measurement of mental fatigue. To her mind, the results of the experiment made on one subject who can maintain an undisturbed mental effort yield truer fatigue curves than those obtained from carelessly conducted experiments made on hundreds of untrained subjects, for the errors in such experiment are not eliminated by the number of tests. The experimenter found it more

TABLE III

Time and error in each successive mental multiplication of a four-place number by a four-place number, both numbers being held in memory. Feb. 24–Mar. 2. Subject T. A. Times in minutes and seconds.

Feb. 24, '09 From 3:16–5:50 P. M.

No.	Time	Er.
1	14.10	3
2	7.05	2
3	10.30	2
4	6.55	5
5	11.00	1

Feb. 25, '09 From 7:04–11:09 P. M.

No.	Time	Er.
1	5.40	2
2	10.00	1
3	7.30	0
4	8.00	3
5	10.20	1
6	5.40	5
7	6.20	2
8	10.00	3
9	8.15	0
10	9.00	0
11	9.20	5
12	8.10	0
13	8.50	6
14	11.20	1
15	8.10	2
16	11.50	0
17	19.00	3
18	18.15	1
19	16.15	1
20	15.30	1

Feb. 26, '09 From 10:23 A.M.–2:47 P.M.

No.	Time	Er.
1	7.30	3
2	5.50	1
3	6.25	1
4	6.20	0
5	6.25	2
6	7.40	5
7	10.40	2
8	5.10	0
9	6.55	0
10	8.30	3
11	8.50	4
12	10.00	1
13	10.05	3
14	10.10	6
15	8.50	2
16	8.30	0
17	12.20	0
18	4.20	5
19	13.25	6
20	11.20	2
21	7.50	2
22	12.40	3
23	11.00	6
24	13.20	2

Feb. 27, '09 From 10:12 A.M.–2:67 P.M.

No.	Time	Er.
1	4.30	2
2	7.25	5
3	8.10	1
4	7.55	3
5	8.50	3
6	6.15	0
7	8.30	0
8	8.40	2
9	6.10	5
10	6.10	4
11	8.30	0
12	7.30	6
13	5.55	1
14	9.00	1
15	14.00	2
16	5.30	5
17	9.10	3
18	8.50	1
19	8.10	1
20	6.55	6
21	6.40	3
22	6.00	4
23	7.00	0
24	10.15	0
25	10.10	2
26	7.20	5
27	12.00	3
28	9.00	0
29	7.00	1
30	8.45	1

Feb. 28, '09 From 10:42 A.M.–9:15 P.M.

No.	Time	Er.
1	5.50	3
2	6.30	0
3	10.20	3
4	9.05	4
5	6.45	6
6	8.40	0
7	15.00	0
8	6.00	0
9	8.50	1
10	8.00	3
11	9.30	2
12	6.50	2
13	11.10	5
14	7.05	0
15	7.50	0
16	8.20	1
17	7.35	0
18	7.20	3
19	6.50	3
20	8.05	2
21	7.50	6
22	8.40	1
23	12.55	0
24	12.05	1
25	12.15	0
26	6.55	3
27	5.35	6
28	10.15	2
29	10.40	5
30	8.00	1
31	15.00	0
32	10.00	2
33	15.30	2
34	10.10	3
35	13.00	1
36	11.45	1
37	13.40	5
38	11.37	3
39	16.30	3
40	14.30	4
49m.	rest,	di'er
41	10.00	2
42	3.00	3
43	8.00	3
44	4.00	4
45	5.55	0
46	5.40	0
47	9.40	2
48	8.30	6
49	8.10	1
50	15.20	0
51	13.03	5

Mar. 2, '09 From 10:42 A.M. 9:15 P.M.

No.	Time	Er.
1	6.50	2
2	7.25	1
3	5.30	0
4	7.15	0
5	6.45	5
6	12.00	6
7	4.25	1
8	4.20	2
9	11.50	2
10	5.30	3
11	9.20	0
12	7.30	4
13	8.30	4
14	9.30	2
15	7.30	6
16	10.00	0
17	8.15	2
18	11.30	1
19	9.40	1
20	6.00	2
21	7.30	0
22	16.05	3
23	12.40	4
24	8.25	0
25	9.05	4
26	7.30	1
27	9.40	1
28	9.50	5
29	11.40	0
30	13.20	0
31	12.30	0
32	9.10	1
33	18.30	2
34	10.50	3
35	10.40	3
36	8.25	0
37	16.10	4
38	9.20	0
39	10.20	0
40	8.20	5
41	9.10	1
42	8.10	1
43	14.00	2
44	12.10	2
45	9.00	0
46	9.00	0
47	12.40	3
48	12.50	1
49	8.45	0
50	13.20	4
51	11.50	0
52	8.20	0
53	19.40	1
54	17.30	5
55	11.50	3
56	12.10	1
57	18.45	3
58	11.10	0
59	9.25	3

advantageous to use an ordinary watch instead of the stop watch, for this made it easier to record the time when a certain example was done. The slight error of observation is of no consequence in view of the long time required for a single example and the great variation of examples in difficulty.

On March 3, 4, 5 and 6, the subject did the mental multiplication from 11 a. m. to 11 p. m. without any pauses except the two or three seconds between the examples for recording time. But the subject had taken a heavier breakfast than usual at 10 a. m. and a light supper after 11 p. m. Her health was in good condition and she slept soundly at night. The contents of her consciousness during the experiments were very simple, all desires being completely subjected to the one desire to get true fatigue curves. The results of these experiments are summarized in Table IV.

TABLE IV

Time and errors in each successive mental multiplication of a four-place number by a four-place number, both numbers being held in memory. Mar. 3–6. Subject T. A. The times are in minutes and seconds.

No. of Example	Mar. 3		Mar. 4		Mar. 5		Mar. 6	
	11:01, 30 A.M.–11:07 P.M.		11:12 A.M.–10:52 P.M.		10:07, 30 A.M.–10:55 P.M.		11:15 A.M.–11:27, 40 P.M.	
	Time	Error	Time	Error	Time	Error	Time	Error
1	5.50	5	4.30	0	5.10	0	5.00	0
2	5.50	1	7.20	2	4.50	2	4.40	1
3	5.25	0	4.40	0	4.20	2	4.45	2
4	6.30	2	6.10	3	6.10	2	4.20	1
5	6.00	3	4.40	1	4.50	2	5.00	2
6	6.45	5	6.05	2	4.40	0	5.10	3
7	4.25	0	6.20	4	3.55	2	4.30	1
8	5.05	0	6.00	3	4.10	2	6.00	7
9	6.20	0	6.50	2	5.00	2	5.05	0
10	5.40	1	5.40	1	5.40	2	4.40	3
11	7.10	4	10.05	0	5.00	1	5.55	3
12	6.20	0	6.10	0	6.30	1	6.15	4
13	7.15	2	12.45	2	6.05	1	6.30	2
14	8.15	1	6.10	0	4.20	2	7.20	1
15	6.20	0	4.45	2	6.15	4	5.15	0
16	8.00	1	6.10	1	6.10	1	6.10	2
17	8.05	0	7.10	1	8.15	0	6.00	3
18	7.30	0	7.20	1	7.30	2	5.25	0
19	8.55	2	6.50	2	4.15	5	6.20	0
20	6.55	0	6.20	3	8.20	1	6.00	0
21	5.50	0	7.05	4	12.40	3	9.10	3
22	9.05	2	8.30	2	6.00	2	4.25	1
23	6.10	1	7.30	4	5.20	0	5.05	0
24	8.50	1	5.45	1	6.50	0	8.20	3
25	9.40	0	10.50	4	5.50	0	5.50	1
26	8.50	0	10.30	2	6.55	2	6.15	2
27	7.10	4	7.00	1	6.40	1	9.50	2
28	9.40	3	5.50	4	8.50	0	6.35	6
29	8.00	1	6.00	2	8.05	1	6.45	1
30	9.00	1	5.40	1	8.20	3	9.00	3
31	9.30	0	9.00	0	8.00	0	10.50	2
32	7.40	3	5.40	3	6.50	0	7.10	2
33	8.00	1	9.50	0	6.00	1	7.00	2
34	9.00	1	7.40	1	4.00	0	6.30	0
35	10.50	1	17.10	3	3.50	0	7.35	2

TABLE IV—*Continued*

No. of Example	Mar. 3		Mar. 4		Mar. 5		Mar. 6	
	11:01, 30 A.M.–11:07 P.M.		11:12 A.M.–10:52 P.M.		10:07, 30 A.M.–10:55 P.M.		11:15 A.M.–11:27, 40 P.M.	
	Time	Error	Time	Error	Time	Error	Time	Error
36	13.20	4	7.40	2	6.55	2	8.15	1
37	13.50	0	12.50	5	8.15	4	7.50	3
38	10.45	2	12.10	0	9.05	1	7.10	1
39	10.15	5	11.50	0	12.00	2	11.05	1
40	15.00	1	7.15	1	10.35	0	10.20	5
41	11.00	5	9.00	2	8.25	0	6.00	0
42	13.05	2	11.00	1	11.10	1	11.20	3
43	15.40	1	13.35	4	9.10	4	10.35	2
44	19.35	2	10.55	2	12.50	1	7.40	3
45	10.15	3	9.50	1	15.20	1	12.10	1
46	7.50	2	10.20	2	11.00	2	7.30	1
47	10.20	3	13.10	3	9.30	3	7.10	1
48	12.50	2	14.10	0	16.00	7	9.30	3
49	8.05	1	9.55	0	8.20	2	10.50	2
50	10.00	0	12.00	2	12.40	3	9.40	0
51	15.00	0	12.00	2	10.00	3	9.10	1
52	10.00	3	10.40	2	10.00	0	14.40	7
53	9.20	0	19.50	0	9.00	3	8.40	1
54	12.05	1	8.50	0	8.20	2	6.10	2
55	11.10	3	16.10	3	8.20	3	8.00	4
56	15.10	1	6.40	4	8.10	3	7.00	1
57	15.20	3	9.00	5	8.20	1	9.05	7
58	9.00	1	8.10	0	6.00	4	10.40	6
59	8.00	1	12.25	1	7.20	2	9.30	6
60	11.20	0	7.00	1	5.50	2	6.10	6
61	6.55	1	7.00	4	8.20	3	8.50	6
62	12.20	0	11.30	5	16.50	6	9.40	5
63	16.20	2	10.00	2	10.50	2	9.00	2
64	10.20	0	14.30	4	7.30	2	7.35	5
65	16.15	0	19.10	4	10.10	4	8.20	2
66	15.50	5	11.20	2	8.50	4	11.10	1
67	16.30	1	12.10	1	10.20	3	7.40	1

The introspective reports of the subject after each experiment were: March 3, " In the morning I felt very well. I did not have any special feeling of fatigue in the course of the experiment. Towards the end of the test, however, it was hard to keep the original figures and partial products in mind, and I repeated the same products over and over again. Association became very slow and my mind wandered very much." March 4, " I feel excellent after the work and am not fatigued at all." March 5, " This morning, I did not feel so enthusiastic about my experiments as I did yesterday. After work, I have a little headache and feel very weak." March 7, "After a week's concentrated mental work, I am as cheerful as usual. Physically and mentally no effect of the hard work seems to remain this morning."

Along with the multiplication test, the test for 'transferred fatigue' was made. Before and after mental multiplication lasting for some time, the time taken for establishing connections between English words and their corresponding German words was measured. The procedure in the test was as follows: Two sets of materials were prepared. One of them consisted of many lists, each containing ten German words with their English equivalents. The other set consisted of lists containing the English words which were in the first set, but arranged in different order. The subject first learned the German equivalents of the English words in the first set. When this was done, i.e., when the subject could call out the German words when the English words were presented, she took the corresponding list of the second set and wrote down as quickly as possible by the English words their corresponding German equivalents. The time spent in this process was measured from the instant of first sight of the list with the German and English words to the completion of the task of writing down the German equivalents. Before and after mental multiplication, four of these lists were learned and the time taken for learning each one recorded. The results of the experiment are given in Table V.

TABLE V

Time for learning German equivalents of English words before and after approximately eleven hours of continuous mental multiplication of four-place numbers by four-place numbers.

Date	Multiplication practice test			Association test	
	The time of day for mental multiplication	Number of examples done	Rest period	Time taken for one group, before mental multiplication	Time taken for one group, after mental multiplication
Feb. 24	7:37.20–11:24,45 P.M......	20	..	..	..
				m s*	m s*
Feb. 25	7:04–11:09 P.M	24	..	2.05 3.15 2.40 2.10	3.00 2.15 2.25 3.00
Feb. 26	10:22.30 A.M.–2:46,45 P.M..	30	..	1.50 1.20 2.55 2.40	2.35 3.30 2.00 2.15
Feb. 28	10:41,30 A.M.–9:14,45 P.M..	51	90 m., lunch and dinner	1.45 1.25 2.50 4.30	3.35 2.40 2.20 3.05
March 2	10:22,30 A.M.–9:53,25 P.M..	59	..	..	..
March 3	11:01,30 A.M.–10:50,30 P.M.	67	..	2.15 1.30 1.35 1.25	2.40 3.30 2.30 2.40
March 4	11:12 A.M.–10:40,30 P.M...	67	..	2.10 2.05 2.00 2.00	1.45 1.40 2.20 1.50
March 5	11:07,30 A.M.–10:44,30 P.M.	67	..	1.10 1.50 1.20 1.20	2.10 2.00 2.20 2.10
March 6	11:15 A.M.–11:20 P.M......	67	..	1.40 1.30 2.30 2.00	1.20 2.00 1.50 2.20

*'m' and 's' equal minutes and seconds.

Experiment II

The purpose of this experiment was to investigate the influence of general mental work on the special mental and physical functions, and the relation of one function to the other.

For this purpose, the differences between the morning and the evening efficiencies, (1) in memorizing German equivalents of English words, (2) in doing mental multiplication, and (3) in pulse and feeling were measured. Their direction and degree according to the varying duration of mental work were then worked out. The subject of the experiment was the writer herself. The experiment covered seventy-eight days between February the first and the end of June.

The method of testing the efficiency of memory is the same as that used in Experiment I, except that two lists of German words instead of four were memorized. Efficiency in mental multiplication of a three-place number by a three-place number was measured, following the same method as in Experiment I. States of feeling were classed as *good, medium* or *tired*. Pulse rate was measured by the number of radial pulse beats per minute.

In the morning at about 10 o'clock before any mental work was done and in the evening after a day's work, the subject measured her pulse and her efficiency in memory and in multiplication, using different lists and examples on each occasion. The state of feeling was recorded by introspection. With the records of these measurements, there were carefully written down the number of hours of sleep the night before and of mental work during the days when the tests were made. Health was recorded *good* when every physical function was normal, *not well* when it was below the normal and *bad* when the subject was in any abnormal physiological condition.

In this investigation, the subject performed the tests on all days when external circumstances made them possible. In order to avoid errors which possibly might come from suggestion or interest of some kind, the records of experiments which were obtained from day to day were kept out of sight. The subject carefully guarded against speculating on the results of the experiments. If there were errors at all in the results of the experiments, they were beyond the control of the experimenter. The results of Experiment II are given in Table VI.

TABLE VI

Efficiency in memorizing and in mental multiplication, pulse-rate, degree of fatigue felt, and state of physical well-being observed before and after each day of general mental work.

Date	1	2	Morning						Evening					
	Hours of mental work during the day	Hours of sleep the night before	3 Time taken for memoriz. per Ger. word in secs.	Time taken for multiplying per example. Ave. of 3 examples in seconds		6 Number of pulse beats per minute	7 Subject's report of feeling	8 Subject's report of physical condition	9 Time taken for memoriz. per German word	Time taken for multiplying per example. Ave. of 3 examples		12 Number of pulse beats per minute	13 Subject's report of feeling	14 Subject's report of physical condition
				4 Time	5 Error					10 Time	11 Error			
Feb. 4	4.30	. .	20.	155.0	1.	82.5	Fresh	Good	22.9	288.0	1.0	. .	Tired	Not well
" 5	0	. .	. .	157.5	1.	. .	Medium	"	. .	175.0	0	. .	Medium	Good
" 6	0	. .	. .	. . .	. .	83.	Good	"	. .	. . .	. .	76.	Good	"
" 7	8.50	9.	. .	173.3	1.0	85.	Medium	"	. .	325.0	1.	86.5	Tired	"
" 8	6.45	7.	15.0	218.3	2.	93.	"	"	19.0	187.7	0	80.0	"	Headache
" 9	5.30	7.	17.5	206.7	1.0	83.	"	"	18.9	176.7	0	74.	Good	Good
" 10	8.20	7.15	30.3	. . .	. .	83.6	Good	"	33.3	. . .	. .	79.0	Tired	"
" 11	0	8.15	15.0	185.0	1.	84.0	"	"	20.5	258.7	.7	84.5	Good	"
" 12	0	6.	. .	. . .	. .	87.0	"	"	. .	. . .	. .	84.	Tired	"
" 14	4.30	7.20	. .	. . .	. .	. .	"	"	. .	. . .	. .	. .	"	"
" 15	2.30	7.30	18.8	188.3	1.3	73.0	"	Not well	24.4	133.3	.3	79.	"	"
" 16	8.05	8.00	16.8	163.3	.7	86.	Medium	"	20.8	169.0	1.7	77.	Medium	Not well
" 17	5.30	8.00	21.2	144.3	.7	78.	"	Good	28.8	213.3	1.7	91.	Tired	Good
" 18	4.03	7.00	15.8	175.0	.7	86.	Tired	"	22.9	209.0	2.0	79.	Good	"

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Feb.	19	4.30	8.15	20.0	...	..	85.0	Medium	"	22.9	...	..	79.	Tired	Not well
"	20	0	9.00	..	...	..	85.	"	"	..	...	..	84.	Medium	Good
"	21	5.30	9.00	19.8	115.0	.7	87.	"	"	22.5	160.0	.3	86.5	"	"
"	22	8.30	..	18.5	124.3	.7	84.	"	"	21.9	186.3	.3	81.	"	"
"	23	7.30	7.30	17.5	175.0	1.0	87.	Good	"	19.8	123.3	1.0	76.	Good	Not well
"	24	7.30	8.30	14.5	125.0	1.3	92.	"	"	27.5	180.0	1.7	88.5	Tired	Good
"	25	0	7.00	..	...	..	..	...	...	..	...	..	..	...	...
"	26	2.30	9.20	..	156.7	1.0	81.	Tired	Not well	..	110.5	.7	91.	Tired	Not well
"	27	0	9.30	19.0	115.0	1.0	87.	Medium	Good	17.3	120.0	.7	87.	Medium	Good
"	28	8.30	9.00	22.8	120.0	.7	92.5	Good	Not well	20.3	144.0	1.3	78.0	"	Not well
Mar.	1	7.55	7.00	23.3	123.3	.3	81.0	Medium	"	27.5	180.0	1.7	73.5	Tired	"
"	2	0	..	..	143.3	1.0	..	...	Bad	..	265.0	1.3	82.0	...	Headache
"	3	4.10	6.30	11.3	160.0	1.3	87.0	Medium	Good	12.3	165.0	2.0	83.0	Medium	Good
"	4	1.30	7.20	13.3	141.7	1.3	73.0	"	"	12.0	170.0	1.7	80.0	Tired	"
"	5	2.30	7.50	11.3	138.3	.7	75.0	"	Not well	13.1	140.0	1.3	71.	"	Not well
"	6	0	7.30	11.0	87.5	1.0	79.5	...	"	10.6	132.5	.3	83.5	...	"
"	7	3.30	9.00	11.5	131.7	1.7	82.0	Medium	Good	15.0	140.0	1.0	80.0	Medium	Good
"	8	0	8.00	16.6	130.0	1.3	78.	"	"	18.1	133.3	.7	70.0	"	"
"	9	3.30	7.00	18.0	156.0	.7	79.	...	...	20.5	128.3	.7	70.0	...	...
"	10	0	8.00	18.0	126.7	1.0	79.	Good	Good	..	126.3	1.0	..	Medium	...
"	11	2.30	7.30	20.0	146.7	.7	83.5	Medium	"	20.3	123.3	.7	89.	Tired	Good
"	15	7.55	7.00	17.8	120.0	.7	..	Good	"	22.2	125.0	3.0	..	Good	"
"	16	8.50	6.30	16.5	124.3	.3	86.0	Medium	"	20.8	111.7	.7	84.0	Medium	"
"	18	6.30	6.00	14.2	220.0	.7	90.0	Good	"	18.	153.3	12.3	83.5	"	"
"	21	6.30	6.00	25.6	118.3	1.3	92.0	"	"	30.3	150.0	.3	90.	"	"
"	22	7.20	7.30	16.3	...	..	85.5	Medium	"	23.9	...	..	88.5	Tired	"
Apr.	5	6.00	7.00	12.3	123.3	1.0	85.5	Good	"	14.8	175.0	.3	84.5	Good	"
"	6	4.30	7.00	11.0	143.3	1.7	92.0	"	"	12.0	138.3	.7	90.0	Tired	"
"	7	9.77	6.30	13.8	138.3	1.	92.5	Medium	Not well	14.0	156.7	1.7	87.5	"	"
"	10	0	8.00	..	...	..	85.0	Good	"	..	...	..	..	...	...
"	11	8.00	7.30	15.0	140.0	1.3	83.0	"	...	16.8	163.3	1.3	83.0	Medium	...
"	12	7.30	6.30	20.2	137.5	2.5	87.5	Medium	Not well	22.8	147.5	1.5	78.0	Tired	...
"	13	7.00	8.00	10.5	120.0	1.0	85.5	Good	...	15.9	112.5	0	80.0	Good	Good
"	14	7.45	8.00	12.5	115.0	.7	82.5	"	...	12.0	178.3	1.3	78.0	Medium	...

