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DIURNAL VARIATIONS IN MEMORY AND ASSOCIATION

BY

ARTHUR I. GATES

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TABLE V

The Absolute and Relative Mean and Median of Figures Recognized (Penalized Score)

	A.M.				P.M.				
Hour.....	8:30	9:30	10:30	11:30	1:30	2:30	3:30	4:30	5:30
Av. No. recognized	10.8	12.5	13.2	12.5	11.5	12.0	13.0	13.0	12.8
Mean variation	2.0	1.9	1.9	1.8	1.9	1.8	1.8	2.1	2.0
Mean, per cent....	100.0	115.7	122.2	115.7	106.5	111.0	120.0	120.0	118.5
Median	11.1	12.0	13.0	12.3	10.6	11.0	13.0	13.5	13.0
Median, per cent....	100.0	108.0	117.0	112.0	96.4	99.0	117.0	121.0	117.0

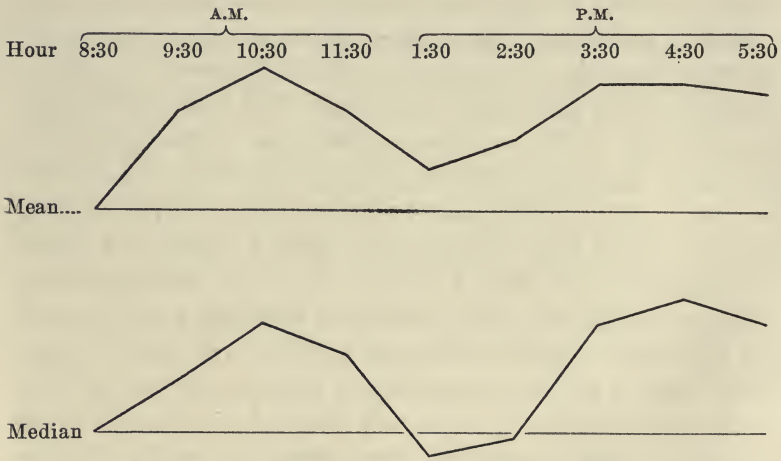


Fig. 5.—The diurnal course of recognition of figures. (Penalized score)

The figures, relatively, are not greatly changed by penalizing the subjects for erroneous recognitions. 11:30 A.M., by virtue of fewer errors, shows a slightly higher efficiency, while 5:30 P.M., on account of more frequent errors, shows less relative efficiency than before. The mean variations of the two last hours of the day remain high. The changes brought about by penalizing the subjects for errors have resulted in making the curves correspond more closely than formerly to the curves of functions considered earlier.

Table VI shows the amount of errors made at different hours of the day, without regard to the total amount of correct recognitions. The percentage columns show efficiency and do not show the relative number of errors; i.e., the larger this percentage, the fewer the errors.[4]

TABLE VI. ERRORS IN RECOGNITION

SHOWING THE MEAN AND MEDIAN ERRORS MADE, WITH THE RELATIVE EFFICIENCY AT EACH HOUR

	A.M.				P.M.				
Hour.....	8:30	9:30	10:30	11:30	1:30	2:30	3:30	4:30	5:30
Av. No. errors.....	2.31	2.04	1.78	1.93	2.16	2.40	1.90	3.06	2.50
Mean variation	1.13	1.40	1.22	1.76	1.45	1.48	1.27	1.82	1.95
Relative efficiency	100.0	112.0	130.0	120.0	107.0	96.3	121.5	75.5	92.5
Median	2.00	2.00	1.50	1.50	1.80	2.15	1.32	2.30	2.00
Relative Median	100.0	100.0	133.0	133.0	111.0	93.0	151.5	87.0	100.0

