MENTAL FATIGUE

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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.

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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

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[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-

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[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

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[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

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[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.