TABLE VI—*Continued*

Date	1	2	Morning						Evening					
	Hours of mental work during the day	Hours of sleep the night before	3 Time taken for memoriz. per Ger. word in secs.	Time taken for multiplying per example. Ave. of 3 examples in seconds		6 Number of pulse beats per minute	7 Subject's report of feeling	8 Subject's report of physical condition	9 Time taken for memoriz. per German word	Time taken for multiplying per example. Ave. of 3 examples		12 Number of pulse beats per minute	13 Subject's report of feeling	14 Subject's report of physical condition
				4 Time	5 Error					10 Time	11 Error			
Apr. 15	3.30	7.00	15.8	117.5	.5	88.0	...	...	16.6	177.5	1.	..	...	Good
" 18	6.00	6.00	15.8	220.0	.7	88.5	Good	...	20.9	153.3	1.7	90.0	Tired	...
" 20	7.00	6.30	23.6	115.0	.7	82.5	"	...	21.9	178.3	1.3	..	Good	...
" 21	3.50	6.45	17.1	142.5	0	..	"	Not well	16.8	115.0	1.5	..	"	Not well
" 22	3.45	..	11.8	91.7	0	93.0	Medium	...	15.0	148.0	1.7	90.0	Tired	...
" 23	5.30	7.20	11.7	175.0	1.0	83.0	Good	Good	12.8	123.3	1.0	84.0	"	Good
May 9	5.37	..	11.5	118.3	1.0	91.0	"	"	13.3	148.3	2.0	79.0	Good	"
" 10	5.00	7.30	9.5	113.3	1.0	84.0	...	"	10.5	101.7	.7	90.0	...	"
" 11	5.10	7.00	10.9	100.0	1.3	95.0	Medium	"	14.3	125.0	1.0	88.5	Tired	"
" 12	5.30	8.00	10.0	105.0	.3	96.0	...	...	12.3	117.5	1.5	96.0	...	...
" 13	3.00	8.30	10.8	118.3	.7	95.5	...	Not well	13.3	133.3	1.0	..	...	...
" 14	9.50	6.30	13.0	100.0	0	92.5	...	"	18.3	163.3	0	92.5	...	Not well
" 16	9.05	7.30	.90	135.0	1.0	107.0	Medium	Good	18.4	173.3	2.7	94.0	Tired	Headache
" 17	1.30	7.20	..	161.7	2.3	94.	"	Not well	..	126.7	2.3	98.5	Medium	Not well
" 19	3.00	8.00	..	...	..	100.0	"	"	..	...	..	96.5	Tired	"
" 21	1.30	6.40	13.7	96.7	0	92.5	Good	Good	13.0	130.0	1.7	89.0	Good	Good

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
May	23	1.30	8.00	12.2	161.7	2.0	94.5	"	Not well	10.5	126.7	.7	90.5	"	Not well
"	24	4.50	8.00	10.00	90.0	1.7	92.0	"	Good	15.0	120.0	2.0	90.0	Tired	Good
"	25	1.30	5.00	15.0	103.3	1.0	96.0	"	...	10.8	96.7	1.3	87.0	Medium	...
"	26	5.30	7.25	13.5	91.7	1.7	94.0	"	...	12.5	123.3	1.3	88.0	"	...
"	27	4.50	7.00	8.0	121.8	1.0	98.5	"	...	10.5	125.0	1.7	87.0	Good	...
"	28	1.50	7.45	10.0	96.7	1.0	100.0	"	Good	9.5	120.0	.7	92.0	"	Good
June	6	2.30	8.00	10.6	118.3	.3	101.0	Medium	"	11.6	123.3	0	92.5	"	"
"	7	2.30	6.30	..	103.3	1.3	..	...	...	..	156.7	1.3	..	...	...
"	8	2.50	8.30	..	...	..	96.5	...	...	..	...	..	..	...	...
"	9	6.30	7.45	..	...	..	104.0	...	...	..	...	..	..	...	...
"	16	6.30	8.00	..	220.	.7	98.0	Medium	Headache	..	153.3	2.0	96.0	Medium	Headache
"	20	6.00	8.00	..	118.3	1.3	101.0	"	...	..	150.0	.3	101.0	"	...
"	22	6.10	8.45	..	101.7	1.7	103.0	Good	Good	..	121.7	1.3	98.5	Good	Good
"	23	6.00	7.30	..	120.	..	101.5	Medium	...	..	138.3	..	..	Tired	...

Experiment III

During November and December of 1910, the author translated into Japanese some chapters of Dewey's "Influence of Darwin on Philosophy and Other Essays," the time taken for translating each page being recorded. Before and after a period of translation lasting for some time, the writer measured the temperature under the tongue. Since the materials of the test were not selected for the purpose of experiment and varied considerably in difficulty, one could not expect to obtain accurate data on the change in the rate of fatigue; but it will be seen that the results are valuable when we come to discuss the relation of body temperature to mental work. The results are summarized in Table VII.

Experiment IV

This main series of experiments was performed during the academic year of 1910-'11 at Teachers College, Columbia University.[1]

The primary purposes of the experiment were to investigate, (1) the work curve of a single mental function exercised for two or three hours; (2) the influence of fatigue of one mental function on the efficiency of another mental function; (3) the relation of the amount of mental work done to the length of rest period; and (4) the relation between mental fatigue and certain physiological processes of the organism.

The function tested for this continuous work was that exercised in multiplying mentally a two-place number by a two-place number. For the test of transferred fatigue, the mental functions tested were the ability to memorize nonsense syllables, the ability to add 8 columns of 10 one-place numbers, and the ability to call up the opposite of each word of a list of words. For the study of the relation of amount of work done to the length of rest period, three different lengths of rest were used; 10 minutes, 60 minutes and 180 minutes. To test the relation of mental fatigue to physiological processes, the pulse rate and temperature were measured before and after the mental work.

Of the subjects of the experiments, all but seven were professors and graduate students of psychology. Among the seven,

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[1] The writer is indebted to the men and women who co-operated in this experiment. Their zeal and care made the results especially valuable.

TABLE VII

Change of body temperature caused by mental labor as observed during the translation of English into Japanese, the speed of work being measured by the average time per line for each page.

Date	Temperature under tongue measured before and after translation				The speed of translation is given by the average time taken for translating per line on each successive page, in seconds								
	Before translation		After translation										
	Time of day	Temp.	Time of day	Temp.	1st P.	2nd P.	3rd P.	4th P.	5th P.	6th P.	7th P.	8th P.	9th P.
November 29	1:30 P. M.	98.	5: P. M.	97.8	57.7	58.4	51.1	53.2	52.3	53.	55.4	48.5	
" 30	10:37 A. M.	97.2	12: M.	97.6	Study of German.								
" 30	1:42 P. M.	97.7	4:55 P. M.	98.1	51.	55.3	60.	56.	56.3	74.[1]	68.		
" 30	7:41 "	97.9	9:20 "	98.	69.7	76.	63.7						
December 2	10:59 A. M.	97.6	12: M.	97.	Study of German.								
" 2	1:36 P. M.	98.	4:55 P. M.	97.8	85.2	69.6	66.0	58.2	67.2				
" 8	7: "	97.1	8: "	97.9	Translation for two hours, did not measure its speed.								
" 9	2:10 "	96.6	4:15 "	97.2	75.0	64.2	61.8	61.8					
" 13	3:15 "	..	5:28 "	..	74.4	62.4	60.0						
" 13	7:20 "	..	10:08 "	..	94.2	97.8	79.0	55.8					
" 14	11:08 A. M.	..	11:43 A. M.	..	69.2	101.4							
" 14	2:19 P. M.	..	5:33 P. M.	..	94.2	51.6	72.	57.2	65.4	67.2			
" 15	10:56 A. M.	97.5	12:02 "	..	73.8	71.2							
" 15	1:55 P. M.	..	4:40 "	..	42.6	58.2	54.0	57.6	48.0	56.4	53.4	51.6	
" 15	7:23 "	..	8:50 "	97.7	50.4	60.0	58.2						
" 16	2:05 "	..	3:28 "	..	59.4	58.8	63.6						
" 17	2:36 "	..	4:21 "	..	54.6	56.4	57.6	48.0					

[1] Here a new chapter, which is much harder than the old, was begun. The sudden rise of the time taken is due to the change of materials.

the subject C. T. T. was a student in the Department of Political Science and was taking graduate courses in Psychology; the subject Sn. belonged to the Department of Philosophy and was taking undergraduate work in the Department of Psychology; the subjects, M. M., G. D. S. and P. E. R., were a professor and graduate students in Education; C. T. R. and S. W. were the mechanicians of the Psychological Department. All except M. M., G. M. K. and P. E. R. were men. All but four acted as subjects twice or more than twice.

These experiments can be divided into two kinds according to the different materials used for the measurement of the transferred fatigue. We shall call the first kind *memory-fatigue tests,* in which the ability to memorize nonsense syllables was tested before and after continuous work in mental multiplication, and the second kind, *addition-and-association tests,* in which the ability to add numbers and the ability to associate the words with their antonyms were tested.

Again the experiments can be divided into three kinds, according to the different lengths of rest period, namely *ten-minute-rest-period tests, sixty-minute-rest-period tests* and *one hundred-eighty-minute-rest-period tests.* The procedure of the tests was in the main, as follows: In *memory-fatigue tests,* the subject was required to sit quietly for about ten minutes after his entrance to the experiment room. The experimenter measured the pulse rate of the subject by the number of the radial pulse beats per minute and tested the temperature under the tongue. The subject was then asked to memorize a list of ten nonsense monosyllables. These syllables consisted of two consonants with a vowel between them like *gid, yat* and *sut.* At the end of two minutes, the signal was given and the subject wrote down the syllables remembered. Then another list of the ten nonsense syllables was given to the subject to repeat the same process. The score was made by the number of letters remembered in their original order. For instance, if one remembered all three letters in one syllable, the score 1 was given; if he remembered only two letters in their right place, the score .7 was given while for one letter remembered in its right place the score .3 was given. When the memory test was completed, the subject was asked to be ready for the mental multiplication.

With the signal 'go,' the subject looked at the first example, and memorized the two-place numbers. With the eyes closed he multiplied them mentally. As soon as the answer was obtained it was written down. He immediately proceeded to the next example. The experimenter recorded the time when the subject finished writing each answer. The work on mental multiplication lasted for two hours with most of the subjects and three hours with a few subjects. After this period of continuous mental work, the *memory-fatigue-test* was given with different lists of nonsense syllables and by exactly the same method. The pulse rate was measured here. A definite period of rest followed this test. After the rest the subject did mental multiplication again for ten minutes. In *the addition-and-association-fatigue test,* the whole process was the same as in the *memory-fatigue test,* except that the time spent in adding eight columns of ten single numbers, and writing the answer under each column, and the time spent in associating antonyms with the given words were taken before and after the mental multiplication.

A word must be added to explain the use of the rest period. In the ten-minute rest period, the subject remained in the experimental room and was allowed to do no mental work and spent the time in conversation with the experimenter. In the *sixty-minute-rest-period test* some subjects went to take luncheon and others spent it just as they did with the ten-minute rest. In the one-hundred-eighty-minute-rest-period test, it was impossible to keep the subjects from doing something. The subjects who took this length of rest were a professor and an instructor who had to spend some part of the time for teaching. Compared with the intense and most concentrated mental work like mental multiplication, however, the time they spent in customary class-room work was like a rest. The summary of the results of Experiment IV is given in Table VIII.

TABLE VIII

Time spent per multiplication in each successive ten minutes, number of nonsense syllables held in memory correctly for two minutes, time taken for adding eight columns of ten single numbers and writing down the answer under each column, and time spent in associating antonyms before and after the mental multiplication—in each trial of each individual.

	Subjects	C. D. T.		C. D. T.		C. D. T.		C. D. T.		MS.		MS.		MS.		MS.	
	Date	April 1		April 15		May 11		May 26		March 18		March 18		April 21		May 11	
	Time of day	2:21–4:00		10:17–12:10		9:14–12:04		2:02–5:02		9:30–11:30		1:27–2:45		1:35–3:32		9:36–12:35	
Before work	Temperature	97° F.															
	Pulse	80		68				68						73			
	Memory	19		20				18				9					
	Association					95s								95s			
	Addition													67s			
		Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error
Mental multiplication	1st 10 minutes	44.3	.25	54.5	0	32.8	0	28.6	.19	144.2	2.	39.7	1.6	38.2	1.7	25.1	1.14
	2nd "	37.7	.12	41.1	0	29.5	.05	23.9	0	130.8	.8	48.3	1.3	46.7	1.7	26.2	1.17
	3rd "	44.9	0	38.4	.06	26.9	.03	28.4	0	118.4	1.	62.6	1.0	45.8	1.4	27.6	.62
	4th "	41.3	.14	37.5	.13	28.0	0	29.3	.13	80.3	1.4	50.3	1.3	32.9	1.5	25.9	1.09
	5th "	40.5	.07	39.4	.13	41.0	.0	26.3	.08	65.9	1.5	57.4	1.5	31.0	1.5	26.8	1.43
	6th "	36.5	.13	33.3	.06	32.0	.21	31.7	0	50.5	1.6	55.7	1.1	42.9	1.5	24.1	1.44
	7th "	31.4	.16	33.8	.06	28.6	.2	27.6	0	73.1	2.	54.1	1.5	32.6	2.1	29.6	1.45
	8th "	36.2	.35	32.4	.1	26.5	0	27.5	0	40.2	.9	57.5	1.0	31.7	1.7	25.1	1.37
	9th "	36.9	0	28.1	.05	27.6	.05	31.1	.21	55.0	1.			39.0	1.7	20.9	1.1
	10th "	35.7	0	29.7	.05	36.0	.18	27.1	.0	60.7	.4			48.8	1.2	22.4	1.4
	11th "			27.1	.03	31.7	.06	33.4	.06	59.7	.62			46.5	.7	22.3	1.1
	12th "			30.0	0	31.3	.11	25.6	.04	46.6	1.5			40.6	1.3	24.8	1.3
	13th "					29.6	.0	30.3	0							23.1	1.15
	14th "					28.5	.09	29.5	0							26.3	1.26
	15th "					28.6	0	26.6	0							24.8	1.29
	16th "					33.6	.06	21.7	0							24.3	1.12
	17th "					26.1	0	30.0	0							22.1	1.
	18th "							25.9	0								
After work	Temperature	98° F.															
	Pulse	73		64				62						64			
	Memory	19		20				19				10					
	Association					152s								105s			
	Addition													78s			
	Rest	10 m.		60 m., with lunch		10 m.		10 m.		60 m., with lunch				60 m.		60 m., with lunch	
Mental mult.	1st 10 minutes	24.0	.13	27.2	0	25.6	.26	21.7	0	39.7	1.6		21.8		1.1	19.4	.92
	2nd "			23.5	0	60 m. rest											

TABLE VIII—*Continued*

		R. S. W.		R. S. W.		H. A. R.		H. A. R.		J. T.		J. T.		Pog.		Pog.	
Subjects		R. S. W.		R. S. W.		H. A. R.		H. A. R.		J. T.		J. T.		Pog.		Pog.	
Date		April 7		April 28		April 8		May 5		March 22		April 5		April 10		April 23	
Time of day		9:50–11:59 A.M.		9:43–11:40 A.M.		10:59–11:42 A.M.		10:28–11:20 A M.		9:45–11:54 A.M.		9:50–11:50 A.M.		1:54–4:08 P.M.		1:27–3:36	
Before work	Temperature	97.8										98.5° F.					
	Pulse	66		62								75		90		92	
	Memory	16.7				19.7				13		15.7		18.1			
	Association			57 s.				63 s.								50 s.	
	Addition			55 s.				54 s.								45	
		Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error
Mental multiplication	1st 10 minutes	46.3	.15	35.3	.58	31.7	.25	48.8	.61	59.3	1.25	96.6	3.5	70.	.3	53.2	.8
	2nd "	56.3	.27	32.6	.59	28.1	.35	41.8	.59	86.0	3.	116.	1.4	77.5	.7	62.0	.1
	3rd "	57.7	1.4	34.6	.28	31.3	.32	45.1	.49	164.0	2.	115.8	1.3	75.0	.5	60.0	.7
	4th "	35.9	.75	42.3	1.27	40.1	.13	27.2	.18	182.0	3.5	136.2	1.	69.3	1.29	51.3	.3
	5th "	34.1	.17	42.2	.79	31.4	.5	30.8	.45	189.5	.5	100.0	1.8	110.8	.17	51.4	.2
	6th "	30.8	.26	40.0	.67	28.3	.2	26.3	.43	100.0	0	163.3	1.7	81.3	.9	50.0	.1
	7th "	37.5	.31	42.2	.71	32.8	.11	28.4	.15	166.3	3.	138.8	.25	77.5	.6	49.6	.3
	8th "	29.8	.3	39.2	.75	26.5	.1	22.6	.38	310.0	2.	176.0	1.	71.1	.4	66.7	.7
	9th "	26.3	.9	34.2	.53	24.2	.25	17.4	.5	227.0	2.	160.0	.5	76.3	1.	57.2	.3
	10th "	33.2	.44	29.8	.15	24.3	.13	17.7	.26	117.5	1.5	143.8	1.5	69.4	.4	46.9	.5
	11th "	31.1	.26	32.1	.63	25.6	0	16.3	.6	150.0	2.	183.3	.33	61.1	.6	52.3	.3
	12th "	29.0	.8	32.9	.58	25.5	.2	16.0	.5	77.0	2.5	161.7	1.25	55.	.8	55.4	.3
	13th "	32.6	.24	31.2	.5					162.5	2.0			54.5	.5	46.8	.5
	14th "																
	15th "																
	16th "																
	17th "																
	18th "																
After work	Temperature	97.2										97°					
	Pulse	56		53								56		88		87	
	Memory	16.7				19				8		9.7		19.7			
	Association			63 s.				59 s.								60 s.	
	Addition			55 s.				50 s.								43 s.	
	Rest	60 m., with lunch		60 m		180 m.		180 m.				180 m.		10 m.		10 m.	
M. M.	1st 10 minutes	28.5	.6	33.8	.15	32.6	.31	21.7	.55			157.6	1.2	51.1	.5	42.	.1

TABLE VIII—*Continued*

	Subjects	Chs.		Chs.		M. M.		M. M.		G. M. K.		G. M. K.		C. T. R.		C. T. R.	
	Date	May 19		May 20		March 20		May 6		May 2		May 5		May 8		May 15	
	Time of day	10:32 A.M.–12:22 P.M.		9:22–11:22 P.M.		2:30–4:28 P.M.		2:16–4:10 P..M		3:14–5:05 P.M.		12:56–2:46 P.M.		14:3–3:40 P.M.		2:34–4:34 P.M.	
Before work	Temperature					98° F.				88							
	Pulse	72		60		76		83									
	Memory			18		16											
	Association							90 s.		80 s.		55 s.		74 s.			
	Addition							110 s.		46 s.		50 s.					
		Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error
Mental multiplication	1st 10 minutes	103.	.15	55.	.9	160.0	0	100.8	0	60.0	1.5	52.7	.8	177.7	1.	89.8	1.3
	2nd "	90.	1.1	52.1	.8	149.5	1.25	92.5	.17	68.8	1.1	41.7	.4	114.4	.6	58.8	1.3
	3rd "	87.8	.8	45.1	.5	140.3	0	101.7	.5	61.9	.7	64.4	.7	118.1	0	79.0	1.5
	4th "	70.3	.6	52.5	.7	165.8	.5	108.2	1.	102.0	1.	50.5	.5	94.	.3	87.1	2.8
	5th "	70.2	1.3	38.8	.4	165.5	.25	114.8	1.	54.7	.36	42.1	.5	138.4	.6	75.6	1.
	6th "	73.2	.9	62.2	.5	114.7	.7	178.3	0	66.3	1.7	41.0	.2	99.0	.8	73.5	.6
	7th "	71.2	.9	37.9	.3	173.3	0	125.0	.17	66.7	.67	53.2	.5	103.3	.17	75.0	1.
	8th "	68.7	.4	42.7	.9	146.3	.75	151.3	0	64.4	.44	38.8	.6	100.5	0	125.4	.8
	9th "	69.5	1.	35.9	.7	150.0	0	112.0	.2	55.9	.36	38.3	.3	101.4	1.	118.8	.8
	10th "	121.0	.2	40.3	.4	180.3	1.3	77.3	1.4	42.2	.0	61.1	.3	130.0	0	81.9	.5
	11th "	114.0	.4	55.0	1.	119.0	0	128.3	.5	43.1	.7	40.6	.2	150.5	.2	60.6	0
	12th "	122.0	.7	38.4	.3	92.5	.5	112.0	.7	42.5	0	45.3	.3	117.6	.2	81.9	.8
	13th "																
	14th "																
	15th "																
	16th "																
	17th "																
	18th "																
After work	Temperature					98° F.											
	Pulse	63		56		66		75		82							
	Memory			19		14											
	Association							60 s.		63 s.		59 s.					
	Addition							90 s.		58		45 s.		70 s.			
	Rest	60 m.		10 m.				10 m.				10 m.		10 m.		10 m.	
Mental mult.	1st 10 minutes	63.5	.6	34.7	.6			69.4	.9					83.1	.2	57.3	.3
				60 m.													
				30.	.9												