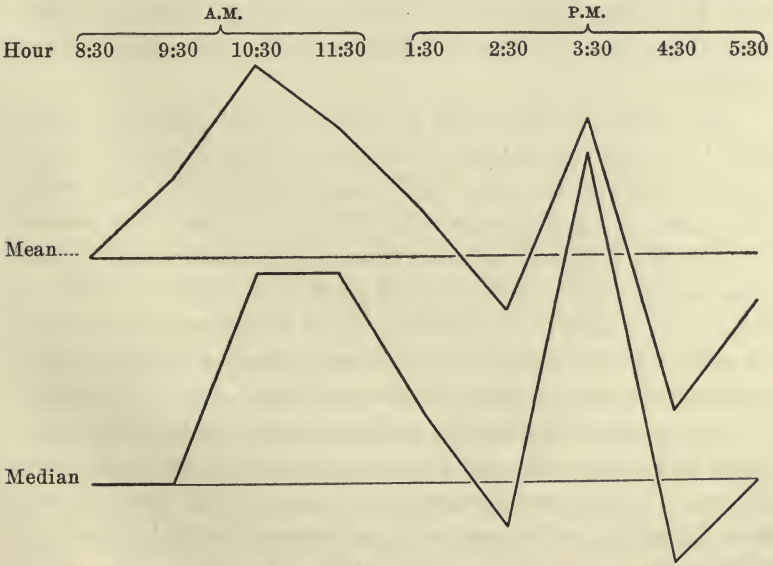
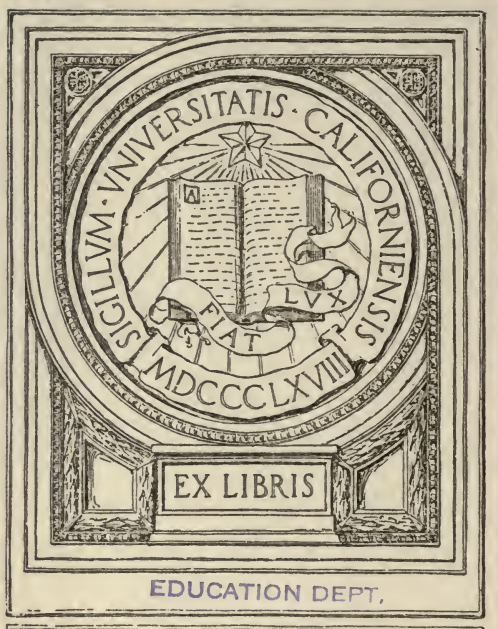


Fig. 6.—The diurnal course of efficiency with regard to decrease of erroneous recognitions

[4] The figures showing the relative efficiency are obtained by dividing the score for eight o'clock by the score for any particular hour.



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DIURNAL VARIATIONS IN MEMORY AND ASSOCIATION

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I. The Problem and the General Method of Procedure

A year ago, the writer attempted to summarize the more important results obtained by earlier investigators on the problem of diurnal variations in efficiency, adding certain experimental findings of his own obtained by tests upon school children. A more extended discussion of the problem, its significance, and difficulties will be found in that article.[1]

The present investigation differs from the earlier one in several respects. In the present work adults served as subjects in the tests, which were extended over a greater portion of the day than previously. In the first investigation, moreover, tests for a variety of mental and motor functions were employed, while in the present work the tests are all included in the general field of memory and association.

One hundred and sixty-five college students, members of a class in elementary psychology, served as subjects for the experiments. Three full days were required to complete the experiments. The temperature on the particular days chosen varied from 56 to 66 degrees Fahrenheit. The tests were given to groups, each includ-

[1] Variation in Efficiency during the Day, together with Sex Differences, Practice Effects, and Correlations, *Univ. Calif. Publ. Psychol.*, vol. 2 (1916), no. 1.

ing from six to fourteen students at each hour of the day, except from noon to 1:00 o'clock, the first beginning at 8:00 A.M. and the last at 5:00 P.M. The subjects were seated at a long table, at one end of which stood the experimenter. The tests were given in the order in which the results are presented in this article. The time required for all the tests of any single sitting was about half an hour.

For the purpose of gaining fuller information with regard to his habits of life and especially of variations from the normal routine of the day, the following questionaire was filled out by each student:

1. Name.
2. College year.
3. Did you do any especially hard work today? What?
4. Did you do any especially hard work just before this hour? What?
5. What time do you usually go to bed?
6. What time do you usually get up?
7. Did the time of going to bed last night or the time of getting up this morning differ from the average? How much?
8. Do you usually eat a heavy or a light breakfast?
9. Do you usually eat a heavy or a light lunch?
10. Any exception today with regard to meals?
11. What hours do you think are your best for work or study?
12. What are your reasons for believing so?