		P. E. R.		P. E. R.		P. E. R.		S. W.		S. W.		S. W.		H. L. H.		A. J. C.	
Subjects		P. E. R.		P. E. R.		P. E. R.		S. W.		S. W.		S. W.		H. L. H.		A. J. C.	
Date		March 27		March 28		April 26		April 10		April 13		May 10		April 8		April 1	
Time of day		3:54– 5:27		4:08– 5:08		9:40– 10:40 A.M.		9:42– 11:50 A.M.		1:16,15– 3:40 P.M.		1:53– 3:48 P.M.		10:25 A.M.– 12:15 P.M.		9:25– 12:04	
Before work	Temperature			99° F.													
Before work	Pulse			83		98		82		83		68		59		85	
Before work	Memory							10.7		14.4		12		20		19	
Before work	Association					175 s.						57 s.					
Before work	Addition					120 s.						100 s.					
		Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error
Mental multiplication	1st 10 minutes	106.		72.8	1.1	49.6	.7	93.0	.6	74.3	.14	69.0	1.2	44.1	0	39.2	.8
Mental multiplication	2nd "	76.4		84.1	.9	52.5	.75	157.5	1.	85.0	.14	54.9	1.5	88.0	1.	47.6	.5
Mental multiplication	3rd "	110.8		56.5	.7	66.0	.7	84.2	1.	74.4	.5	102.5	.7	39.6	.07	46.1	.5
Mental multiplication	4th "	78.2		57.5	.2	47.8	.5	113.6	.6	87.4	1.9	198.4	1.	45.8	.15	33.1	.4
Mental multiplication	5th "	66.9		67.2	1.2	51.8	.4	122.0	.6	90.4	.6	186.3	1.	39.7	.27	43.4	.2
Mental multiplication	6th "	83.7		52.7	.9	61.0	.1	85.7	.4	63.3	1.	166.0	1.	65.9	.44	36.4	.13
Mental multiplication	7th "	115.0				68.9	.7	123.0	.6	66.7	1.3	170.0	1.	50.0	.16	30.6	.28
Mental multiplication	8th "	66.9				50.4	.7	106.7	.8	71.7	2.2	Went to sleep		51.4	.09	30.4	.47
Mental multiplication	9th "	59.3				52.1	.2	104.1	1.7	70.9	.63			45.9	.01	26.6	.34
Mental multiplication	10th "	47.5				44.2	.5	119.0	1.6	64.7	.58	77.5	.5	34.4	.16	31.1	.55
Mental multiplication	11th "					46.5	.2	103.3	1.8	101.4	1.4	52.	.8	36.0	.27	26.5	.22
Mental multiplication	12th "					46.3	1.	103.3	.8	71.3	1.1			39.0	0	22.7	.23
Mental multiplication	13th "							126.0	.2	98.7	.7					25.0	.21
Mental multiplication	14th "							88.0	.6	62.3	.5					28.0	.68
Mental multiplication	15th "									67.0	1.					26.5	.69
Mental multiplication	16th "															31.5	.47
Mental multiplication	17th "																
Mental multiplication	18th "																
After work	Temperature			98° F.													
After work	Pulse			85		81		65		65		61		49		66	
After work	Memory							10.7		10		8.7		20		14	
After work	Association					60 s.						62 s.					
After work	Addition					90 s.						119 s.					
	Rest					10 m.		60 m., with lunch		10 m.		60 m.		60 m., with lunch		60 m., with lunch	
Mental mult.						44.3	.3	100.0 71.9	.8 1.3	61.	.6	80.	1.4	32.6	.31	16.7	.59

TABLE VIII—*Continued*

		Sn.		G. D. S.	
Subjects		Sn.		G. D. S.	
Date		May 14		May 25	
Time of day					
Before work	Temperature				
	Pulse	82		72	
	Memory			17.5	
	Association	96 s.			
	Addition	111 s.			
		Time	Error	Time	Error
Mental multiplication	1st 10 minutes	76.3	.63	61.4	1.4
	2nd "	105.8	.83	47.2	1.5
	3rd "	86.9	.57	65.7	.78
	4th "	114.4	.8	54.8	.82
	5th "	122.	.8	62.7	1.3
	6th "	86.7	.67	47.3	.25
	7th "	127.1	.6	49.1	.77
	8th "	107.8	.5	68.	1.
	9th "	117.	.2	55.5	.5
	10th "	153.	.75	63.	.4
	11th "	127.8	.4	48.2	.5
	12th "	90.2	.75	51.6	1.1
	13th "				
	14th "				
	15th "				
	16th "				
	17th "				
	18th "				
After work	Temperature				
	Pulse	78		66	
	Memory			13.7	
	Association	72 s.			
	Addition	111 s.			
	Rest	60 m.		10 m.	
Mental Mult.	1st 10 minutes	114.0	.6	46.3	.72
				60 m.	
				44.6	1.15

C. D. T. remembered all syllables in the second trial. So in the fourth trial, only one and a half minutes was given instead of two minutes for memorizing ten nonsense syllables; and yet the subject remembered all syllables as easily as before. For the second list we shortened the time to one minute. Therefore, the number of syllables in the table is that which he memorized in only two minutes and a half.

Introspective reports of the subjects:

After the experiments each subject answered the following questions:

1. How did the subject feel after the long mental work?
2. What made the time taken for multiplying one example any longer than that for the other?

Subject C. D. T.

After trial 1, "A slight pain across the eyebrows. The fluctuation of the time taken for multiplying one example is partly due to the difference of difficulty of different examples and partly to the disturbing thoughts."

After trial 2, "I have a slight pain across eyebrows, feel fine generally. I wondered sometimes whether I was doing well, and forgot the numbers. Sometimes, I saw the table between my eyelashes and was disturbed. Once, a voice outside made me stop a moment. After about three-fourths of the test was over, I found my hand was shaking, I have known it to do this only occasionally when playing chess. I had to stop it by thinking hard."

After trial 3, "I worked very hard to-day. The main difficulty is lack of ability to concentrate the attention. I was disturbed by what I saw whenever I opened my eyes."

After trial 4, "The process became almost automatic. Sometimes I could get the answer by the first sight of the example."

Subject MS.

After trial 1, "I feel well in general but have pain in my eyes which I never had in reading and studying. I can visualize the numbers very easily. The process is very difficult, and the length of the time is due to the inability to move. The mind seemed perfectly blank. If I could only have moved across the room, I could have done the work much easier."

After trial 2, "I can not say that I am tired. I have severe pain in my eyes and head. I got very angry when I could not do the work so well as I wanted."

After trial 3, "The sums of nines and eights confused me. I felt so discouraged that I felt most of my answers were merely guesses at those points. The smaller numbers seemed easy to me and I felt no discomfort with the last sheet. I feel very uncomfortable—I have no headache. I could visualize very easily, I think much more easily than in the other test. Perhaps this is due to the prolonged test I have been taking on imagery since I took the last test."

Subject R. S. W.

After trial 1, "(1) I feel well. (2) Some problems were done by short cuts, e.g., $54 \times 98 = 54 \times 100 - 54 \times 2 = 5400 - 108 = 5292$; or again $75 \times 86 = \frac{1}{2}$ of 8600 or $4300 + \frac{1}{2}$ of this. Other problems were difficult to remember; that seemed the main difficulty. One or two distractions from noise outside; aside from these not much distraction. (3) Sometimes I felt clearer-headed than at other times. I did not reduce the methods to automatic uniformity. It seemed to me than conscious effort entered mostly when I was obstructed."

After trial 2, "(1) Felt pretty good but yawned several times. Felt rather dull and confused most of the time. (2) Used no shortcut methods except near the start as noted. Hitherto, I had always $\div 4$ instead of $\times 25$, and $\times 100 - 2$ instead of $\times 98$. But I decided it would be better to stick to a routine method. (3) The great trouble seemed to be the remembering of the given numbers, and I changed the method of retaining them. Hitherto, I had repeated over '2, 4, 7, 3,' when the problem was 24×73; and sometimes I had also said '2, 7; 2, 3; 4, 7; 4, 3;' this being the order of my multiplications. But this did not seem to work very well as a device for remembering the numbers; and I tried a new method which seemed to work better, i.e., taking the 4 digits around in a circle. Thus for the pair $\frac{35}{79}$, I begin with three and said '3, 5, 9, 7; 3, 5, 9, 7;' two or three times before beginning to multiply. Then I multiplied by 3, as in the usual way, viz., '$3 \times 9 = 27$; $3 \times 70 = 210, + 27 = 237$.' Next added to the partial sum 5×7; then multiplied by 10 and added 5×9. This seemed to be more reliable than previous methods of memorizing the numbers. (4) No visual images. I tapped the table, locating the digits as it were, but without going there with any writing movements."

Subject H. A. R.

"Conditions favoring rapidity: (a) Inhibition of external stimuli. (b) Inhibition of (1) distracting or (2) inhibiting ideas. (1) Irrelevant ideas—(not more than seventeen in this case). (2) Especially unfavorable attitudes, self-conscious fears of errors inhibiting from letting himself go—positive side, an attitude of confidence or freedom. (c) Short-cut method, e.g., multiplying by 97 multiply by 100 and subtract the product of $3 \times$ the no. (d) Apparently easier objective combinations."

Subject J. T.

After trial 1, "I feel pain behind the eyeball, dull and diffuse. The greatest length of time is due to the inability to keep the problem in mind and the partial products while arranging them for the addition."

Subject M. M.

After trial 1, "I have no pain in my eyes. The length of time is due to the number of repetitions without results."

After trial 2, "It was very hard for me to remember the figures. I had no headache."

Subject Pfg.

After trial 2, "I felt lazy when I was multiplying them. I had pain in my eyes and cramp in my right arm."

Subject C. T. R.

After trial 1, "It became more and more easy to visualize the numbers. The trouble is that I do not seem to have enough energy to go on."

Subject P. E. R.

After trial 1, "I feel all right and have no pain in my eyes."

Subject H. L. H.

"1. Feel well and in average shape mentally.

"2. Some problems are distinctly harder than others. The difference seems chiefly due to the difficulty of adding the two sums after the multiplication has been performed. I can only image these two sums in their proper special position for adding for a brief moment. If the numbers to be added combine quickly enough, the addition can be made in this brief moment. If not I have to start the adding all over again. I cannot hold the two numbers in the form of visual imagery. I have to keep saying either both of them or at least one of them (usually the multiplier) to myself. The multiplying comes quickly. Then I find that the original numbers are gone completely and I am left alone with the two products. I frequently find myself hanging on to these products, saying them over and over again, but being unable to get a special picture so as to know which of the digits to add together. If I lose one of these products, I have to look at the paper again in order to learn what the original numbers are.

"3. Was not conscious of a wave of attention, but the problems seemed to get easier toward the end of the series. In the first part of the series, I did not have a perfectly comfortable position. Felt rather formal and restrained. As the test went on I began to slouch down in my chair in a position which I frequently assume at my desk. Along with this change the problems seemed to become easier. I can not say whether I felt like assuming this attitude because the problems were not so difficult and permitted a little relaxation, or whether the change in position was what made the task easier.

"4. In the beginning, I was conscious of nothing but the numbers, but as the test progressed I found my mind wandering to other things—to accidental and irrelevant characteristics of the numbers (such as that the multiplier was just half or just one-third of the multiplicand). During the latter part of the test I once found myself in the midst of the problem, looking at a sparrow that has been playing on the window sill. Up to this time I had ignored him.

"5. In the beginning, it was easy to confine my attention to the problems. But toward the end it became more and more difficult to keep outside thought out of my mind, although there was, in spite of this tendency to distraction, the feeling that I was making better time in the test than in the first part of the series. I found myself wondering if this increased speed was partly due to the fact that my mind wandered a little and enabled me to approach each problem without so much feeling of effort."

CHAPTER III

THE INFLUENCE OF MENTAL WORK ON PHYSIOLOGICAL PROCESSES

In Table IX, an attempt is made to find the difference in the pulse rate of subject T. A. in the morning and in the evening according to the different number of hours of mental work during the day. The days are divided into ten different kinds according to the different number of hours of mental work, and under each kind there are given in pairs the morning and the evening pulse rates. In the table, " 0—1 " means the days when the duration of mental work was from zero to fifty-nine minutes inclusive, " 1—2," from one hour to an hour and fifty-nine minutes inclusive, and so on. The data came from Table VI.

TABLE IX

The relation between the degree of change in the pulse-rate and the number of hours of mental work.

0–1 Hours of work				1–2 Hours of work			
Date	Morning	Evening	Ratio	Date	Morning	Evening	Ratio
Feb. 5	79.5	77.0	96.8	Mar. 4	73.0	81.0	110.9
" 10	88.0	79.5	90.3	May. 17	94.0	98.5	104.8
" 27	85.0	84.0	98.8	" 21	92.5	89.0	96.2
Mar. 6	79.5	83.5	105.0	" 23	94.5	90.5	95.7
" 8	78.0	70.0	89.7	" 25	96.0	87.0	90.6
				" 28	100.0	92.0	92.0
Average			96.1				96.7

2–3 Hours of work				3–4 Hours of work			
Date	Morning	Evening	Ratio	Date	Morning	Evening	Ratio
Feb. 15	73.0	79.0	108.2	Mar. 7	82.0	80.0	97.6
" 26	81.0	91.0	112.1	" 9	79.0	70.0	88.6
Mar. 5	75.0	71.0	94.7	Apr. 22	93.0	90.0	96.9
June 7	101.0	92.5	91.6				
Mar. 11	83.5	89.0	106.6				
Average			102.6				94.4

4–5 Hours of work			
Date	Morning	Evening	Ratio
Feb. 4	81.5	83.5	102.4
" 18	86.0	79.0	91.8
Mar. 3	87.0	83.0	95.4
Apr. 16	86.0	84.0	97.7
May 18	100.0	96.0	96.0
" 24	92.0	90.0	97.8
" 27	98.5	87.0	88.3
Average			95.6

5–6 Hours of work			
Date	Morning	Evening	Ratio
Feb. 9	83.0	74.0	89.1
" 17	78.0	91.0	116.7
" 21	87.0	86.5	99.4
Apr. 23	83.0	84.0	101.2
May 9	91.0	79.0	86.8
" 10	84.0	90.0	107.1
" 11	95.0	88.5	93.2
" 12	94.0	88.0	93.6
			98.4

6–7 Hours of work			
Date	Morning	Evening	Ratio
Mar. 8	93.0	80.0	86.0
" 18	90.0	82.5	91.7
Apr. 5	85.5	74.5	87.1
" 18	100.5	101.0	100.5
June 20	98.5	90.0	91.3
" 22	98.5	87.0	88.3
" 23	103.3	98.5	95.3
Average			91.5

7–8 Hours of work			
Date	Morning	Evening	Ratio
Feb. 23	89.0	76.0	85.4
" 24	92.0	88.5	96.2
Mar. 1	81.0	73.5	90.7
Apr. 12	87.5	78.0	89.1
" 23	85.5	80.0	93.6
" 14	82.5	78.0	94.6
			91.6

8–9 Hours of work			
Date	Morning	Evening	Ratio
Feb. 7	85.0	86.5	101.8
" 10	83.6	79.0	94.5
" 16	86.0	77.0	89.5
" 22	84.0	80.5	95.8
" 28	92.5	78.0	84.3
Mar. 16	86.0	84.0	97.7
Apr. 11	83.0	74.0	89.2
Average			93.2

9–10 Hours of work			
Date	Morning	Evening	Ratio
Apr. 7	92.5	87.5	95.7
May 14	92.5	92.5	100.0
" 16	107.0	94.0	87.8
			94.5

If we examine the average ratios of the different kinds of days on which observations were made, we find that the ratio does not decrease regularly with the number of hours of mental work (*i e.,* the pulse rate does not decrease in any strict arithmetical ratio to the amount of increase in the time of mental work). That the changes in the two factors in question are not wholly independent of each other is, however, shown by the following fact: If we take the average of the average percentages of decrease on the days of "0—1," "1—2" and "2—3;" that of the percentages on the days of "3—4," "4—5" and "5—6;" and that of the percentages on the days "6—7," "7—8," "8—9" and "9—10," we get respectively 98.5 with A. D.[1] of 6, and A. D. (t. av.—obt. av.) of 1.5, 96.1 with A. D. of 5.5 and [2]A. D. (t. av.—obt. av.) of 1.3, and 92.7 with A. D. of 3.2 and A. D. (t. av.—obt. av.) of .6. This means, of course, on the whole, that by evening the pulse rate has decreased least compared with the morning rate when the subject has worked mentally less than three hours during the day, the ratio of the decrease being 1.5 per cent, and that the decrease is greatest when the hours of mental work are from six to ten, the ratio of decrease being then 7.3 per cent of the morning rate. The difference, however, might be greater if the pulse rates were measured immediately before and after the mental work, for the following reason: Since the time of day at which the mental work was performed varies, the mental condition in the evening cannot be expected to be the same on all the days when the same number of hours were devoted to mental work. For instance, if the subject did seven hours of mental work from 10 a. m. to 6 p. m. and spent the evening in rest or recreation, the mental condition at 10 o'clock in the evening, when the pulse rate was measured, might be only a little affected by the work of the day. This state of mind cannot be the same as that at 10 p. m. after seven hours of mental work between 2 p. m. and 10 p. m. This tends to minimize the difference between the days of greater and less mental work. If, therefore, 5.8 per cent (which is the difference between the average percentage when the mental work lasted for more than six hours and that of the days when it lasted less than three hours) means a real difference due to the greater amount of mental work, it would be still greater if the pulse had been measured just at the close of a certain amount of work.

A fair inference from the actual figures given above would be that, so far as the particular subject tested goes, the average decrease of pulse rate tends to become greater as the duration of mental work increases. The chances are 8.9 to 1 that the

[1] Average deviation.
[2] Reliability.

true average percentile decrease of pulse rate during days of 0—3 hours of mental work will not exceed the average obtained for decrease of pulse rate during the days of 3—6 hours' mental work; and the probability is 52 to 1 that the true average percentile decrease in pulse rate during a day of 4—6 hours' mental work will not exceed the decrease during a day of 7—10 hours of mental work.

Let us now consider the correlations between change in pulse rate and in efficiency of certain mental functions.

If the decrease of pulse rate can, to a certain extent, be a measure of mental fatigue, there ought to be some correlation between this and the decrease of efficiency in the mental functions tested, provided that the latter is a true measure of mental fatigue. Table X gives in full the relations of changes in the two factors.

Using the formula, $r = \frac{\Sigma x. y}{\eta. \sigma_1 \sigma_2}$, we obtain a correlation of about -.11, between the decrease of the pulse rate and the decrease of the time taken for memorizing the German equivalents of given English words, and a correlation of -.11, between the decrease of the pulse rate and the decrease of the time taken for doing mental multiplication. If we use the median ratio method, using the formula,

$$r = \frac{1}{2}\left\{\frac{\text{Mid A/B ratio}}{\frac{\text{var. A}}{\text{var. B}}} + \frac{\text{Mid B/A ratio}}{\frac{\text{var. B}}{\text{var. A}}}\right\}$$

the former correlation becomes -.243; and the latter, -.2193.

Since measurements of the mental abilities were made by the times taken to do equal amounts, a greater decrease of mental ability is indicated by a larger percentage. A greater decrease of pulse rate is indicated by a smaller percentage. Therefore, a negative correlation indicates that the greater the decrease in the pulse rate the greater the decrease in the mental efficiency of the function studied.

A fair conclusion from the figures obtained would be that in the case of the individual T. A., the decrease of the pulse rate is a little correlated with the decrease in efficiency of the function of memory and of mental multiplication.

TABLE X

Rate of pulse for morning and evening; rate of decrease and the divergence of the individual percentages from the average percentage; average time taken to memorize a German word in the morning and in the evening; rate of decrease and the divergence of the individual percentages from the average percentage; average time for mental multiplication in the morning and in the evening; rate of decrease; and the divergence of the individual percentages from the average. Subject T. A.