The answers to question 7 showed that the majority of these students go to bed at 10:30 or 11:00 o'clock. The following table shows the distribution:

Hour	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00
No. of inds.	1	8	24	43	71	64	22	7
Per cent	0.4	3.3	10.0	17.8	29.6	26.6	9.2	2.9

The following table shows the time of getting up:

Hour	5:00	5:30	6:00	6:30	7:00	7:30	8:00
No. of inds.	4	0	28	58	90	57	3
Per cent	1.6	0.0	11.6	24.2	37.4	23.7	1.2

Seven o'clock is the favorite hour of rising, although about one-fourth arise at 6:30 and another fourth at 7:30.

The matters of chief importance in this connection are the departures from the normal habits of life on the part of the sub-

jects. Answers to 2, 3, 7, and 10 gave the information with regard to such departures. In most cases where the subject had gone to bed much later than usual, had got up much later than usual, or missed a meal, or had some especially hard work just before the test, the data from him were not included.

Following are the chief factors, in addition to those just enumerated, which seemed to give just reason for discarding a subject's work: (1) Copying from others or using unfair methods of any sort, although such cases were very rare; (2) lack of interest, or inattention; (3) physical defects, such as conspicuous defects of sight or hearing, or sickness, bruised fingers, and the like, when of such a nature as to interfere with maximal performance; (4) failure to understand directions, etc., after the test had been started.

On the whole, however, nearly all of the subjects conformed to all the rules of the tests and the results were considered trustworthy and to be the products of their very best efforts. Many minor differences among the individuals existed with regard to the character of the day's activity. Some had many and some had few college exercises before the test; some had done more and some less studying than usual. The possibilities of such differences were, of course, greater for those coming in the latter part of the day; but except for reasons mentioned above, the data from all subjects were retained. Perfect conditions would consist in an identical programme for the day for all the subjects, one in which very little or no fatiguing work was done; but such conditions could not be obtained.

The following table shows the distribution of individuals according to their preferred hours for study and work:

	A.M.								NOON
Hour.....	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
No. of inds.	2	17	36	42	109	137	87	38	5
	P.M.								
Hour.....	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00
No. of inds.	2	2	2	11	12	5	17	29	22

10:00	11:00	12:00	No preference.
20	6	0	9

The morning hours are preferred by most individuals, with the evening hours next in order. Nine A.M. is the most popular hour, although 8 A.M. is preferred by nearly as many persons. Ten A.M. follows next in order of preference and 6 and 7 A.M. rank higher than the best afternoon or evening hours. Eight P.M. is the preferred evening hour and 4 and 5 P.M. are the preferred afternoon hours.

The reasons given by the subjects for believing that their preferred hours are really their best hours are very much alike. In almost every instance the reasons amount merely to an opinion based on their subjective feelings. An effort will be made in this work to discover how closely the curve of distribution of preferred hours follows the curve of real efficiency as shown by the experimental findings. For the morning hours the reports are of this sort: "I feel more energetic;" "I am in better condition, physically and mentally;" "My mind is clearer;" and the like. Those who prefer the afternoon hours report: "I have got into the swing better;" "I am more wide-awake;" and so on. The statements with regard to the evening hours are much the same, although those preferring the late evening and the very early morning hours attribute their greater efficiency to the existence of fewer distractions at those times. Many admit that they seem to have greater success at a particular time largely because, on account of the force of circumstances or by arbitrary choice, it had become habitual for them to do their hardest work at those hours.

II. Tests in Auditory Memory

For a test in auditory memory the following series of digits were used: 9627, 41852, 736294, 8513627, 38471629, 529468371. 2574638197, 83519472631, 628194357283.

Detailed instructions with regard to the method of conducting the tests were given. The digits, beginning with the shortest series, were read sharply and without rhythm at the rate of one each three-fourths of a second, the rate being fixed by a silent

pendulum invisible to the subjects. The tests in auditory memory was given first of all to the groups on the first two days of the experiment, and second (following the visual series) on the last day.