Day	Pulse				Memory test				Mental multiplication test			
	Morning	Evening	The ratio of E. to M.	Deviation	Morning	Evening	The ratio of E. to M.	Deviation	Morning	Evening	The ratio of E. to M.	Deviation
No. 1	78.	91.	116.7	+21.7	21.3	28.8	133.8	+15.0	151.0	230.0	152.3	+34.5
" 2	73.	81.	111.0	+16.0	13.3	13.7	103.	—15.8	141.7	170.0	120.0	+22.
" 3	73.	79.	108.2	+13.2	18.8	24.4	129.7	+10.9	201.7	136.7	67.6	—50.2
" 4	84.	90.	107.1	+12.1	9.5	10.5	110.5	—8.3	123.3		87.6	—30.0
" 5	83.5	89.	106.6	+11.6	10.6	11.6	109.4	—9.4	153.7	130.0	83.9	—33.9
" 6	79.5	83.5	105.0	+10.	16.6	18.1	108.5	—10.3	97.5	132.5	135.9	+18.1
" 7	83.	84.	101.2	+6.2	11.7	12.8	109.4	—9.4	185.0	133.3	70.9	—46.9
" 8	82.5	92.5	100.0	+5.0	13.0	18.3	140.8	+22.0	100.0	163.3	163.3	+45.5
" 9	85.	84.	98.8	+3.8	11.	10.6	96.4	—22.4	125.0	126.6	101.3	—16.5
" 10	47.	86.	98.3	+3.3	19.8	22.5	113.0	—5.8	121.7	163.3	133.9	+16.1
" 11	92.	90.	97.8	+2.8	10.5	13.6	108.8	—10.0	113.3	140.0	123.6	+5.8
" 12	86.	84.	97.7	+2.7	11.3	12.3	115.2	—3.6	160.0	145.3	90.6	—27.2
" 13	86.	84.	97.1	+2.7	16.5	20.8	126.1	+7.3	127.7	118.3	92.6	—25.2
" 14	82.	80.	96.6	+2.6	11.5	15.0	130.5	+11.7	148.3	150.0	101.1	—16.7
" 15	75.	77.	96.7	+1.7	15.0	20.5	133.3	+14.5	153.7	130.0	84.6	—33.2
" 16	100.	96.5	96.3	+1.5	12.0	13.8	115.0	—3.8	138.3	111.8	80.9	—36.9
" 17	92.5	89.	96.2	+1.2	13.7	13.0	99.3	—19.5	96.7	130.0	134.4	+16.6
" 18	92.	88.	96.2	+1.2	14.5	21.5	148.3	+29.5	138.3	196.7	142.2	+24.4
" 19	84.	80.5	95.8	+.8	18.5	21.9	118.4	—.4	165.0	231.7	140.4	+22.6
" 20	94.5	90.5	95.8	+.8	12.2	10.5	85.2	—33.6	123.3	97.4	78.9	—38.9
" 21	87.	83.	95.4	+.4	20.	22.9	108.8	—10.0	173.3	185.0	106.8	—11.0
" 22	83.6	79.	95.2	+.2	30.3	25.3	116.6	—2.2	212.7	278.7	131.0	+13.2

TABLE X—*Continued*

Day	Pulse				Memory test				Mental multiplication test			
	Morning	Evening	The ratio of E. to M.	Deviation	Morning	Evening	The ratio of E. to M.	Deviation	Morning	Evening	The ratio of E. to M.	Deviation
No. 23	75.	71.	94.7	—.3	11.3	13.1	115.1	—3.7	145.3	153.3	105.5	—12.3
" 24	92.5	87.5	94.6	—.4	13.8	14.0	101.5	—17.3	125.3	143.3	114.3	—13.5
" 25	93.	90.	94.6	—.4	11.8	15.0	127.1	+8.3	148.3	173.3	116.9	—.9
" 26	82.5	78.	94.5	—.5	10.3	14.5	140.8	+22.0	121.7	191.7	157.5	+39.7
" 27	85.5	80.	93.	—2.0	10.3	15.9	154.4	+35.6	162.5	162.5	100.	—17.8
" 28	95.0	88.5	93.	—2.0	10.9	14.3	131.2	+12.4	113.3	135.0	119.1	+1.3
T 29	94.0	88.	93.	—2.0	10.	12.3	123.0	+4.2	110.0	132.5	120.4	+2.6
" 30	100.0	92.	92.	—3.0	10.	9.5	95.0	+22.8	106.7	127.0	119.0	+1.2
" 31	86.	79.	91.1	—3.1	15.8	22.9	144.9	+26.1	181.7	229.0	110.9	—6.9
" 32	101.	92.5	91.6	—3.4	20.0	20.3	101.5	—17.3	116.3	186.7	160.5	+42.7
" 33	98.5	90.0	91.4	—3.6	15.8	20.9	132.3	+13.5	108.3	198.3	183.1	+65.3
" 34	81.	73.5	90.7	—4.3	23.3	26.4	113.3	—5.5	126.3	170.0	135.3	+16.5
" 35	96.	87.	90.6	—4.4	15.0	10.	72.0	—46.8	130.0	138.3	100.6	—17.2
" 36	88.	79.	90.4	—4.6	19.0	17.3	87.5	—31.3	195.0	265.5	136.1	+18.3
" 37	90.	89.	90.3	—4.7	14.2	18.0	126.7	+7.9	118.3	150.0	126.8	+9.1
" 38	78.	70.	89.7	—5.3	18.0	20.0	111.1	—7.7	143.3	140.0	97.7	—20.1
" 39	86.	77.	89.2	—5.8	10.0	20.0	123.8	+5.0	124.3	186.3	149.9	+32.1
" 40	83.	74.	89.1	—5.9	17.5	18.9	105.9	—12.9	153.3	176.7	115.3	—2.5
" 41	83.	74.	89.1	—5.9	15.0	16.8	112.0	—6.8	216.7	176.7	81.5	—36.3
" 42	87.5	78.	89.1	—5.9	20.0	22.8	112.9	—5.9	127.3	155.5	122.9	+5.1
" 43	79.	70.	88.6	—6.4	18.0	20.5	113.9	—4.9	122.5	187.5	153.9	+36.1
" 44	98.5	87.	88.3	—6.7	8.0	10.5	131.3	+12.5	131.7	145.0	110.1	—7.7
" 45	87.0	76.	87.3	—7.7	17.5	19.8	113.1	—5.7	145.0	173.1	119.5	+1.7
" 46	107.	94.	87.2	—7.8	9.	18.4	204.0	+85.2	145.0	200.0	137.9	+21.1
" 47	85.5	74.5	87.0	—8.	12.3	14.8	120.3	+1.5	130.0	178.0	136.9	+19.1
" 48	91.	79.	86.8	—8.2	11.5	13.3	115.7	—3.1	125.0	168.3	135.5	+17.7
" 49	93.	80.	85.9	—9.1	15.0	19.0	126.7	+7.9	238.3	190.7	82.5	—35.3
Average			95.				118.8				117.8	

In the case of the group of individuals (the materials are obtained from the results of Experiment IV, given in Table VIII), we find such differences of pulse rate before and after two hours of mental multiplication as are shown in Table XI.

TABLE XI

The pulse rate before and after two hours of mental multiplication and the percentage which the latter is of the former for each individual, and for the average of the group.

Subjects	Before	After	%
C. D. T.	72	66	91.7
MS.	73	64	87.7
R. S. W.	64	54.5	85.2
J. T	75	56	74.7
Pog.	91	87.5	96.2
P. E. R.	98	81	82.6
S. W.	82.5	65	78.8
H. L. H.	59	49	83.1
A. G. C.	85	66	77.6
Chs.	68.5	59.5	86.8
M. M.	79.5	70.5	88.7
G. M. K.	88	82	93.2
Su.	82	78	95.1
G. D. S.	72	66	91.7
Average			86.7

The figures in the table show that the pulse rate is invariably lower after mental work, the difference being 13.3 per cent of the pulse rate before mental work. This difference, however, might be due to the fact that the subject sat for two hours with very little muscular movement which invariably increases the pulse rate. Indeed, experiments tried on the subjects R. S. W. and C. H. S. showed that the pulse rate decreased during a one-hour rest after two hours of mental work and that the average rate of decrease is then about 5 per cent of the rate immediately before rest.

Consider now the correlations between *change* in the pulse rate and *change* in efficiency of certain mental functions, the facts being given in Table XII.

Relating the divergence of an individual from the average change in the mental function to his divergence from the average gross change in pulse rate, we get a coefficient of correlation

TABLE XII

The relation of change in pulse rate to change in efficiency in the process of multiplication from the first to the last ten minutes of a two hour period.

Subjects	Pulse						Multiplication			
	Pulse rate before multiplication	Pulse rate after multiplication	Difference of pulse rates before and after multiplication	Deviation of each difference from the average	Ratio of pulse rate after to that before multiplication in percentages	Deviation of each percentage from the average percentage	Average time taken for multiplying one example in the first 10 m.	Average time taken for multiplying one example in the last 10 m.	Ratio of average time after to that before multiplication: in percentages.	Deviation of each percentage from average percentage
Pfg.	91.0	87.5	4.	—5.5	96.2	+8.7	61.6	50.7	82.3	—9.6
Sn.	82.0	78.0	4.	—5.5	95.1	+7.6	76.3	90.2	118.2	+26.3
C. D. T.	72.0	66.3	6.	—3.5	92.1	+4.6	42.5	27.0	62.5	—29.4
G. M. K.	88.0	82.0	6.	—3.5	93.2	+5.7	60.0	43.1	70.2	—21.7
M. M.	71.5	65.5	6.	—3.5	91.6	+4.1	130.4	97.3	74.6	—27.3
G. D. S.	72.0	66.0	6.	—3.5	91.7	+4.2	61.4	51.6	80.0	—11.9
P. E. R.	90.5	83.0	7.	—2.5	91.7	+4.2	61.8	49.5	80.9	—11.0
MS	73.0	64.0	9.	—0.5	87.6	+.1	38.2	40.6	106.2	+14.3
Chs.	72.0	63.0	9.	—0.5	87.4	—.1	103.0	114.0	110.7	+18.8
R. S. W.	64.0	55.0	9.	—0.5	85.9	—1.6	40.8	32.8	80.4	—11.5
H. L. H.	59.0	49.0	10.	+0.5	83.0	—4.5	44.1	36.0	81.6	—10.3
S. W.	82.5	64.0	19.	+9.5	77.6	—9.9	83.8	77.5	92.5	+.6
A. G. C.	85.0	66.0	19.	+9.5	77.6	—9.9	39.2	21.5	80.4	—11.5
J. T.	75.0	56.0	19.	+9.5	74.7	—12.8	96.6	161.7	167.4	+75.5
Central tendency			9.5		87.5				91.4	

of about .4 (.442 by the Pearson method and .366 by the median ratio method). Using the percentile change in pulse rate, we get a coefficient of correlation of .42 (.429 by the Pearson and .413 by the median ratio method). The individual who loses most or gains least in the course of the work shows, to a considerable extent, the greatest drop, absolute or relative, in pulse rate.

The similar relation of loss in ability to memorize nonsense syllables to lowering of pulse rate is shown in full in Table XIII.

Relating the divergence of an individual from the average in one change to his divergence from the average in the other as before, we get a coefficient of correlation of about .795 (.828 by the Pearson method and .75 by the median ratio method, using gross changes in both traits; and, .76 by the Pearson method and .84 by the median ratio method, using the percentile changes).

TABLE XIII

Subjects	Pulse						Memory					
	Pulse rate before mult.	Pulse rate after mult.	Gross diff. bet. pulse rate before and after mult.	Deviation	Percentage rate of pulse rate after to that before mult.	Deviation	No. of nonsense syllables remembered before mult.	No. of nonsense syllables remembered after mult.	*Gross diff. bet. No. of syllables before and after mult.	Deviation	Percentage ratio of No. of syllables after to that before mult.	Deviation
J. T....	75	56	19	+7.5	74.7	—10.5	15.7	9.7	+6.0	+4.3	61.8	—27.6
A. G. C..	85	66	19	+7.5	77.6	—7.6	19.0	14.0	+5.0	+3.3	73.7	—15.7
S. W....	82.5	65	18	+6.5	78.8	—6.4	12.5	10.4	+2.1	+.4	83.4	—6.0
R. S. W.	66	56	10	—1.5	84.0	—1.2	16.7	16.7	0	—1.7	100.0	+10.6
M. M....	76	66	10	—1.5	86.8	+1.6	16.0	14.0	+2.0	+0.3	87.8	—1.6
Pfg.....	98	88	10	—1.5	89.8	+4.6	17.5	13.7	+3.8	+2.1	78.3	—11.1
G. D. S..	72	63	9	—2.5	87.5	+2.3	18.1	19.7	—1.6	—3.3	108.8	+19.4
Chs.....	60	56	4	—7.5	93.3	+8.1	18.0	19.0	—1.0	—2.7	105.6	+16.2
C. D. T..	68	64	4	—7.5	94.2	+9.0	18.0	19.0	—1.0	—2.7	105.6	+16.2
Averages	.....	.....	11.5	....	85.2	.....	.....	.....	+1.7	.....	89.4	

In memory + means shows increase of efficiency.
In memory — " " decrease " "

The relation of decrease in the ability to perform the association test and the addition test as described in Experiment IV to decrease of pulse rate is shown in full in Table XIV.

TABLE XIV

Subjects	Pulse				Association				Addition			
	Pulse rate before mental multiplication	Pulse rate after mental multiplication	Percentage ratio of pulse rate after to that before mental multiplication	Divergence of each ratio from the average	Time taken to do the apposite association test before mental multiplication	Time taken to do the apposite association test after mental multiplication	Percentage ratio of the time after to that before mental multiplication	Divergence of each ratio from the average	Time taken to perform the addition test before mental multiplication	Time taken to perform the addition test after mental multiplication	Percentage ratio of the time after to that before mental multiplication	Divergence of each ratio from the average
P. E. R..	98	81	82.7	—5.9	115.0	60.0	51 1	—39.7	120.0	90.0	75.0	—26.7
G. M. K.	88	82	83.2	—5.4	80.0	63.0	75.9	—14.9	46.0	58.8	126.1	+24.4
R. S. W.	62	53	85.5	—3.1	57.0	63.0	110:5	+19.7	55.0	55.0	100.0	—1.7
MS......	73	64	87.6	—1.0	95.0	105.0	110.5	+19.7	67.0	78.0	116.4	+14.7
S. W....	68	61	89.7	+1.1	57.0	62.0	108.5	+17.7	100.0	119.0	119.0	+17.3
M. M....	83	75	90.3	+1.7	90.0	60.0	74.4	—16.4	110.0	90.0	81.8	—19.9
Pfg.....	92	87	94.5	+6.9	50.0	60.0	120.0	+29.2	45.0	43.0	95.5	—6.2
Sn......	82	78	95.1	+6.5	96.0	72.0	75.0	—15.8	111.0	111.0	100.0	—1.7
Average.	.....	.....	88.6.	.....	.....	.....	.....	.....	.....	.....	101.7	

Relating the divergence of an individual from the average change in the pulse rate to his divergence from the average change in the ability to associate opposites, we get a coefficient of correlation of about .14 (+ .32 by the Pearson method and –.04 by the median-ratio method). Since the ability of the mental function is expressed by the time taken to do a certain amount of work, a higher percentage indicates a greater decrease of mental efficiency, while it means in the case of pulse rate a smaller degree of decrease. For this reason, a plus correlation in the case described above means an inverse relation, *i.e.*, an individual whose pulse rate decreased most during two hours of mental multiplication, did best in the association test given after two hours of work.

Relating the divergence of an individual from the average change in pulse rate to his divergence from the average in adding single numbers as before, we get a coefficient of correlation of about –.134 (–.069 by the Pearson method and –.199 by the median ratio method). There is, thus, a correlation between the decrease in the pulse rate and that in the ability to add. On the whole, the facts from this small group of subjects favor the existence of a slight correlation between lowered pulse and lowered efficiency in intellectual work. Proof of its existence and a reasonably accurate measure of its amount can be had only by repeated tests with many more subjects.

The Influence of Mental Work on Body Temperature

Data obtained from Experiment III, given in Table V, give the results of many different observations with one individual on the difference of temperature before and after mental work. These are summarized in Table XV.

On the average, according to the figures in the table, the temperature rose only 0.1 per cent during 2 hours and 3 minutes of translation work.

Experiment IV gives data on the changes of temperature in six individuals during two hours of mental multiplication, which are given in full in Table XVI. The average fall of temperature during two hours of mental multiplication is 0.2 per cent in terms of the temperature before the mental multiplication.

TABLE XV

The temperature immediately before and after certain hours of translation of English into Japanese, in each different test.

Date	Before translation		After translation		The percentage which 'after' is of "before"
	Time of day	Temp-erature	Time of day	Temp-erature	
Nov. 29.......	1:30 P. M.	98° F.	5: P. M.	97.8	99.8
" 30.......	10:37 A. M.	97.2°	12: A. M.	97.6	100.4
" 30.......	1:42 P. M.	97.7°	4:55 P. M.	98.1	100.4
" 30.......	7:41 "	97.9°	9:20 "	98.0	100.1
Dec. 2.......	10:59 A. M.	97.6°	12:00 A. M.	97.0	99.2
" 2.......	1:36 P. M.	98.0°	4:55 P. M.	97.8	99.8
" 8.......	7: "	97.1°	8: "	97.9	100.8
" 9.......	2:10 "	96.6°	4:15 "	97.2	100.6
Average...					100.1

Consider now the relation between change in temperature and in efficiency of certain mental functions.

According to the results of Experiment IV, given in Table VIII, a coefficient of correlation of .22 is found to exist between the fall of temperature and the decrease of the ability to memorize nonsense syllables. The figure, however, is unreliable, for the number of cases is not sufficient.

TABLE XVI

Subjects	Time of day	Temperature before mental multiplication	Temperature after mental multiplication	Percentage ratio of the temperature after to that before mental multiplication
R. S. W...	9:50 -11:59 A. M.	99.8° F.	97.2° F.	99.5
J. T.......	9:50 -11:50 "	98.5 "	97.0 "	98.5
A. G. C...	9:25 -12:04 "	97.0 "	98.0 "	101.0
C. D. T...	10:17 A. M.-12:10 P. M.	97.0 "	98.0 "	101.0
M. M.....	2:30 - 4:28 "	98.0 "	98.0 "	100.0
P. E. R...	4:08 - 5:08 "	99.0 "	98.0 "	98.9
Average.				99.8

CHAPTER IV

THE INFLUENCE OF MENTAL WORK ON THE FEELING OF FATIGUE

The writer has, by introspection, arrived at a conception of the nature of the feeling of fatigue very similar to that presented by Professor Thorndike, which runs as follows:

"When I tried to analyse my feelings during states which in accord with the social consciousness I called feelings of mental fatigue, of inability to do mental work, I found in them emotions of repugnance at the thought of certain forms of mental activity, amounting sometimes to a sort of mental nausea; feelings of dullness or stupidity (by which names I mean a state of unsuggestiveness, of insipidity), cravings for certain familiar forms of mental relaxation, feelings of sleepiness, heavy feelings in the head, pains in the chest or back (from leaning against a table and sitting upright during work) and sometimes a feeling best characterized by the awkward phrase 'mental goneness,' which reminds one of the feeling of physical faintness. This last is most likely the supposed feeling of incompetency, but I get it only very rarely and not necessarily after especially hard mental work. I fancy that it has some direct physical cause. I was constantly surprised to find myself when feeling, as I would certainly have said, 'mentally tired,' unable to demonstrate in the feeling anything more than emotional repugnance to the idea of doing mental work. On at least half the occasions this seemed to be all there was."

Comparing the introspective reports of the subjects on the feelings of fatigue with the actual efficiency of mental functions, Thorndike drew the following conclusions, "Our third conclusion was that the feelings of fatigue, such as they were, were not measures of mental inability. Kraepelin has emphasized this fact, but chiefly in connection with the claim that we can be mentally fatigued without feeling so. What I wish to emphasize is that we can feel mentally fatigued without being so, that the feelings described above serve as a sign to us to stop working long before our actual ability to work has suffered any important decrease which an experimenting psychologist could measure and use as a warning to us."

In order to study the problem the writer used two methods. One was to find whether the change in feeling is in any regular relation to that in the actual decrease of efficiency.

We classify the feelings into three: 'good,' 'medium' and 'tired,' no finer distinction being practicable. The figures representing the degree of efficiency in mental and physical functions were grouped under the different kinds of feelings accompanying them. Comparing the averages of these three groups of figures, we can find the average conditions of mental and physical efficiency accompanying these different feelings. In the second method, comparison was made between the change in feeling and change in mental efficiency produced by mental work lasting for certain hours. In comparison, let 1 stand for the feeling 'good,' 2 for the feeling 'medium' and 3 for the feeling 'tired.' The change '1—1' signifies that the subject felt well both before and after certain hours of work. The change '2—2' signifies that the subject felt no better and no worse than usual before and after mental work. Thus nine possible changes are represented by the combinations of these figures; namely, '1—1' (from good to good), '2—2' (from medium to medium), '3—3' (from tired to tired), '1—2' (from good to medium), '2—3' (from medium to tired), '1—3' (from good to tired), '3—2' (from tired to medium), '2—1' (from medium to good), and '3—1' (from tired to good). We express change in mental efficiency by the ratio which the time taken to do a given amount of work, or the amount of work done in a given length of time in a 'late' test, bears to the time taken or the amount of work in a given length of time in an 'early' test. The degree of change in pulse rate and temperature is indicated by the percentage which the number of beats or the degrees of temperature *after* is of that *before*, the continuous work. We then group the percentages according to the different changes in feeling which accompany them and compare these groups. The third method is to obtain a coefficient of correlation between the degree of change in feeling and that in physical or mental efficiency. Since the classification of the feelings is only approximate, getting coefficients of correlation may not be a suitable method for the data. However, we shall use this method simply to supplement others. In getting the coefficient of correlation, we count the number of like and unlike signed pairs and calculate r by the formula, $r =$ cosine π (percentage of unlike-signed pairs).

I shall report first the results obtained from the facts of Table VI for subject T. A.

The degree of change in feeling from morning to evening is recorded by the method described above. The minus sign is used when the feeling in the evening is worse than that in the morning, and the plus sign in the opposite case, e.g., the changes '1—2' and '1—3' are expressed respectively as -1 and -2; '2—1' and '3—1' are expressed as + 1 and + 2. We classify the differences into four groups according to the hours of mental work performed during the day and obtain the average difference of each group. On the days of from 0—2 hours of mental work, the average difference in feeling from morning to evening is 0. On days when the work lasted between two and four hours, it is -.44; on days when it lasted between four and six hours, -.58; on days of from six to eight hours of mental work, -.75; and on days of from eight to ten hours of work, -.87.

The feeling of fatigue and the pulse rate:

With the first method described above, we find that the average pulse rate accompanying the feeling 'good' is 87.2 with A. D. 5.5 and A.D. (t. av.—obt. av.) 0.8; the average pulse rate accompanying the feeling 'medium' is also 87.2 with A. D. 6.5 and A. D. (t. av.—obt. av.) .9; and the average pulse rate accompanying the feeling 'tired' is 85.2 with A. D. 5.4 and A. D. (t. av.—obt. av.) 1.1. The probability that the true average pulse rate accompanying the feelings 'good' and 'medium' will not drop lower than that accompanying the feeling 'tired' is six to one.

With the second method, we find the following relations between the change in the feeling of fatigue and the percentage which the evening pulse rate is of the morning pulse rate.

Change in feeling	Change in pulse rate			
	Average	A. D.	A. D. (t. av.–obt. av.)	Number of days
'2-1'	90.8	1.2	0.7	3
'1-1'	93.4	3.9	1.2	11
'2-2'	97.1	3.1	0.9	11
'3-3'	112.3			1
'1-2'	92.9	3.5	1.3	7
'2-3'	97.2	10.3	2.5	17
'1-3'	99.4	3.3	1.2	8

If there were any relation between the change in the feeling of fatigue toward worse and the decrease of the pulse rate, it would be expected that the change in the feeling from good to tired would be accompanied by the greatest drop in the pulse rate, and that the percentage would be near 100 when the change in the feeling is '1—1,' '2—2' or '3—3.' The actual results are very different. The average percentage accompanying the change of the feeling '1—3' is 99.4 and is next to the highest. The change '2—1' has a percentage of 90.8. On the whole, then, the pulse rate does not change in a regular relation with the change in the feeling of fatigue in the particular subject tested.

With the third method, we find a coefficient of correlation of zero existing between the change in the pulse rate and that in the feeling.

The feeling of fatigue and efficiency in memorizing words:

With the first method, we find that, in 41 measurements, the average time taken to memorize a German word is 15.7 sec. with A.D. 4.1 sec. and A. D. (t. av.—obt. av.) 0.64 sec. when the subject felt 'good'; 16.9 sec. with A. D. 3.5 sec. and A. D. (t. av.—obt. av.) 0.56 sec. in 38 measurements when the subject felt 'medium'; and 18.8 sec. with A. D. 5.37 sec. and A. D. (t. av.—obt. av.) 1.18 sec. in 21 measurements when the subject felt 'tired.' Thus, the efficiency of the function of memory is highest when the subject feels best and lowest when worst.

With the second method, the following relations are found between the change in feeling and that in the speed of memory during the day.

Change in feeling	Percentile change in time, required to memorize			
	Average %	A. D.	A. D. (t. av.– obt. av.)	Number of cases
'3-1'	144.9	. .	. .	1
'2-1'	108.8	0.8	0.5	2
'1-1'	113.6	16.3	4.7	12
'2-2'	115.9	10.1	3.6	8
'1-2'	100.7	15.5	5.9	7
'2-3'	116.8	13.0	3.6	13
'1-3'	144.8	28.6	10.9	7

Grouping these facts we have:—

'2-1', '3-1'	120.8	3
'1-1', '2-2'	114.5	20
'1-2', '2-3'	111.2	20
'1-3'	144.8	7

If there is any relation between the two as in the results obtained by the first method, it is to be expected that the change of feeling '2—3' and '1—2' will accompany higher percentages, *i.e.*, greater decrease of speed of memory than the changes '1—1' and '2—2'; and the change of feeling '1—3' still higher percentages than the other two. The actual figures given above do not show much of this. Yet there is an indication that changes in the two are not entirely independent. Percentages accompanying '1—1' and '2—2' are about the same as those accompanying '1—2' and '1—3,' but highest is the one accompanying '1—3.' The single case of '3—1' is, however, also very high.

With the third method, a coefficient of correlation of 0.13 is found between the change in one function and that in the other.

The feeling of fatigue and efficiency in mental multiplication:

By the first method, the average time taken to multiply mentally a three-place number by a three-place number is found to be 138.8 sec. with A. D. 30.6 sec. and A. D. (t. av.—obt. av.)

4.9 sec. when the subject feels 'good'; 142.9 sec. with A. D. 20.6 sec. and A. D. (t. av.—obt. av.) 3.3 sec. when 'medium'; and 151.3 sec. with A. D. 28.8 sec. and A. D. (t. av.—obt. av.) 4.6 sec., when 'tired.' The average number of wrong digits in each answer under these different conditions of feeling are respectively 1.0, 1.1 and 1.1.

The chances are 7 to 3 that the true average time taken to do an example accompanying the feeling 'good' will not be greater than that which accompanies the feeling 'medium.' Chances are nearly 14 to 1 that the former will be smaller than that which accompanies the feeling 'tired.'

By the second method, we obtain the following relation between the change in feeling and that in the efficiency of the function exercised in mental multiplication.

Change in feeling	Percentile change in time required for multiplication			
	Average %	A. D.	A. D. (t. av.– abt. av.)	Number of cases
'1–1'	115.1	22.4	6.1	13
'2–2'	105.5	13.8	4.0	12
'3–3'	70.5	. .	. .	1
'1–2'	114.5	23.1	8.2	8
'2–3'	124.6	23.8	6.5	13
'1–3'	108.6	36.7	2.6	7
'2–1'	89.4	24.3	14.3	3

According to the figures given above, we have a much smaller percentage accompanying the change in feeling '1—3' than that accompanying the change in feeling '1—1,' '1—2' or '2—3.' This is quite contrary to what we would expect if there were any regular relation between the two changes. That the percentages accompanying the changes in feeling '1—2' and '2—3' are greater than that accompanying the change of '2—2,' and that the percentage accompanying the change in feeling of '2—1' is the next to the smallest, might however serve as an indication of some relation existing between the two changes studied.

By the third method, we get a coefficient of correlation of .31 between a decrease of mental efficiency and a change for the worse in the feeling.

The change in feeling as related to the duration of sleep the night before:

By the third method, we find a coefficient of correlation of zero between the change in the feeling toward the worse and the decrease of the number of hours of sleep the night before. In other words, the length of sleep the night before seems to have nothing to do with the evening feelings on the next day. Such results as this might not be obtained if the different durations of sleep ranged from three to nine hours instead of from six to nine as they did in our experiment.

The results so far in this chapter concern the subject T. A. We next consider the relations of the feeling of fatigue to changes in physical and mental functions in the case of a group of individuals. Here we take the materials mainly from the results of Experiment IV (given in Table VIII) and the introspective reports of the subject. In this experiment, the introspective reports were obtained only after the tests. Therefore, we are able to study only the relations of the efficiency in mental and physical traits to the feeling *after* continuous mental work. A change in any trait is expressed by the percentage which the efficiency after is of that before the work.

The change in the feeling and that in the pulse rate:

Of nine individuals whose pulse rate was measured before and after the two hours of mental multiplication and whose feelings were recorded after the work, five reported that they felt 'medium.' These had an average rate of late to early pulse rate of 87.5 with A. D. 8.3 and A. D. (t. av.—obt. av.) 3.7. The remaining four reported that they felt 'tired,' and had an average rate of late to early pulse rate of 79.6 with A. D. 3.6 and A. D. (t. av.—obt. av.) 1.8. On the whole, those who felt worse after the work were those whose pulse rate decreased most. The chances are 19 to 1 that the true average decrease in the pulse rate accompanying the feeling 'medium' will be less than that accompanying the feeling 'tired.'

By the third method, we find a coefficient of correlation of 0.77 between the change in the feeling and the decrease in pulse rate.

The changes in feeling and the efficiency of memorizing nonsense syllables:

Of nine individuals, five reported that they felt 'medium.' For these the average ratio which the average number of nonsense syllables remembered *after* is to that *before*, the two hours of mental multiplication, is 101.2 with A. D. 3.1 and A. D. (t. av.—obt. av.) 1.4. The remaining four reported that they felt 'tired,' their average ratio in the efficiency of memory being 80.6 with A. D. 14.9 and A. D. (t. av.—obt. av.) 6.8. On the whole, then, those who felt worse had a greater decrease of efficiency of memory.[1] The chances are 99 to 1 that those who report that they feel 'tired' will have a greater decrease of efficiency in memorizing than those who report that they feel 'medium.'

By the third method, we obtain a coefficient of correlation of .99 between the changes of feeling and of memory ability.

The feeling of fatigue and the decrease of efficiency in the function exercised in mental multiplication of a two-place number by a two-place number:

The decrease of ability is shown by the ratio of the average time taken per example in the last ten minutes to that in the first ten minutes. Of 12 individuals, six reported that they felt 'medium' and had the average percentage of 76.3 with A. D. 15.3 and A. D. (t. av.—obt. av.) 6.3. The others, reported as having felt 'tired,' had an average percentage of 97.3 with A. D. 35.0 and A. D. (t. av.—obt. av.) 14.6. There is a probability of 6 to 1 that those who feel 'medium' will on the average show less decrease of efficiency in the function.

By the third method, the coefficient of correlation is found to be .37 between the change in the feeling and that in the efficiency of the function of mental multiplication.

[1] Since the efficiency of memory is measured by the number of syllables, a higher percentage means less decrease of efficiency.

CHAPTER V

THE INFLUENCE OF MENTAL WORK ON THE EFFICIENCY OF MENTAL FUNCTIONS

Methods of Measurement. A glance at the figures in the tables of Chapter II will show that the subject does the work with higher speed in the second than in the first test. The favorable influence which the continued exercise of a function exerts on its own efficiency and which does not entirely disappear within a few minutes is called the effect of practice.

A comparison between the speed of performance at the beginning with that at the close of a course of work shown in Table IV on page 38 shows that the former is much higher than the latter. The unfavorable effect which continued exercise of a function produces in its own efficiency is called fatigue. That which it exerts on other functions is called transferred fatigue.

The amount of practice gain during a certain work-period is measured by the excess of ability after a certain length of rest immediately succeeding it over that at the beginning of the work-period. It is, of course, impossible to measure the exact amount of practice gain, for too long a rest causes a considerable loss of practice, while too short a rest does not completely eliminate the effect of fatigue. The measure which I shall use for the practice gain is obtained by taking the percentile gain in efficiency of the function when tested under similar conditions of rest.

The ideal method of investigating the fatigue is to test a subject who has approximately reached the limit of practice in the work used. Under ordinary circumstances, however, it is not easy to get such persons. In our investigations, the subject T. A. was apparently in a very high stage of practice in mental multiplication, (see Experiment I, Part 2). With these materials we measure fatigue by simply taking the difference between the efficiency at the beginning of the period and that at the end.

The coefficients of fatigue are obtained from these tables by two different formulas according as different units of efficiency are used. The formula A is used when efficiency is measured by the time taken to do a given amount of work, and the formula B when it is measured by the amount of work done in a given time.

A. Coef. of fatigue $= \frac{(T_2 - T_1) \times 100}{T_1}$

B. Coef. of fatigue $= \frac{(A_1 - A_2) \times 100}{A_2}$

T_1 and A_1 = time required and amount done at the beginning of continuous work.

T_2 and A_2 = time required and amount done at the end of continuous work.

In the case of transferred fatigue T_1 and A_1, and T_2 and A_2 represent the efficiency before and after some hours of mental work. We must use, however, a method slightly more complex in dealing with figures including the influence of practice. There are two different methods which were used by previous investigators. One is the method used for the first time by Professor Thorndike and the other that used by Kraepelin and his pupils. The writer will summarize, according to her judgment, two articles which represent the two methods and try to decide for our investigation.

The first is "Mental Fatigue," by E. L. Thorndike, published in the *Journal of Educational Psychology*, Vol. II, No. 2.

I. The function studied. The mental multiplication of a three-place number by a three-place number, neither having any 0's or 1's amongst the digits.

II. The subjects. Sixteen students (sex not stated).

III. The method employed for the test. Each measures the time he takes for getting the answer of each example. He works continuously on one day and on the next day for a half hour or one hour.

IV. The method of calculating the amount of fatigue is measured by the percentage which the time taken to multiply certain numbers of examples at the end of one period is of that after certain hours of rest succeeding the work period.

The second is "Ueber Arbeit und Ruhe," by Ernest H. Lindley, published in Kraepelin's *Psychologische Arbeiten,* Vol. 3, pp. 482-534.

I. The aim of the investigation is to ascertain the factors determinating in work curves which are practice, fatigue, Gewöhnung, 'warming up,' and initial and final spurts.

II. The subjects. Two men and one woman.

III. The function studied. Adding one-place numbers.

IV. The method of measuring the efficiency of addition. By the number of single additions.

V. The method of the test. Each subject works for one hour continuously on the first day; for the two 30 m. periods, with 5 m. rest between, on the second day; for the two 30 m. periods, with 15 m. rest between, on the third day; for the two 30 m. periods, with 30 m. rest between, on the fourth day; for the two 30 m. periods, with 60 m. rest between, on the fifth day. The same program is repeated for the next five days. On the eleventh day, the subject has a complete rest. The tests are made on the next ten days following the same arrangement of hours as in the first ten days. Another complete rest of a day follows here. For the next five days, the same program as was used for the first five days is employed, but is followed by a day with one hour of continuous work. We shall call, for the sake of convenience, the first ten working days group A; the second ten, group B; and the last five, group C.

VI. The methods of measuring each factor, contained in the results of the test described above.

(1) Finding the best rest period.

Take the length of rest which brings about the greatest excess of the amount of work done in the second 30 m. over the amount of work done in the first 30 m.

(2) Finding the practice effect.

Subtract the amount of work done in the first 30 m. on the first day of each of the three groups from the amount of work done in the first 30 m. on the last day of the same group. Divide the answer by the number of the days between the two extreme days of each. By getting the average of the three groups, is obtained the amount of daily gain for each subject.

(3) Finding the amount of 'Gewöhnung.'

It is defined by Lindley thus: "Die Gewöhnung zeight sich in der Schnelligkeit, mit der man sich von innern and äussern störenden Einflüssen unabhängig zu machen in Stande ist." For making a rough estimation of it, get the excess of work done in the first 30 m. of the working period of the second day over the work done in the same period on the first day of each group.

(4) Measuring the rate of practice gain from 30 m. work.

The work after the best period of rest is held to contain a minimum amount of loss of practice effect, fatigue effect and warming up effect. Supposing this to be true, the excess of the amount of work done after the best period of rest over the amount of work done before it may be attributed to the amount of gain due to the 30 m. work preceding. The ratio between this excess and the amount of work done after the best period of work is taken to be the rate of 30 m. practice gain.

(5) Measuring the persistency of the practice gain.

As the persistency of the practice gain relates to its loss in an exactly inverse ratio, the latter is taken to be a measure of the former. To find the loss of practice gain during *x* period of rest, we must calculate first the amount of work which would have been done after the rest, if there were no practice loss at all. This is done by multiplying the amount of work done before the rest by 1 plus the rate of 30 m. practice. The difference between the reckoned amount and the actual amount of work done after the rest is attributed to the amount of loss of practice, for, as during the best period of rest the effects of fatigue and warming up are supposed to have disappeared almost entirely, what occurs during "*x* minus best" period is taken to be the loss of practice gain.

(6) Measuring the effect of fatigue.

During 5 m. rest, according to Lindley, warming up effect is almost all lost, while the effect of practice and that of fatigue remain undiminished. Suppose that we can find the amount of work done in the 30 m. containing the effect of practice, but not that of fatigue resulting from the thirty minutes of work preceding. Then the difference between this and the actual amount of work done after the 5 m. rest may be attributed to the amount of fatigue. The said amount of work, containing practice effect only, is obtained by multiplying the actual amount of work done before the 5 m. rest by 1 plus the rate of the thirty minute practice gain.

(7) Measuring warming up effect.

A comparison of the amount of work done in the sixth 5 m., *i.e.*, the last 5 m. of the first work period with the amount of work done in the seventh 5 m., *i.e.*, the first 5 m. of the second work period shows a certain decrease in the latter after a rest of 5 m. or more, and the amount is more than the average amount of loss of practice gain during the same length of rest period.

Both methods are based on the supposition that the amount of gain through rest can be a measure of fatigue resulting from the work immediately before rest. The point of divergence of the two methods lies in the further presuppositions. Lindley presupposes that the best rest brings about the least loss of practice gain and greatest recovery from fatigue, and naturally, that, if there were no fatigue at all after 30 m. of work, the amount of work done in the next 30 m., less the gain in warming up, should be the same as that done in the 30 m. after the best rest. Therefore, the greater part of excess of this reckoned proportion is attributable to the amount of fatigue. But, from a practical point of view, the validity of Lindley's presupposition depends on the amount of practice gain lost during the best rest. If it is a negligible quality, the problem is simply to find the difference between efficiency in the next 30 m. and that immediately after the best rest. But, if it is a considerable quantity, the efficiency after the best rest will vary according to its amount, provided that the fatigue effect remains the same. According to Tables III and V in Lindley's article (pp. 495-500), in the case of subject B the amount of loss of practice gain in the second 30 m. work period is 11 and the daily loss is 50. Therefore, one-fifth of the whole amount of practice loss during a day is lost during the second 30 m. The loss of the first 30 m., according to this rate of loss, should be approximately 20. Since the amount of B's fatigue is found to be 42 according to Lindley's method, the true amount of fatigue should be about 62, if the amount of recovery outweighing the negative influence of practice loss is counted. Therefore, Lindley's method is justified only when there is a least amount of practice loss.

Thorndike's method disregards practice loss entirely. Its validity depends on the length of rest. If the length of rest is so much that it would cause a great amount of practice loss or if it is so short as to leave a large amount of fatigue, the method is inadequate.

With our present materials, we can not use Lindley's method, for our investigation was not carried out with so many varieties of length of rest as Lindley's. On the other hand, we shall not always follow that of Thorndike exactly. He studied the amount of fatigue by taking the ratio of the time taken before rest to that after rest. But, in our investigation, we shall, when practice is not negligible, use the ratio of difference between the efficiency before rest and that after rest to the latter. We shall, for the sake of convenience, call the method of comparing efficiency before and after the work period, Formula I; and that of comparing efficiency after the work-period with that at the beginning of the next work-period—*i.e.*, after rest, Formula II.

Reducing accuracy and speed to one unit. Quantity and quality are two essential elements which we must consider in determining work done. Kraepelin and his colaborers, however, attached great importance to the former, disregarding the latter. Professor Thorndike attempted to do justice to both of these elements by adding some amount of time for each error. In our investigation, the question arises only in the case of mental multiplication. If errors are distributed evenly in the course of work, they may be due simply to chance and we may disregard them in the study of fatigue. However, according to the results obtained by Experiment I, the errors bear certain relations to practice and fatigue, as will be seen in later pages. So it is not justifiable to disregard them. For this reason we add ten seconds for each wrong digit in the answers of all multiplications.

Fatigue in the special function exercised, in the case of individual T. A. (The materials are obtained from Table I, II, III, and IV):

1. *The amount of fatigue.*—In order to know which formula to use in getting the amount of fatigue, we have to determine the amount of practice involved in each observation. The results of the calculation run as follows:—

Time taken (in minutes and seconds) and errors made per example in the first five examples on each experimental day

Experiment I. Part 1			Experiment II. Part 2		
Date	Time	Error	Date	Time	Error
Feb. 2	10.53	2.8	Feb. 24	9.56	2.6
" 4	5.30	3.2	" 25	8.18	1.5
" 7	4.49	1.2	" 26	6.30	1.5
" 15	5.49	1.4	" 27	7.22	2.8
" 22	4.52	2.0	" 28	7.42	3.2
			Mar. 2	6.45	1.6
			" 3	5.55	2.2
			" 4	5.28	1.2
			" 5	5.04	1.6
			" 6	4.44	1.2

TABLE XVII

The sum of the times taken (plus 10 seconds for each error) for each five examples at the end of each continuous work period, expressing the efficiency before each rest; a similar record at the beginning of the succeeding work period, expressing the efficiency after the rest; and the coefficient of fatigue.

	Length of rest between each successive test. In hours	Length of test before rest. In hours and minutes	Efficiency before rest	Efficiency after rest	Coef. of fatigue
Results from Expt. I, Part 1		h.m.			
	From Feb. 2, 12 A. M. to Feb. 2, 1 P. M.=1	2.30	62.45	33.35	86.9
	From Feb. 2 to Feb. 4=43	1.30	47.45	29.80	57.4
	From Feb. 4, 12:06 P. M. to Feb. 4, 12:40 P. M.=½	2.30	42.23	46.31	—8.9
	From Feb. 4 to Feb. 7=69	2.00	53.51	25.06	114.5
	From Feb. 7 to Feb. 15=173	1.20	62.10	30.15	105.5
	From Feb. 15 to Feb. 22=169	4.17	52.35	26.00	102.3
Results from Expt. I, Part 2	From Feb. 24 to Feb. 25=26	1.32	51.50	42.40	21.4
	From Feb. 25 to Feb. 26=11	4.00	81.50	33.40	143.7
	From Feb. 26 to Feb. 27=19	4.24	58.00	39.10	48.1
	From Feb. 27 to Feb. 28=19	4.34	45.45	43.30	5.2
	From Feb. 28, 6:43 P. M. to Feb. 28, 7:32 P. M.=¾	6.00	70.42	32.55	114.8
	From Feb. 28 to Mar. 2=37	1.42	57.03	35.05	62.6
	From Mar. 2 to Mar. 3=13	11.00	65.00	31.25	106.9
	From Mar. 3 to Mar. 4=12	12.00	76.35	38.20	99.8
	From Mar. 4 to Mar. 5=12	12.00	57.20	26.40	115.0
	From Mar. 5 to Mar. 6=12	12.00	50.10	24.45	102.7

In the figures given above, two important facts are noted: (1) the gain in speed as a result of each test is greater in the beginning and becomes slower as it approaches the end; (2) some practice gain is still observed in the tests of the last four days. However, the average daily practice gain being thirty seconds in these tests, the average practice gain per example in the course of twelve hours of mental multiplication is only four hundredths of a second. The gain per example is so small that in our study of fatigue curves it may be disregarded. The coefficients of fatigue are obtained by Formula II and given in Table XVII.

The figures given above indicate that mental multiplication of four place numbers by four place numbers continued from 1.7 hours to 12 hours causes more or less decrease of efficiency in the function exercised.

The amount of fatigue in the last four tests as determined by Formula I is given in Table XVIII.