The results are given in terms of the average (mean) spans with the mean variation, and of the median spans of the individuals in the different groups. By the "span" is meant the longest series reproduced correctly *in toto*. But in case a series

TABLE I. AUDITORY MEMORY

THE ABSOLUTE AND RELATIVE MEAN AND MEDIAN OF DIGITS REPRODUCED AT DIFFERENT HOURS

	A.M.				P.M.				
Hour.....	8:00	9:00	10:00	11:00	1:00	2:00	3:00	4:00	5:00
No. of subjects....	23	23	28	28	25	25	25	30	25
Av. No. digits.....	7.81	7.61	7.72	8.08	7.60	7.38	7.67	7.46	7.33
Mean variation	1.20	1.10	1.15	1.05	1.40	1.07	0.92	1.00	1.10
Mean, per cent....	100.0	97.5	98.8	103.3	97.4	94.5	98.2	95.5	93.8
Median	7.00	7.20	7.20	7.50	7.40	7.30	7.40	7.10	7.08
Median, per cent....	100.0	103.0	103.0	107.0	105.8	103.9	105.8	101.4	101.0

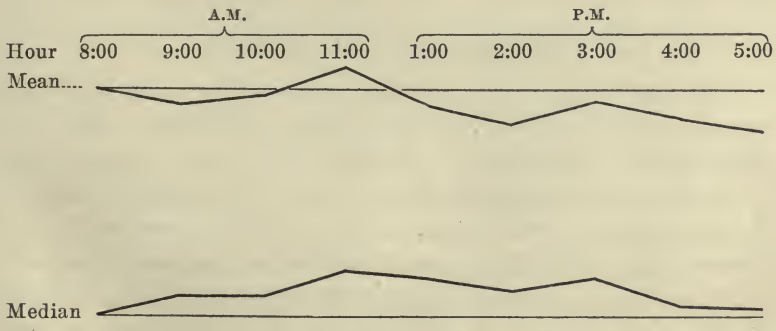

Fig. 1.—Auditory memory.[2] The diurnal course of memory for auditory digits

[2] The diagrams are based on the percentage columns in the corresponding tables.

was correctly reproduced entire, following two or more incorrect series, the correct series preceding the failures was taken as the span. Thus, if an individual reproduced a series of six digits, failed at seven and eight, succeeded at nine and failed thereafter, the series of six digits was considered the span. The results are given in Table I.

The mean and the median both show a marked and steady increase in efficiency during the forenoon, with the exception that the mean for 8 o'clock is high compared to that for 9 or 10 o'clock. The median for this hour, however, is lower than for any other forenoon hour. The maximum efficiency for the day, according to both methods of computation, is at 11 o'clock. Efficiency at 1 o'clock is lower than at 11 o'clock and at 2 o'clock it is still lower, whence it moves upward to the afternoon maximum at 3 o'clock. According to the median, however, 3 P.M. is equal in efficiency to 1 P.M.; and although the mean at 1 P.M. is less than at 3, it is greater than at 2 o'clock. It will be noticed, however, that the mean variation is greater at 1 o'clock than at any other hour of the day, indicating the small reliability of this measure. In general, there is a steady and pronounced increase in efficiency during the forenoon, a fall following the lunch hour, an increase at 3 P.M., and a final drop at the end of the day.

III. Tests in Visual Memory

The following series of digits were used as tests of visual memory: 6283, 57294, 241738, 2170463, 27986543, 215903847, 5978024318, 57402623871, 183570467392. The displays were made up of black gummed digits two and three-fourths inches in height, pasted on white cards two and a half by three and a half inches in size, which were pasted in series on a strip of gray cloth.

The strips were exposed in order of length, beginning with the series of four digits. The folded strip was held before the subjects, the word "ready" was given and the strip was drawn taut with a snap, exposing the series. The subjects wrote the digits as soon as the strip was taken from sight. The time of exposure

varied with the length of the series, being determined by multiplying the number of digits in each series by three-fourths of a second.

The method of treating the data and computing the results was the same as that employed in the tests of auditory memory. The results are stated in the absolute and relative number of digits reproduced, determined by the arithmetical mean and median.