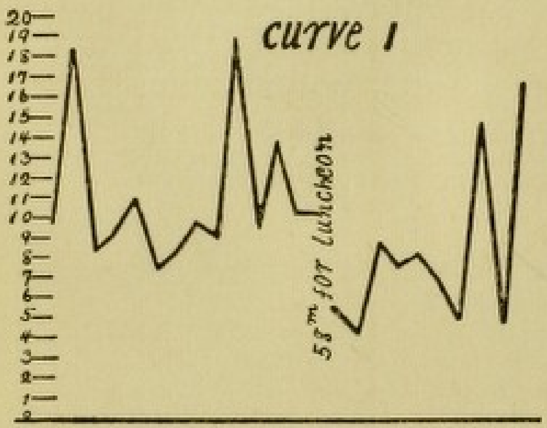
TABLE XVIII

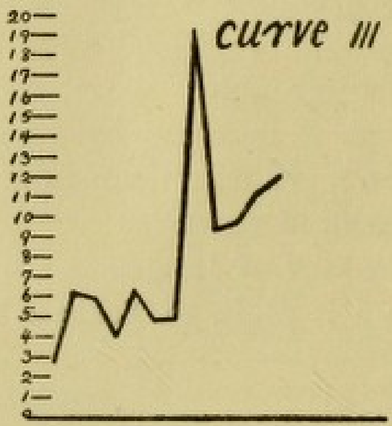
Date	With the difference between first 5 and last 5 examples	With the difference between next to the first 5 examples and next to the last 5 examples	With the difference between first 5 examples and next to the last 5 examples	With the difference between next to the first 5 examples and the last 5 examples	Average of the four methods
Mar. 3	158.8	64.6	62.5	161.8	111.9
" 4	144.7	43.0	66.8	110.6	91.3
" 5	90.5	90.6	79.1	106.7	91.4
" 6	84.2	72.3	88.5	68.3	78.3
					93.2

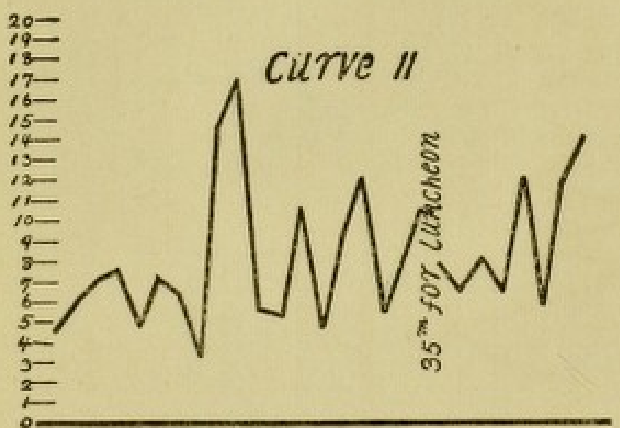
Averaging the four tests, we find that twelve hours of mental multiplication results in a reduction of speed to less than one-half of the original speed. The average coefficient of fatigue thus obtained is 93.2. The average coefficient of fatigue measured by Formula II is 106.1. Therefore, the true coefficient of fatigue (that is increase in time required as a result of eleven hours of this work) would be near 99.6 per cent, the average of the two.

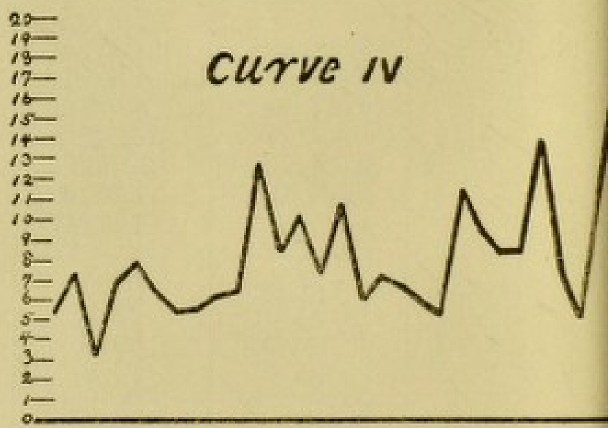
2. *The course of fatigue.* The course of fatigue is represented by a curve made by the following method. A horizontal scale line for the number of examples is drawn. The height of the curve at any point represents the time taken for an example. The rise of the curve, therefore, means decrease of speed or increase of the time taken to do a given amount of work.

Curves I to V represent the courses of work according to Experiment I, Part 1. These curves bring out two important points.

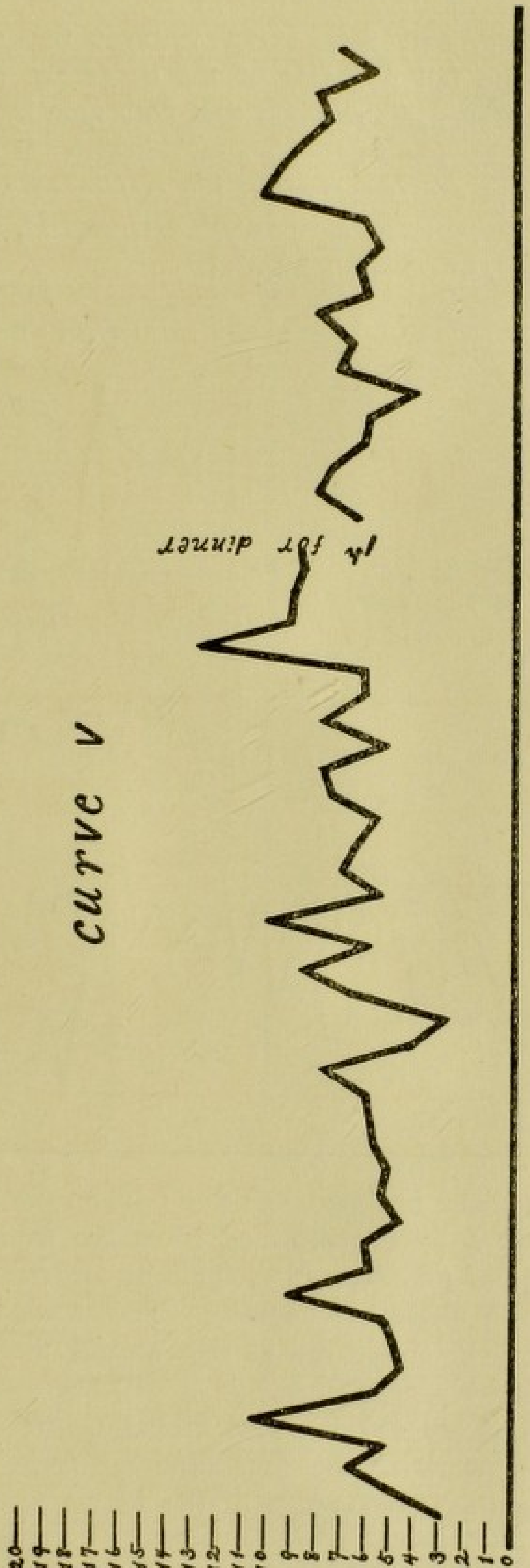






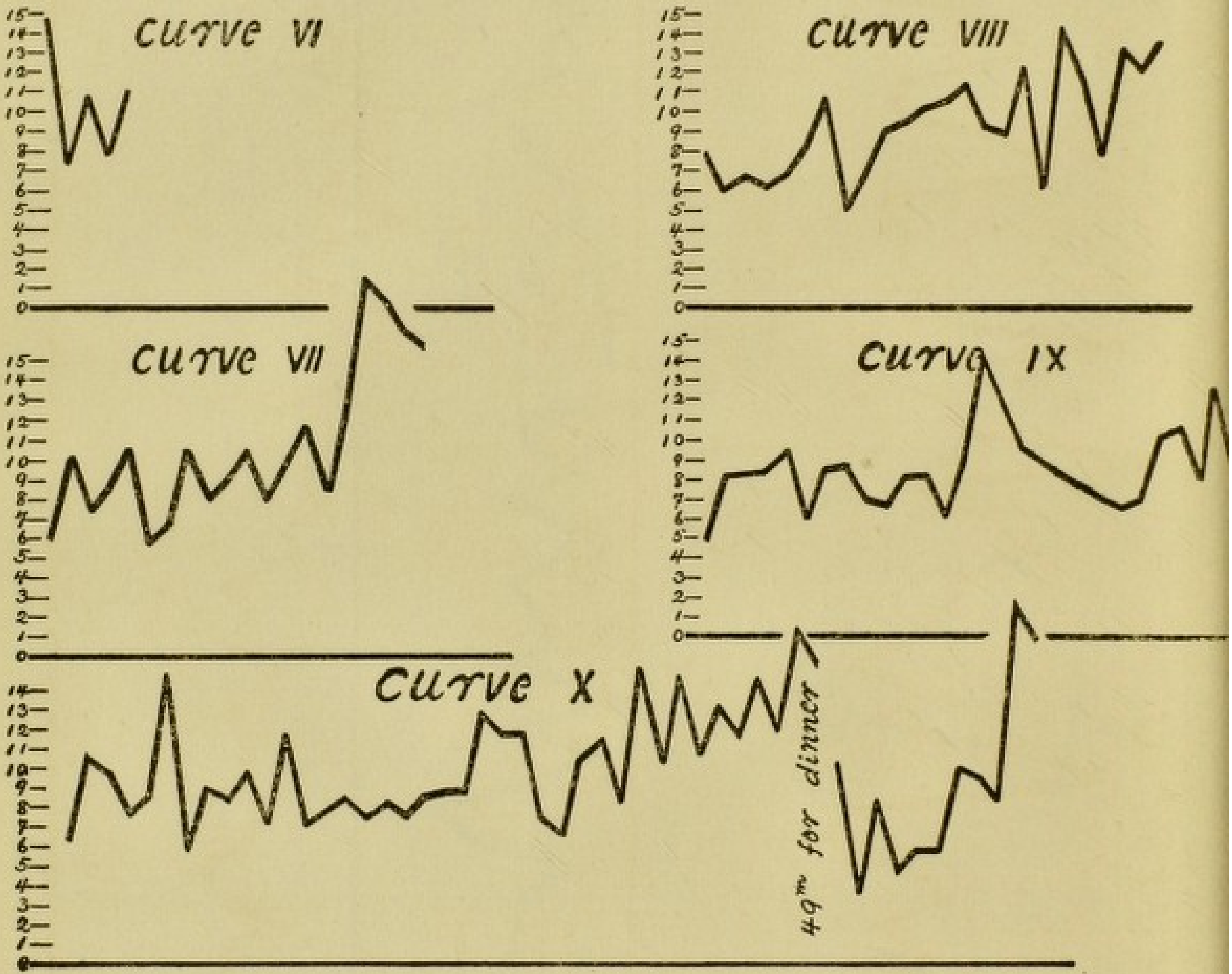


First, the length of the curve increases in the later tests. Since the subject ceased to work the very moment when she thought it desirable to do so, the increase of the working period means that the subject's ability to continue the work increased. This is either because the subject gained by practice a greater power to resist the impulses to stop the work, or because the work became actually easier as a result of practice, or both. Second, the form of the curve varies according to the amount of practice. In general, the curve first falls and then rises; this shows that the effect of practice is stronger than was that of fatigue


Curve V
1h for dinner
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

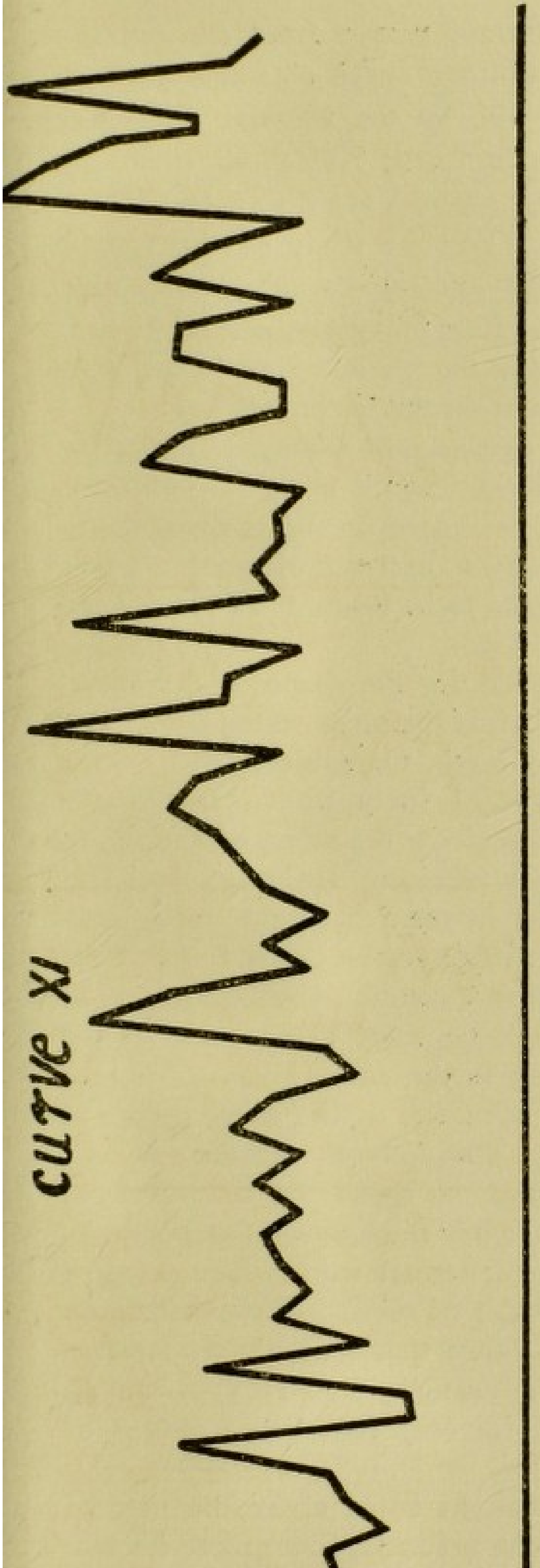
at the beginning, and *vice versa* towards the end. In the earlier tests, the fall and rise of the curve are more marked than the later tests; this signifies that both gain by practice and loss by fatigue become smaller as one's practice is greater.

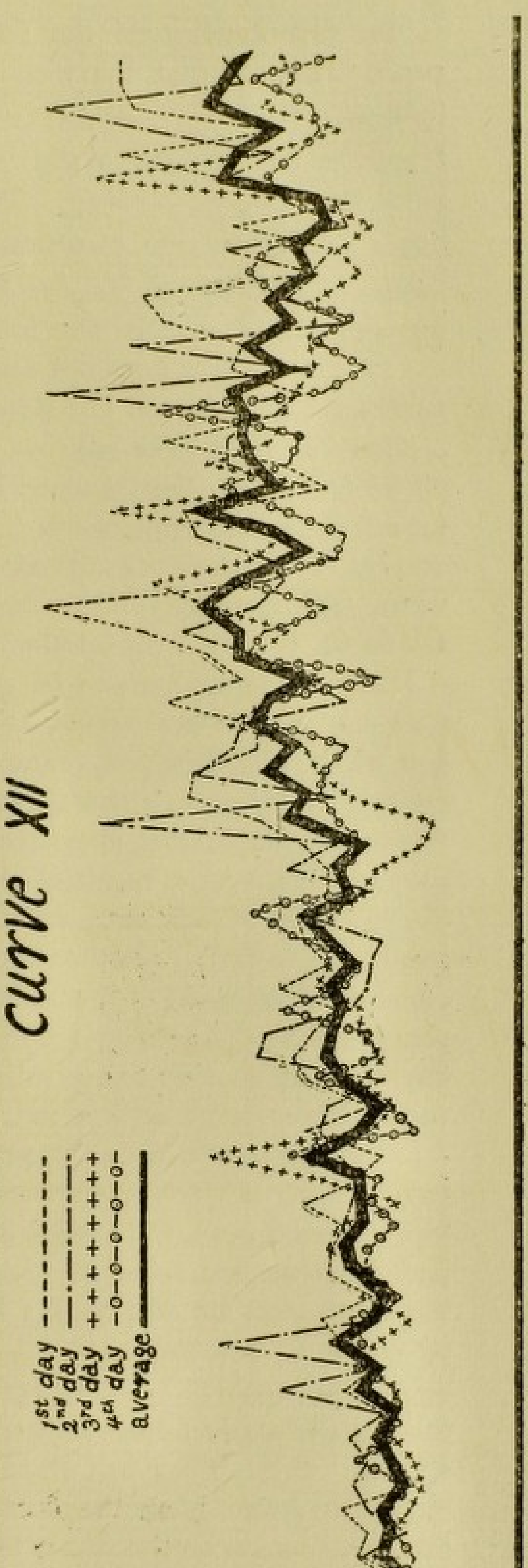
Similar points are observed in the course of work in each of the tests of the practice series of Experiment II, Part 2, which are given below, in curves VI to XI.



As was explained in Chapter II, the tests on the last four days of Experiment I were performed when the subject was in a very late stage of practice and the gain by practice in the course of work is of a negligible quantity. Therefore, the results of these tests may be considered as representing the course of fatigue in a relatively pure form.

Curve XII shows (1) the four different curves representing the course of work in the four different tests, and (2) the curve representing the average of the four.


CURVE XI


CURVE XII
1st day
2nd day
3rd day
4th day
average

The divergencies of the separate curves from the average curve are such that the true average curve obtained from an infinite series of experiments will, on the average, not differ from the average curve shown in Curve XII at any point by more than twelve per cent. The chances are 8 to 2 that it will not so differ in one direction. For the study of the fatigue curve of individual T. A., the average curve will be used throughout. It shows the following important characteristics:

(I) The curve does not fall at the beginning as do the other curves already shown, but rises from the beginning.

(II) It rises gradually up to the 34th example, fluctuating above and below the standard line. Then it takes on a different aspect, the curve being above the standard line up to the 56th example. The rise of the curve is due to decrease of speed. It falls at the 56th example, and continues to be below the line until example 61, it ends with another rise.

Many explanations can be given for the shape of the curve. One explanation is to suppose that, at the point where the sudden rise of the curve begins (example 35), the subject yields to the feeling of fatigue, letting herself go for a while. During the relaxation the subject is recovered from the effect of fatigue to some extent. As a result of this, efficiency again increases and the increase of efficiency results in the fall of the curve (examples 44 to 60). Another way of interpreting the form of the curve is to attribute it to the diurnal course of efficiency, *i.e.*, to suppose that the subject accomplishes more at one time of the day than at another. According to the curve given above, the sudden rise occurs at 5 p. m. The fall of the curve occurs at 8 p. m. and lasts until 10 p. m. This falls in with the subject's habit. The subject is accustomed to spend the time between 5 p. m. and 8 p. m. in recreation, while the hours between 8 p. m. and 10 p. m. are reserved for intellectual work. The slope of the curve may be due to this habit of mind. The examination of curve V, for February 22, shows that the sudden decrease of speed occurs at the 35th example, *i.e.*, at 5 p. m., although the subject had worked for only four hours instead of six.

(III) Aside from the fluctuations noted above, the rise of the curve seems on the whole to be gradual. Since these fluctuations are explained by a fact other than the onset of fatigue, the onset of fatigue may be regarded as gradual.

(IV) The difference between the time taken for one example and that for another is greater in the second half than in the first half of the curve. This fact together with the evidence of introspection of the subject suggests that fatigue not only causes decrease of efficiency, but also loss of the subject's control over herself. For this reason, the subject tends to occasionally relax her original standard of effort.

3. *'Warming up' effect.* The results show little or no effect of 'warming up.' If there were any such effect, it would show itself before being overcome by the fatigue effect and would make itself manifest in the fall of the curve soon after the beginning. There may be a slight effect of this kind, if so, it is so small that the effect of fatigue outweighs it from the beginning.

4. *Spurts or 'Antriebe.'* There is nothing in our curves which corresponds with "Anfang und Schluss-antriebe" or initial and final spurt. The times taken for the first and second four examples at the beginning as well as those taken for the first and second four examples from the end are given below in minutes and seconds.

Number of examples	On Mar. 3	On Mar. 4	On Mar. 5	On Mar. 6
1st 4 from the beginning	24.55	23.30	21.30	19.25
2nd 4 from the beginning	24.35	24.45	18.35	27.50
1st 4 from the end	59.55	49.00	39.00	30.15
2nd 4 from the end.	47.25	42.55	44.00	36.50

The differences between the first and the second four examples at the beginning and that between the first and second four from the end are not regular in all our experiments.

5. *Accuracy and fatigue.* The average number of wrong digits per answer in each successive ten examples in each test is as follows:

Date	Order of each ten examples						
	1st	2nd	3rd	4th	5th	6th	7th
Mar. 3	1.7	1.0	1.3	2.3	1.7	1.3	1.3
" 4	1.8	1.2	2.5	1.5	1.7	1.8	3.1
" 5	1.6	1.8	1.2	1.0	2.4	2.3	3.1
" 6	2.0	1.5	2.2	1.9	1.6	4.1	3.1
Average	1.8	1.4	1.8	1.6	1.9	2.4	2.7

On the whole, accuracy decreases as the work progresses.

Fatigue in the special function exercised, in the case of the group of individuals (the materials being obtained from Table VIII).

The amount of fatigue. The effect of practice in each two hours of mental multiplication is measured by comparing the efficiency at the beginning of a two-hour period with that immediately after rest succeeded it. The coefficients of practice thus obtained (see page 80 for the formula used) are given in Table XIX.

TABLE XIX

COEFFICIENTS OF PRACTICE

Subjects	1st Test	2nd Test	3rd Test	4th Test
C. D. T.	46.6	53.6	20.1	9.5
MS.	74.8		42.6	21.6
R. S. W.	27.8	14.1		
H. A. R.	—4.4	50.5		
J. T.	69.4			
Pfg.		29.7		
P. E. R.			16.4	
S. W.	6.1	11.5		
Chs	33.5	27.8		
M. M.		22.2		
C. T. R.	54.7	33.8		
H. L. H.	19.1			
Sn	—31.2			
G. D. S.	25.6			
A. G. C.	52.1			

The table shows that, in most cases, the amount of practice effect is greater in the first test than in the second test. In both cases, the course of fatigue is involved with the increasing practice effect. Therefore, in measuring the amount of fatigue, Formula II must be used. The coefficients of fatigue in the two-hour work period are given in Table XX.

TABLE XX

Subjects	Coefficients of Fatigue				
	1st Test	2nd Test	3rd Test	4th Test	Average
A. The amount of fatigue measured by recovery during a ten minute rest					
C. D. T.	41.1		7.4	19.3	22.6
P. E. R.			8.7		8.7
S. W.		7.5			7.5
G. D. S.	7.3				7.3
Pfg	6.1	20.2			13.2
Chs		30.7			30.7
M. M.		73.2			73.2
C. T. R.	40.5	49.1			44.8
Average					26.
The amount of fatigue measured by recovery through a sixty minute rest					
C. D. T.		5.6			5.6
MS	10.6		63.7	72.2	48.8
S. W.	15.0				15.0
H. L. H.	8.9				8.9
A. G. C.	53.9				53.9
Sn	—4.6				—4.6
G. D. S.	11.6				11.6
R. S. W.	1.5	2.8			2.2
Chs	85.6	6.2			45.9
Average					20.8
C. The amount of fatigue measured by recovery through a one hundred eighty minute rest					
H. A. R.	—22.9	—22.8			—22.9
G. T.		2.7			2.7
Average					10.1

The fact that the average coefficient of fatigue is about the same in both A and B (excluding C on account of its having too small a number of cases) suggests that the fatigue caused by two hours of mental work is very probably eliminated during a ten-minute rest and that loss of practice effect during the next fifty minutes is insignificant. Therefore, the greater part of the difference between efficiency immediately before and that immediately after the rest is attributable to the whole amount of fatigue caused during the work period. The average amount of decrease of efficiency caused by the two hours of continuous

TABLE XXI

Time taken per example in each ten minutes by each, and by the average of all the individuals—also the average of all but the subject J. T. (J. T.'s records are eliminated in the second average on account of their irregularity). These averages are on the line of the starred average.

A. Results of the first test

Subjects	Ave. Abil.	1	2	3	4	5	6	7	8	9	10	11	12
H. A .R.	31.3	34.2	31.6	34.5	41.4	36.4	30.3	33.9	27.5	26.7	25.6	25.6	27.5
C. D. T.	36.8	54.5	41.1	39.0	38.8	40.7	33.9	34.4	33.4	28.6	30.2	27.4	30.0
R. S. W.	42.3	47.8	59.0	71.7	43.4	35.8	33.3	40.6	32.8	35.3	37.6	33.7	37.0
G. M. K.	67.8	75.0	79.8	68.9	112.0	58.3	83.3	73.4	68.8	59.5	42.2	50.1	42.5
Pfg....	80.9	73.0	84.5	80.0	82.2	127.8	90.3	83.5	75.0	86.3	73.4	67.1	63.0
MS....	89.1	164.3	138.8	128.4	94.2	80.9	66.5	93.1	49.2	56.0	64.7	65.9	61.6
Chs....	96.8	118.0	101.0	95.8	76.3	83.2	82.2	80.2	72.7	79.5	141.0	118.0	129.0
S. W...	116.6	99.0	167.0	94.0	119.6	128.0	89.7	129.0	113.7	121.1	135.0	121.3	111.3
C. T. R.	124.7	187.7	120.4	118.0	97.0	144.4	107.0	105.0	100.5	111.4	130.0	152.5	119.6
M. M...	150.8	160.0	162.0	140.3	120.8	190.5	121.7	173.3	153.8	150.0	193.3	119.0	97.5
J. T....	171.4	71.8	89.0	184.0	217.0	194.5	100.0	196.3	330.0	247.0	132.5	170.0	103.0
Ave....	91.7	98.7	97.7	95.9	99.3	101.4	76.2	94.8	96.4	92.2	95.9	86.4	74.7
Ave.*..	83.4	101.4	97.7	87.1	87.5	92.1	73.8	84.6	73.0	76.7	92.3	78.0	71.9

B. Results of the second test

Subjects	Ave. Abil.	1	2	3	4	5	6	7	8	9	10	11	12
H. A. R.	32.5	54.9	47.7	50.0	29.0	35.3	30.6	29.9	26.4	22.4	20.3	22.3	21.0
C. D. T.	32.7	32.8	34.5	29.9	28.0	41.0	34.1	30.6	20.5	32.6	37.8	32.3	32.4
R. S. W	42.7	41.1	38.5	37.4	55.0	50.1	46.7	49.3	46.7	39.6	31.3	38.4	38.7
G. M. K.	51.9	60.7	45.7	71.4	55.5	47.1	43.0	58.2	44.8	41.3	64.1	42.6	48.3
MS....	52.2	39.9	48.4	59.8	47.9	46.0	57.9	53.6	48.7	56.0	60.8	53.5	53.6
Chs....	52.5	64.0	60.4	50.1	59.5	42.8	67.2	40.9	51.7	42.9	44.3	65.0	41.4
Pfg....	58.5	61.2	63.0	67.0	54.3	53.4	51.0	52.6	73.7	60.2	51.9	55.3	58.4
S. W...	86.4	75.7	86.4	79.4	106.4	96.4	73.3	79.7	93.7	77.2	70.5	115.5	82.8
C. T. R.	93.5	102.8	71.8	94.0	115.1	85.6	79.5	76.0	133.4	126.8	86.9	60.0	89.9
M. M...	124.3	100.8	94.2	106.7	118.2	124.8	178.3	142.0	151.3	132.0	91.3	133.3	119.0
J. T....	153.9	131.6	130.0	128.8	146.2	118.0	180.3	141.3	186.0	165.0	158.8	186.6	174.0
Ave....	71.0	69.9	65.5	70.4	74.1	67.3	76.5	68.5	79.8	72.4	65.3	73.2	69.4
Ave.*..	62.7	63.7	59.0	64.5	68.6	62.2	66.1	61.2	69.2	63.1	56.5	61.9	59.9

C. Results of the two tests combined

Subjects	Ave. Abil.	1	2	3	4	5	6	7	8	9	10	11	12
H. A. R.	31.9	44.6	39.7	42.3	35.2	35.9	30.5	31.9	27.0	24.6	23.0	24.0	24.3
C. D. T.	34.8	43.7	37.8	34.5	33.4	40.9	34.0	37.5	27.0	30.6	34.0	29.9	31.2
R. S. W.	42.5	44.5	48.8	54.5	49.2	42.4	40.1	45.0	39.8	37.5	34.5	36.1	39.9
G. M. K.	59.9	67.9	62.8	63.9	83.8	52.7	58.2	65.5	56.8	50.4	33.2	42.4	45.4
Pfg....	69.7	67.1	68.8	76.5	68.3	90.6	70.7	68.1	74.4	73.3	62.7	66.2	60.7
MS....	70.7	102.1	93.6	94.1	58.1	63.3	62.2	63.9	49.0	60.5	62.8	59.7	62.6
Chs....	74.7	91.0	80.6	75.0	67.9	063.0	70.7	60.6	62.2	51.2	92.7	91.5	84.2
S. W...	101.5	87.4	127.0	86.8	113.0	112.2	81.5	104.4	104.2	99.2	102.8	118.4	96.8
C. T. R.	109.1	145.2	96.1	106.0	106.1	115.0	93.3	98.2	117.0	119.1	108.5	115.6	113.8
M. M...	137.6	130.4	128.1	133.5	144.5	146.0	150.0	150.0	152.4	132.0	142.2	126.2	103.0
J. T....	162.4	101.7	123.0	156.4	181.6	156.3	140.2	168.8	256.0	228.5	145.7	178.3	138.1
Ave....	81.3	84.3	81.6	83.2	85.2	84.4	76.4	81.7	88.1	82.2	80.6	79.8	72.1
Ave*...	73.2	82.4	78.4	75.8	78.1	77.2	70.0	72.9	71.1	69.9	74.4	70.0	65.9

work is then for this group 24.2 per cent of the efficiency after rest.

The course of fatigue. In Experiment IV, all but four subjects took part more than twice. As the tests were made at different times and consequently in different stages of practice, they contain varying amounts of practice effect. For instance, the average time taken per example in each thirty minutes is, respectively: for Subject MS., 131.1, 65.5, 56.1 and 55.7 in the first test and 43.6, 35.6, 34.4 and 45.3 in the second test. Therefore, the average of the two can not be taken as a typical curve of the individual as is generally done. This holds true with the average of the two tests of all individuals. We shall, therefore, present separately the results of the first and the second test as well as the average of the two in Table XXI. The records of the first and second tests of eleven individuals out of sixteen are given, because they worked two full hours at one time.

The following important points are to be observed in the figures given above: First, the absolute speed is greater in the second than in the first test, by 25 per cent. Second, the practice gain is much greater in the first test than in the second. The percentage ratio of the average time taken in the last 30 minutes to that in the first 30 minutes is 79.9 in the former, while it is

TABLE XXII

The average time taken to multiply per example in successive, 30-minute periods

Type	Subjects	1st 30 m.	2nd 30 m.	3rd 30 m.	4th 30 m.
1	Pfg.	70.8	76.5	71.8	63.2
	M. M.	130.7	146.8	144.8	123.8
	J. T.	127.0	159.4	217.8	154.0
	Average	109.5	127.6	144.6	113.7
2	Chs.	82.2	67.2	58.0	89.5
	S. W.	100.4	102.2	102.6	106.0
	C. T. R.	115.8	104.8	111.4	112.6
	Average	99.5	91.4	90.7	102.7
3	H. A. R.	42.2	33.9	27.8	33.8
	C. D. T.	38.7	36.1	31.7	35.0
	R. S. W.	49.3	43.9	40.8	36.8
	G. M. K.	64.9	64.9	57.6	40.3
	MS.	96.9	61.2	57.8	61.7
	Average	58.4	48.0	43.1	41.5

96.4 in the latter case. Third, there are three types of fatigue curves. The first type is represented by the curve which rises first and then suddenly falls in the beginning of the last fourth of the working period. To this type belong the curves M. M., J. T. and Pfg. The second type falls and then rises in the second or third 30 minutes showing that the effect of fatigue outweighs the effect of practice within two hours. To this type, belong the curves of C. T. R., S. W., Sn. and Chs. The last type falls gradually toward the end without showing clearly the point of maximum efficiency from which the effect of fatigue outweighs the effect of practice. To this type, belong most of the individual curves. Table XXII will show these three types by the actual figures which show the average time taken to multiply per example in each successive thirty minutes.

Oehrn[1] in his study of ten individual work curves of the four different psycho-motor and mental functions remarks that the maximum point is reached sooner in the more automatic functions than in the purely mental functions, and that the average point of maximum ability is reached in memorizing the numbers (the most purely mental function) at the end of 60 minutes.

Thorndike[2] gives a detailed report of his investigation of fatigue curves, from which the present writer calculated the time when the maximum efficiency is reached in each individual curve and obtained the following results.

The Time When the Maximum Efficiency is Reached	Number of Individuals
0–1 hrs.	3
1–2 "	1
2–3 "	5
3–4 "	3
4–5 "	0
5–6 "	1
6–7 "	0
7–8 "	0
8–9 "	1

Our results, therefore, correspond with those obtained by Thorndike.

There is a definite relation between the type of curve and efficiency in the function. The average time taken per example

[1] *Psychol Arbeit.* vol. I. p. 136.
[2] *Jour. of Ed. Psychol.* vol. II. No. 2.

in the two-hour working period of the first type is 123 sec. in the case of three individuals; that of the four individuals belonging to the second type is 104.2 sec.; that of nine individuals belonging to the third type is 48 sec. Those who do not show the points of maximum efficiency are the best performers of the group. The types of the curves are, of course, determined by the relation of fatigue to practice effect. The greater the ratio the earlier the point of maximum efficiency occurs and the more marked the slopes of the curve. Their relations depend either on change in the absolute amount of one of the two factors, the other remaining the same in amount or on the change of both, each in different amount. From this fact, an important question arises, namely, which of the two, practice or fatigue, is the determining factor of the relation in our curves. In studying this relation, we have chosen the records of eight individuals taken under relatively uniform conditions.

TABLE XXIII

Coefficients of fatigue and of practice of each individual and the average coefficient of fatigue and of practice for each type, using the average of the first and second trials of each individual.

Type	Subjects	Fatigue Coef.	Practice Coef.
1	Pfg	13.3	26.5
	Average		
	C. T. R.	—30.8	48.
2	S. W.	15.1	19.5
	Chs	45.9	36.3
	Average	30.6	34.6
	H. A. R.	—22.9	23.1
3	C. D. T.	7.1	35.6
	R. S. W.	1.3	19.7
	MS	39.0	53.4
	Average	5.6	33.0

According to the average coefficients of fatigue and those of practice in the three types, the curves of the first and second types contain a greater amount of fatigue than do the curves of the third type, while the practice effect remains the same in both cases. The difference in the form of the curves, then, is due to a difference of absolute amount of fatigue effect. Since it is found that individuals of the third type are much more competent in their work than those belonging to the first and the second, it is probable that the most competent workers are affected least by fatigue.

'Warming up' effect. As the result of study of the work curves after rest, it is found that a curve falls after a rest of sixty minutes, while it keeps practically the same level after a rest of ten minutes. Table XXIV gives the time taken for the first, second and third four examples after both periods of rest.

TABLE XXIV

Time taken in doing the first, second and third four examples after different lengths of rest.

A. After ten minutes of rest

Subjects	1st	2nd	3rd	Difference between 1st and 2nd
C. D. T.	135.0	133.0	120.3	—1.5
Pfg	245.0	227.0	262.5	—7.3
Chs	204.0	211.0	215.0	+3.3
M. M	310.0	357.0	.....	+14.1
P. E. R	225.0	250.0	240.0	+7.4
S. W	258.0	372.0	332.0	+3.9
Average	233.4	238.6	239.0	+3.3
B. After sixty minutes of rest				
R. S. W	219.0	161.5	208.5	—29.3
MS	178.8	193.3	175.8	+2.5
Chs	275.0	320.0	.....	—22.6
S. W	585.0	425.0	535.0	—31.1
H. L. H	180.0	145.0	170.0	—21.2
A. G. C	170.0	58.0	124.0	—95.8
Average	266.6	196.6	242.7	—32.9
C. After one hundred and sixty minutes of rest				
H. A. R	180.0	135.0	110.0	—45.

The difference between the form of the curve after the short period of rest and that for the work after the longer period of rest can not be explained without supposing that a 'warming up' process acts in the course of work and disappears soon after the cessation of work. This warming up process is more completely neutralized during the sixty-minute rest than during the ten-minute rest, and, therefore, the efficiency immediately after the longer rest is less than after the shorter rest.

Spurts. In our experiments, the subjects did not know when the end of the work period was coming. Hence, it is not possible to study the effect of final spurts from our records. For the study of initial spurts, the usual comparisons were made between the time taken for the first example and that for the second, between the first four and the second four examples, and also between the first and the second eight examples. The writer did not find any uniform superiority of the first over the second interval.

Accuracy and fatigue. According to the results of Experiment IV, accuracy in work does not seem to be influenced either by fatigue or practice. For eleven individuals who underwent two tests, the average number of incorrect digits per answer in each successive thirty minutes is .77, .72, .73 and .72 respectively, in the first test, and .78, .80, .67 and .62 in the second. That the absolute number of mistakes is not less in the second trial than in the first suggests that practice has little to do with the number of errors. That fatigue did not influence the accuracy of the work is shown by the fact that in both trials, the number of errors decreased in the course of work.

Supplementary data. An experiment was made on the subjects T. A. and E. B. G. for the investigation of fatigue in the function exercised in reading. T. A. read Dickens' " Bleak House " three hours a day and repeated the process for five days in succession. In this reading the time of beginning every other page and the time spent in reading each two pages was computed. The results of this test are given in Table XXV.

According to the figures given above, the average time taken for reading each ten pages on five days is (in minutes and seconds) respectively 27.07; 26.44; 25.51; 26.27; 26.56 and 27.43. The time decreases gradually to about the fortieth page, the time increasing from then on to the end. It seems more reasonable to attribute the cause of the increase of speed in the beginning of the reading to the ' warming up ' effect than to the effect of practice, for its effect has no influence on the speed of the performance of the next day.

TABLE XXV

Time spent in reading each section of two pages and for each section of ten pages in both tests.

Subject T. A.

Time in minutes and seconds.

Date....	Jan. 17, '10		Jan. 18, '10		Jan. 19, '10		Jan. 20, '10		Jan. 21, '10	
Number of page	Time taken for each successive 2 pages	Time taken for each successive 10 pages	Time taken for each successive 2 pages	Time taken for each successive 10 pages	Time taken for each successive 2 pages	Time taken for each successive 10 pages	Time taken for each successive 2 pages	Time taken for each successive 10 pages	Time taken for each successive 2 pages	Time taken for each successive 10 pages
1st 2 ps.	5.10		4.50		5.15		5.25		5.30	
2nd "	5.10		5.33		5.05		5.25		5.45	
3rd "	5.10	25.45	4.30	25.38	5.10	27.30	5.45	27.15	6.20	29.25
4th "	5.20		5.20		6.35		5.00		5.20	
5th "	4.55		5.25		5.25		5.30		5.30	
6th "	4.45		5.45		4.50		5.20		5.45	
7th "	5.10		5.25		5.15		5.40		5.25	
8th "	5.00	25.15	4.50	26.50	5.30	26.25	5.50	27.00	5.15	27.10
9th "	5.20		5.00		5.00		5.15		5.45	
10th "	5.00		5.50		5.50		4.55		5.00	
11th "	5.00		4.50		5.10		5.20		5.10	
12th "	5.10		4.55		5.20		5.05		5.45	
13th "	4.40	25.10	4.25	24.25	4.55	26.25	6.00	27.00	5.25	26.15
14th "	5.20		5.45		5.40		5.30		5.10	
15th "	5.00		4.30		5.20		5.05		4.45	
16th "	5.00		5.10		5.45		5.55		4.45	
17th "	5.25		5.20		5.15		5.45		5.00	
18th "	5.00	25.40	5.08	25.58	5.05	26.20	5.46	28.10	5.25	26.05
19th "	5.10		5.30		4.55		5.35		5.30	
20th "	5.05		4.50		5.20		5.15		5.25	
21st "	5.05		5.20		4.55		5.25		5.35	
22nd "	5.40		5.30		5.05		5.30		5.20	
23rd "	5.00	26.40	5.45	27.15	5.40	27.15	6.00	27.25	5.45	26.05
24th "	5.05		5.30		5.56		5.30		5.00	
25th "	5.50		5.10		5.45		5.00		4.25	
26th "	5.25		5.14		5.05		5.50		5.30	
27th "	5.45		5.25		5.00		5.45		5.40	
28th "	5.20	27.45	5.15	25.59	6.25	27.15	6.05	29.15	6.00	28.20
29th "	5.40		5.20		4.50		6.20		5.30	
30th "	5.35		4.45		5.55		5.15		5.40	
31st "	5.10		5.25		5.30		5.10		5.25	
32nd "	5.05		5.30		5.35		5.50		4.15	
33rd "			5.20		5.10		5.35	27.30	5.30	26.45
			6.20				5.40		5.15	
							5.15		5.50	
							5.10			

E. B. G. read "Our Mutual Friend." The time for reading was recorded in the same manner as before, except that the record was made by the experimenter, not by the subject herself. The results are given in Table XXVI.

TABLE XXVI

Time spent in reading each two pages and for each ten pages.

Time in minutes and seconds.

Number of page	Time taken for each successive 2 pages	Time taken for each successive 10 pages	Number of page	Time taken for each successive 2 pages	Time taken for each successive 10 pages
1st 2 pages..	2.10		21st 2 pages..	3.00	
2nd " ..	2.30		22nd " ..	2.30	
3rd " ..	2.30	12.25	23rd " ..	2.30	13.30
4th " ..	2.40		24th " ..	2.40	
5th " ..	2.35		25th " ..	2.50	
6th " ..	3.10		26th " ..	3.10	
7th " ..	2.10		27th " ..	2.35	
8th " ..	2.05	12.25	28th " ..	2.45	13.55
9th " ..	2.50		29th " ..	2.45	
10th " ..	2.10		30th " ..	2.40	
11th " ..	2.25		31st " ..	2.40	
12th " ..	2.35		32nd " ..	2.10	
13th " ..	2.20	12.30	33rd " ..	2.30	12.35
14th " ..	2.30		34th " ..	2.30	
15th " ..	2.40		35th " ..	2.45	
16th " ..	2.30		36th " ..	2.20	
17th " ..	2.35		37th " ..	3.00	
18th " ..	2.55	13.15	38th " ..		
19th " ..	2.40		39th " ..		
20th " ..	2.35		40th " ..		

According to the figures given above, E. B. G. seems to have no 'warming up' effect.

Another experiment was performed on the subject T. A. for the purpose of investigating the effect of fatigue on the mental function exercised in filling blanks in sentences where certain words had to be supplied to make sense. This method was used, for the first time, by Ebbinghaus who calls it 'Combinations-methode.' Professor Whipple[1] says concerning this: "The author of the method says in substance: Mental ability demands not merely retentive capacity, readiness of recall, or facile association of specific past experiences; it demands all this and something more, something more complex and, as it were, creative; namely, the ability to combine, into a coherent and signifi-

[1] Whipple, G. M., Manual of Mental and Physical Tests, pp. 446-447.

cant whole, mutually independent and even seemingly a combinative activity. To measure intelligence, therefore, we must employ a test that demands ability to combine fragments or isolated sections into a meaningful whole. Such a test may be afforded by mutilated prose, *i.e.*, by eliding letters, syllables, words, or even phrases, from a prose passage and requiring the examinee to restore the passage, if not to its exact original form, at least to a satisfactory equivalent of it." Of the difficulty of deciding the numbers and qualities of eliding words, the same author says: "The completion method is peculiarly difficult to class psychologically, for the simple reason that the nature of the mental processes that it demands depends almost entirely upon the number and kind of elisions that are made in the test. To take extreme cases, if the elisions are numerous and sweeping, it may become really a linguistic puzzle of a very difficult variety, and it then belongs rather in the group of tests of active or creative imagination of the literary type; if, on the other hand, the elisions are but few and simple, it may degenerate into a simple test of controlled association of any desired degree of ease."