TABLE II. VISUAL MEMORY

THE ABSOLUTE AND RELATIVE MEAN AND MEDIAN OF DIGITS REPRODUCED AT DIFFERENT HOURS

	A.M.				P.M.				
Hour.....	8:00	9:00	10:00	11:00	1:00	2:00	3:00	4:00	5:00
No. of subjects....	23	24	28	24	24	25	26	26	25
Av. No. digits.....	8.00	7.95	8.14	8.14	7.84	8.08	8.15	8.17	8.00
Mean variation	1.25	1.13	1.06	1.19	1.20	1.30	1.08	1.16	1.20
Mean, per cent....	100.0	99.3	101.5	101.5	98.0	100.1	101.7	102.0	100.0
Median	7.50	7.50	7.70	7.60	7.25	7.50	7.80	7.60	7.50
Median, per cent....	100.0	100.0	103.0	101.5	96.7	100.0	104.0	101.5	100.0

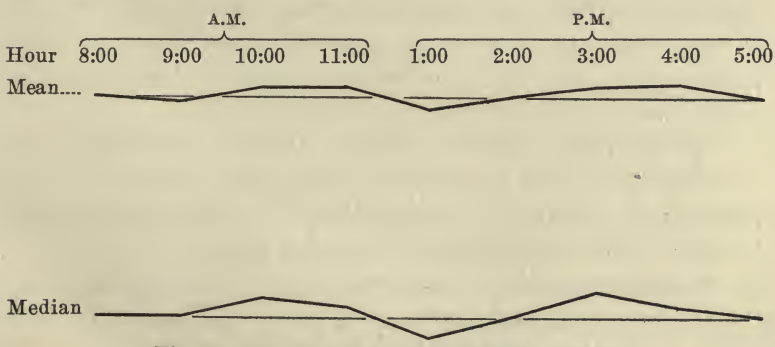

Fig. 2.—The diurnal course of visual memory

In many respects the course of efficiency in memory for visual digits is the same as for auditory digits. The general increase in efficiency during the forenoon is evident, although the same

exception is found with regard to the 8 o'clock hour—i.e., a superiority of that hour over 9 o'clock, as shown by the mean but not by the median. In the case of visual memory, however, 11 A.M. is barely equal to 10 A.M. according to the mean, and is slightly inferior according to the median. In the afternoon, from the fall at 1 P.M. there is a steady increase in efficiency until 3 P.M., as shown by the median; and the mean indicates that this increase persists until 4 P.M. Both measures show a decrease in efficiency following 4 o'clock. On the whole, there is a high degree of correspondence between the curves for the two forms of memory for digits.

IV. Substitution Test

For a test in the rapidity of learning, a form of code was used.[3] This test gives a fair measure of the rapidity with which associations are formed by repetition. The associations consist in the formation of connections between a series of nine symbols and nine digits, and are established gradually as the test proceeds.

The material consisted of printed cardboard "key" forms, three by seven inches, containing nine circles, in each of which was enclosed the symbol and the corresponding digit; and also of test sheets eight and a half by eleven inches in size, on each of which were printed two columns of twenty-five rows of five symbols each, with blank spaces to correspond. Altogether, each sheet contained 250 symbols and 250 blank spaces.

The test sheets and the keys were passed to the subjects, the keys face downward and the test sheets face upward in proper position. The method of conducting the test was then explained in detail. Six minutes were allowed for the work.

The test sheets were checked up for errors and, excluding them, the total number of digits written was computed. The results are given in Table III.

Again an increase in efficiency during the forenoon is found, although 11 o'clock is slightly inferior to 10 o'clock. The after-

[3] For a discussion of this test, see Whipple, G. M., *Manual of Physical and Mental Tests* (1910), pp. 350 ff.

noon maximum stretches from 2 to 4 o'clock, the figures for these hours being nearly the same. The hours of lowest efficiency for the day are 1 P.M. and 5 P.M., the latter being slightly below the former. The curve, in a general way, is very closely akin to those found for the previous functions.

TABLE III. SUBSTITUTION TEST

THE ABSOLUTE AND RELATIVE MEAN AND MEDIAN FOR DIFFERENT HOURS

	A.M.				P.M.				
Hour	8:25	9:25	10:25	11:25	1:25	2:25	3:25	4:25	5:25
No. of subjects	18	23	25	23	19	23	27	24	21
Av. No. digits	174.0	179.0	183.4	181.8	167.0	179.0	177.0	176.6	164.0
Mean variation	33	30	31	27	30	31	33	34	31
Mean, per cent	100.0	102.7	105.2	104.3	96.0	102.6	101.5	101.2	94.3
Median	174.0	176.0	181.0	180.0	166.0	169.0	170.0	170.0	165.5
Median, per cent	100.0	101.2	104.0	103.4	95.5	97.2	97.7	97.7	95.3