A careful attempt to eliminate the sources of error was made in the preparation of the materials for the test. About 55 words were elided on each page of the 1910 edition of Thorndike's "Educational Psychology" in the manner shown below.

"The knowledge of human   which psychology   to
student of educational   and   may roughly
into   . A body of knowledge about instincts, habits,
memory, attention, interest, reasoning, etc., find   in the
ordinary   books. Detailed   of thoughts, feelings
and conduct of certain   at different ages are available
in   of child   ."

The difficulty of the work differs with different individuals. Such materials as quoted above do not seem to be too difficult or too easy to serve our purpose. The test was begun at about noon and lasted to 9 p. m., with intermissions of a few seconds now and then spent in recording the body temperature and pulse rate, and with a fifty-minute rest for supper. The subject recorded the time of beginning each page and the time spent on each page was computed. The results are given in Table XXVII.

TABLE XXVII

Time spent for each page and for each five pages, in completing passages; together with the temperature and the pulse rate at irregular intervals.

Number of page	Time taken per page in minutes and seconds	Time taken for successive 5 pages	Number of page	Time taken per page in minutes and seconds	Time taken for successive 5 pages
Pulse........	98		27th page....	14.15	
Temperature..	9.68° F.				
			Pulse........	74	
1st page....	13.10		Temperature..	98.9° F.	
2nd "	13.00				
3rd "	14.21	69.41	Supper.......		
4th "	13.24				
5th "	15.46		Pulse........	84	
6th "	13.15		Temperature..	98.2° F.	
7th "	13.30				
8th "	12.30	61.20	28th page....	14.30	
9th "	11.15		29th "	11.40	
10th "	10.50		30th "	12.10	73.35
11th "	12.50		31st "	14.50	
12th "	12.10		32nd "	20.25	
13th "	15.20	65.50	33rd "	15.30	
14th "	11.15				
15th "	14.15		Pulse........	82	
16th "	10.55		Temperature..	88.6° F.	
17th "	16.05				
18th "	13.00	66.50	34th page....	11.01	
19th "	13.15		35th "	14.54	
20th "	13.35		36th "	12.40	75.35
21st "	11.15		37th "	14.00	
			38th "	15.00	
Pulse.......	75		39th "	14.10	
Temperature..	99° F.				
			Pulse........	80	
22nd page...	18.45		Temperature..	98.6° F.	
23rd "	14.25				
24th "	13.40	79.11	Next morning.		
25th "	17.15				
26th "	15.06		40th page....	12.30	
			41st "	10.10	

The figures given in Table XXVII form another typical work curve. The speed increases in the beginning for about two hours. After that, it decreases gradually until the end. The rest for supper restores the lost energy to some extent, the time taken for the five pages after the rest being 92.7 per cent of that spent for those before the rest. The fatigue effect appears again in the second hour after rest.

Tranferred Fatigue

I. The effect of fatigue from the continuous exercise of the function of mental multiplication transferred to other functions:

According to the results of Experiment I, mental multiplication lasting for certain hours without rest brings about such changes in efficiency in memorizing German words as are shown in Table XXVIII.

TABLE XXVIII

Number of hours of mental multiplication; number of examples; time taken to memorize 40 German words, 10 being memorized at one time, both immediately before and after the mental multiplication; and coefficient of fatigue. (The minus sign in the coefficient column means an *increase* in efficiency as a result of continuous work.)

Date	Hours of mental multipli-cation	Number of examples done	Time taken for memorizing 40 German words before and after multiplication		Coef. of fatigue
			Before	After	
			m. s.	m. s.	
February 25..	4	24	10.10	10.40	5.0
" 26..	5	30	8.45	10.20	18.1
" 28..	9	51	10.30	11.40	11.1
March 3..	12	67	6.45	11.20	72.9
" 4..	12	67	8.15	7.35	—8.1
" 5 ..	12	67	5.40	8.40	52.9
" 6..	12	67	7.40	7.30	—2.2
Average..	9.4	53			21.4

Table XXVIII shows that an average of 9.4 hours of mental multiplication causes a 21.4 per cent increase in the time taken to memorize. The time of memorizing does not, however, increase in any exact proportion to the increase of the number of hours of mental multiplication.

Eleven individuals (Experiment IV) memorized nonsense syllables before and after two hours of mental multiplication. The effect of fatigue caused by continuous mental multiplication on the function of memory in each individual is given in Table XXIX.

Table XXIX shows that, with all but five individuals, the number of nonsense syllables remembered decreases during the

TABLE XXIX

Number of nonsense syllables remembered before and after two hours of mental multiplication, and coefficients of fatigue.

Subjects	Number of nonsense syllables remembered		Coef. of fatigue
	Before	After	
C. D. T	18.9	19.3	—2.1
Chs	18.0	19.0	—5.3
M. M	16.0	14.0	14.3
S. W	12.6	10.4	21.2
H. L. H	20.0	20.0	0
A. G. C	19.0	14.0	35.7
R. S. W	16.7	16.7	0
H. A. R	19.7	19.0	3.8
J. T	14.4	8.9	61.8
Pfg	18.1	19.7	—8.1
G. D. S	17.5	13.7	7.7
Average			13.5

two hours of mental multiplication. For all the subjects, the average decrease was 13.5 per cent.

Eleven individuals underwent the association test before and after the two hours of mental multiplication. The effect of fatigue caused by the mental multiplication on the speed in associating the antonyms with given words is, for each individual, as follows:

TABLE XXX

Time of associating antonyms before and after two hours of mental multiplication, and coefficients of fatigue.

Subjects	Time (in seconds) taken for association		Coef. of fatigue
	Before	After	
C. D. T	95	152.0	60.0
MS	95	105.0	10.5
M. M	90	60.0	—33.3
S. W	57	62.0	8.8
R. S. W	57	63.0	10.5
H. A. R	63	59.0	—6.3
Pfg	50	60.0	20.0
P. E. R	175	60.0	—65.7
C. T. R	74	70.0	—5.4
G. M. K	67.5	61.0	—9.6
Sn	96	72.0	—25.0
Average			—2.7

The foregoing table shows that five subjects out of eleven lose speed during the mental multiplication, while the rest give opposite results. The individual differences are too great to draw any general conclusion from the figures given above.

Nine individuals underwent the addition test before and after two hours of mental multiplication. The effect of fatigue caused by the work on efficiency in addition is given in Table XXXI.

TABLE XXXI

Time taken for addition as described in Experiment IV, before and after mental work, and coefficients of fatigue.

Subjects	Time (in seconds) taken for addition		Coef. of fatigue
	Before	After	
MS	67	78	16.4
M. M	110	90	—18.2
S. W.	100	119	19.0
R. S. W.	55	55	0
H. A. R.	54	50	—7.4
Pfg.	45	43	—4.5
P. E. R	120	90	—25.0
G. M. K.	48	52	8.3
Sn.	111	111	0
Average			—.2

Here, too, the effect of two hours of mental multiplication is subject to great individual differences.

II. The effect of fatigue caused by general mental work transferred to special mental functions:

The materials for the discussion are obtained from Experiment II. One year elapsed between Experiments I and II. The practice effect in Experiment I might still be at work in the test of mental multiplication in Experiment II. The results show that practice has influence only on the first eight mornings.

In order to know clearly the effect of practice on the results of the memory test of Experiment II, we must note the facts of a short preliminary test. During April, 1909, about ten months before the beginning of Experiment II, the same subject made a series of practice tests of the function exercised in memorizing German words. Each day, the subject memorized five lists of ten German words each and noted the time when she began to memorize each list and the time when she finished writing them down in their original order. The same process was repeated five times at each test. The average time taken for memorizing a list on each day of the experiment is shown in Table XXXII.

TABLE XXXII

Day	Time required	Day	Time required
1	380 sec.	11	180 sec.
2	222 "	12	138 "
3	260 "	13	280 "
4	212 "	14	118 "
5	188 "	15	120 "
6	182 "	16	108 "
7	165 "	17	105 "
8	200 "	18	102 "
9	132 "	19	100 "
10	145 "	20	92 "

The figures of Table XXXII give a typical curve. The gain by practice is greatest at the beginning and becomes smaller as it approaches toward the end.

After this preliminary experiment, the memory test of Experiment II was made. We find, in this test, the average daily gain to be about .18 sec. and the gain observed in the morning test only .09 sec. Therefore, in dealing with the observations made in Experiment II, practice effect can be neglected without causing any grave error.

The fatigue caused by general mental work during the day is measured by a direct comparison of the efficiency in the morning with that of the evening. If the results of the comparison show that fatigue through the day increases in proportion to the increase in the amount of mental work, we are justified in supposing that the fatigue is caused directly by general mental work during the day. The relations of these two factors are given in Tables XXXIII and XXXIV.

According to Tables XXXIII and XXXIV, the transferred fatigue increases with the number of hours of mental work for both functions tested, at least from three hours on.

Relations of Fatigue in Different Mental Functions Caused by the Same Cause

In the foregoing section it was found that fatigue in one function is, in part, transferred to some other mental function. The question rises here, whether the transfer is equal for all functions. We can answer this question by calculating the coefficient of correlation between the fatigues of two functions. The correlations are obtained between fatigue in the special function exercised and its transferred fatigue, and also between the transferred fatigue in one function and that in another caused by the same work. All the correlations which will be mentioned in this section were obtained by the Pearson method.

In the case of fatigue from mental multiplication transferred to the function of memorizing, the correlation is –.19 in the sub-

TABLE XXXIII

Ten different kinds of days according to different amounts of mental work done ('0–1' meaning a day of zero to one hour of work, '1–2' a day of one to two hours, etc.); time taken to memorize per word in the morning and in the evening; and coefficients of fatigue (i.e., the percentage which the difference between the times taken in two cases is of the former).

Hours of work, 0–1			
Date	Morning	Evening	Coef. of fatigue
Feb.27	19.0	17.3	—8.9
Mar. 6	11.0	10.6	—3.7
" 8	16.6	18.1	—9.1
" 10	18.8		
" 20	18.0	20.0	—11.1
Ave...			1.9

Hours of work, 1–2			
Date	Morning	Evening	Coef. of fatigue
Mar. 4	13.3	13.7	3.0
May21	13.7	13.0	—5.5
" 23	12.2	10.5	—13.9
" 25	15.0	10.8	—28.0
" 28	10.0	9.5	—5.0
Ave...			—9.9

Hours of work, 2–3			
Date	Morning	Evening	Coef. of fatigue
Mar.15	—11.3	—13.1	15.9
" 11	20.0	20.3	1.5
Jun. 6	10.6	11.6	9.
Ave...			8.9

Hours of work, 3–4			
Date	Morning	Evening	Coef. of fatigue
Mar. 7	11.5	15.0	30.4
" 9	18.0	20.5	13.8
Apr.15	15.8	16.6	5.1
" 21	17.1	16.8	—1.2
May13	10.8	13.3	23.1
Ave...			14.2

Hours of work, 4–5			
Date	Morning	Evening	Coef. of fatigue
Feb.19	20.0	22.9	14.5
Mar. 3	11.3	12.0	6.2
Apr. 6	12.0	13.8	15.0
May19	10.5	16.9	60.9
" 24	12.5	13.6	8.8
" 27	8.0	10.5	13.1
Ave...			19.8

Hours of work, 5–6			
Date	Morning	Evening	Coef. of fatigue
Feb.17	21.3	28.8	35.2
" 21	19.8	22.5	13.6
Apr.23	11.7	12.8	9.4
May 9	11.5	13.3	15.7
" 10	9.5	10.5	10.5
" 11	10.9	14.3	31.2
" 12	10.0	12.2	22.0
Ave...			19.7

Hours of work, 6–7			
Date	Morning	Evening	Coef. of fatigue
Mar.18	14.2	18.0	23.2
" 21	25.6	30.3	18.4
Apr. 6	12.3	14.8	20.3
" 18	15.8	20.9	32.3
Feb.18	15.8	22.9	44.9
Ave...			27.8

Hours of work, 7–8			
Date	Morning	Evening	Coef. of fatigue
Feb.23	17.5	19.8	13.2
" 24	14.5	27.5	89.7
Mar. 1	23.3	26.4	13.3
" 15	17.8	22.2	24.7
" 22	16.3	23.9	48.4
Apr.12	20.2	22.8	12.8
" 13	10.3	15.9	54.4
" 14	10.3	14.5	40.8
" 20	17.4	22.2	27.6
Ave...			36.1

Hours of work, 8–9			
Date	Morning	Evening	Coef. of fatigue
Feb.16	16.8	20.8	124.4
" 22	18.5	21.9	118.4
Mar.16	16.5	20.8	126.7
Apr. 7	15.0	16.8	112.0
Ave...			20.4

Hours of work, 9–10			
Date	Morning	Evening	Coef. of fatigue
Apr. 7	13.8	14.4	4.3
May14	13.0	18.3	40.8
" 16	9.0	18.4	104.4
Ave...			49.8

TABLE XXXIV

This table is made on the same plan as Table XXXIII, but with the time taken to do mental multiplication of three-place numbers by three-place numbers in place of the time of memorizing.

Hours of work, 0–1

Date	Morning	Evening	Coef. of fatigue
Feb. 5	157.5	175.0	11.1
" 10	185.0	258.7	38.8
" 27	115.0	120.0	4.4
Mar. 6	87.5	132.5	51.4
" 8	130.0	133.3	2.6
" 10	126.7	126.3	—.4
Ave...			18.1

Hours of work, 1–2

Date	Morning	Evening	Coef. of fatigue
Mar. 4	128.3	153.3	19.5
May17	161.7	126.7	—21.1
" 21	96.7	113.3	17.2
" 23	103.3	96.7	—4.4
" 25	120.0	125.0	4.2
" 28	96.7	120.0	24.1
			6.6

Hours of work, 2–3

Date	Morning	Evening	Coef. of fatigue
Feb.15	188.3	133.3	—29.2
" 26	156.7	141.7	—9.6
Mar. 5	138.3	140.0	1.3
" 11	146.7	123.3	—15.9
Jun. 6	118.3	123.3	4.3
" 7	103.3	156.7	52.7
			.6

Hours of work, 3–4

Date	Morning	Evening	Coef. of fatigue
Mar. 7	131.7	140.0	6.
" 9	153.3	128.3	—16.3
Apr.15	117.5	177.5	51.1
" 21	142.5	115.0	—19.3
May13	118.3	133.3	12.7
Ave...			6.8

Hours of work, 4–5

Date	Morning	Evening	Coef. of fatigue
Feb. 4	155.0	288.0	85.8
" 18	175.0	209.0	19.4
Mar. 3	160.0	165.0	3.1
Apr. 6	143.3	138.3	—3.5
May19	125.0	112.3	—10.5
" 24	90.0	120.0	33.3
" 27	121.8	125.0	2.6
			18.6

Hours of work, 5–6

Date	Morning	Evening	Coef. of fatigue
Feb. 9	206.7	176.7	—14.5
" 17	144.3	213.3	47.8
" 21	115.0	160.0	39.2
Apr.23	175.0	123.3	—29.5
May 9	118.3	148.3	25.4
" 10	113.3	101.7	—10.2
" 11	100.0	125.0	25.0
" 12	105.0	117.0	11.4
" 26	91.7	123.3	34.4
			14.3

Hours of work, 6–7

Date	Morning	Evening	Coef. of fatigue
Feb. 8	218.3	187.7	—14.0
Mar.18	118.3	150.0	27.0
May 6	123.3	175.0	41.9
" 18	98.3	181.7	84.8
Jun.18	220.0	153.3	—30.3
" 20	118.3	150.0	27.7
" 22	101.7	121.7	19.8
" 23	120.0	138.3	15.3
Feb.18	175.0	209.0	25.2
Ave...			21.9

Hours of work, 7–8

Date	Morning	Evening	Coef. of fatigue
Feb.23	141.7	163.3	15.2
" 24	125.0	180.0	45.6
Mar. 1	123.3	146.7	19.0
Apr.12	120.0	125.0	4.2
" 13	137.5	147.5	7.3
" 14	115.0	178.7	55.4
" 20	135.0	146.7	8.7
			22.2

Hours of work, 8–9

Date	Morning	Evening	Coef. of fatigue
Feb. 7	173.3	325.0	87.5
" 10	201.0	265.3	31.8
" 16	163.0	109.0	—33.1
" 22	158.3	234.3	47.8
" 28	120.0	144.0	20.0
Mar.16	124.3	111.7	20.1
Apr.11	140.0	163.3	16.6

Hours of work, 9–10

Date	Morning	Evening	Coef. of fatigue
Apr. 7	138.0	156.7	113.8
May14	100.0	163.3	163.3
" 16	135.0	173.3	128.4
Ave...			35.0

ject T. A., according to the results of Experiment I.[1] The correlation is .21 in the group of ten individuals, according to Experiment IV.[2]

In the case of fatigue from mental multiplication transferred to the function of association, there is no correlation (.003) according to the result of Experiment IV.[3]

[1] See Tables III, IV; and compare Tables XVII and XXVIII.
[2] See Table VIII; compare Tables XX and XXIX.
[3] See Table VIII; compare Tables XX and XXX.

In the case of fatigue transferred to the function exercised in adding, the correlation is +.1 (.088) according to the results of Experiment IV.[1]

For correlations between the transferred fatigue in one function and that in some other function caused by the same work, we have the following:

In the case of the subject T. A., according to Experiment II, there is a correlation of .13 between the diminution in ability to memorize and that in ability to do mental multiplication.[2]

In the group of individuals, according to Experiment IV, there is a correlation of .77 between the fatigue in association and the fatigue in addition.[3]

[1] See Table VIII; compare Tables XX and XXXI.
[2] See Table X.
[3] Compare Tables XXX and XXXI.

CHAPTER VI

CONCLUSIONS

I. *Mental Fatigue and Physiological Processes*

In the case of the individual T. A., the morning to evening decrease in pulse rate was on days of less than three hours of mental work, 1.5 per cent. On days of three to six hours of mental work, it was 3.9 per cent and on days of more than six hours of mental work, 7.3 per cent. This decrease in pulse rate is correlated to decrease of efficiency in memory by a coefficient by .18 and to decrease of efficiency in mental multiplication by a coefficient of .17. In the group of individuals performing mental multiplication for two hours there was a decrease in pulse rate of 13.3 per cent, which decrease is correlated to loss of efficiency in memory, multiplication, addition, and association by the coefficients, .73; .41; .24; and –.14 respectively. We may, therefore conclude that there is a decrease of pulse rate as a result of continuous mental work which decrease is positively, though slightly, related to decreases in efficiency of the various mental functions tested.

We are unable to draw any conclusions from the results obtained from our observations on body temperature during mental work.

II. *Fatigue and Feelings of Fatigue*

In repeated measurements on the individual T. A., the direction and degree of change in feeling from morning to evening depended somewhat on the hours of mental work during the day. For instance, the feeling changed more toward the worse with prolonged mental work and *vice versa*. These changes are slightly correlated to the changes in pulse rate and in efficiency in memory and in mental multiplication. These changes seem to have no direct relation to the duration of sleep during the previous night. In the case of the group of individuals, we find similar relations between the degree of the feeling or fatigue, the decrease in efficiency of mental functions and decrease in pulse rate. From these facts, we conclude that the feeling of fatigue is somewhat, though far from perfectly, correlated with the state of mental inefficiency.

III. *The Amount of Mental Work and Changes in Mental Efficiency*

1. Factors which influence the efficiency of mental functions.

In the course of several experiments on each individual, we find that efficiency increases during continuous work and that this increase affects efficiency during the next experiment. We almost invariably find this favorable effect—the effect of practice—in the results of the experiment, except in the few cases where the subject had already reached the limit of practice. But we do not observe any regular 'warming up' effect. In the four twelve-hour fatigue curves taken after the subject had reached the limit of practice, there is no initial increase of efficiency. But the results of the two-hour experiment tried on the group of individuals, perhaps shows the existence of the factor in question. In the reading experiment, the one who was less used to English showed this effect, while the other who had read it much more showed none. It seems then, to be a fact that 'warming up' is not present in functions in which the subject has reached the limit of practice. For this reason, the writer is inclined to conclude that the 'warming up' effect is only a part of the effect of practice. In none of our fatigue curves are the spurts observable. The unfavorable effect which is observed in our results is, of course, attributable to fatigue. Besides these factors, it is probable that habits of diurnal changes have some influence on the efficiency in mental functions.

2. The effect of mental work on the efficiency of the special mental function.

Difficult and disagreeable continued work brings about a decrease in the efficiency of the function exercised. In the case of individual T. A., the time taken to do a certain number of examples is almost doubled during twelve hours of mental multiplication. In the case of the group of individuals (inexperienced subjects), the increase in the time taken to do a certain amount of work is 24 per cent during two hours of mental multiplication.

3. Transferred mental fatigue.

Continuous exercise of a mental function not only causes a decrease in the efficiency of the function tested, but may have an unfavorable influence on other functions. For instance, in the case of individual T. A., 9.4 hours of mental multiplication increases the time taken to memorize words by 21.4 per cent. After two hours of mental multiplication the group of individuals showed 13.5 per cent decrease in ability to memorize nonsense syllables. But there was hardly any change in the functions of addition and association. General mental work decreases the efficiency of special mental functions. Fatigue and its transferred fatigue are, as a rule, correlated, though the correlation is very low. There is also a very slight, but positive, correlation between two transferred 'fatigues' caused by the same mental work. On the whole, then, we are led to conclude that fatigue in a special mental function as well as in general is slightly transferrable to other functions and that the greater the fatigue the greater the transferred fatigue.

IV. *Individual Differences*

We find great individual differences in the susceptibility to fatigue. As a rule, the more competent people are less affected by fatigue.