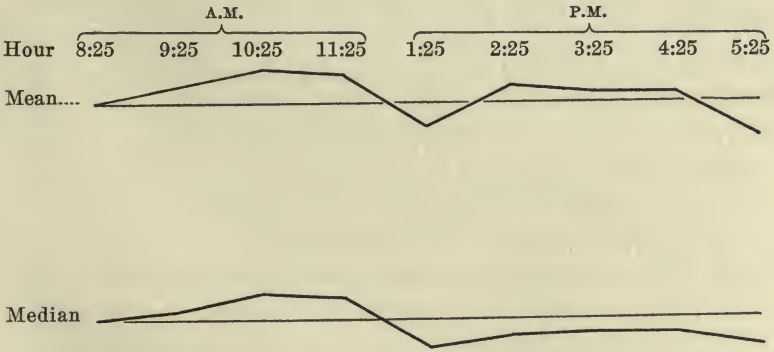

Fig. 3.—The diurnal course of efficiency in the substitution test

V. TESTS IN RECOGNITION

The material consisted of a sheet of twenty-five geometrical figures for a learning series and a larger sheet containing the original twenty-five figures mixed indiscriminately with twenty-five new figures for a test series. The subjects marked off on the

test sheet the recognized figures. No one succeeded in recognizing all of the figures, and very few completed the tests without erroneous recognitions.

The method of conducting the test was explained in detail and both sheets were passed out face downward. One minute was allowed for the study period and two minutes for the recognition work.

TABLE IV. RECOGNITION TEST

The Absolute and Relative Mean and Median of Figures Correctly Recognized

	A.M.				P.M.				
Hour.....	8:30	9:30	10:30	11:30	1:30	2:30	3:30	4:30	5:30
No. of subjects....	21	24	29	28	24	25	27	29	22
Av. No. recognized	13.1	14.5	15.1	14.3	13.6	14.0	15.3	16.3	16.3
Mean variation	2.5	2.8	2.7	2.0	2.1	2.3	2.2	3.1	3.3
Mean, per cent....	100.0	111.5	115.0	109.0	104.0	107.0	116.8	124.5	124.5
Median	11.7	15.0	15.0	14.5	12.5	14.2	15.2	16.1	16.0
Median, per cent....	100.0	128.0	128.0	124.0	107.0	121.0	130.0	137.5	136.6

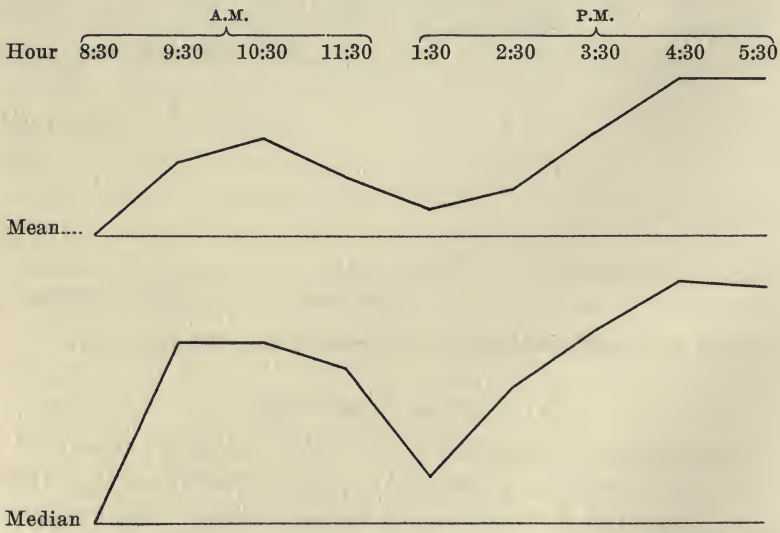

Fig. 4.—The diurnal course of efficiency for recognition of figures

The data were scored by counting the number of figures correctly cancelled and the number incorrectly cancelled. Twenty-five would be a perfect score. The results have been computed, first, on the basis of the number of figures correctly cancelled; second, on the basis of a penalized score in which, from the number correctly recognized, one credit is deducted for each erroneous recognition; and finally, tabulations have been made of the number of errors occurring at each hour.

Table IV gives the results according to the first method of computation.

The main features of the curves for efficiency in the recognition of figures are the same as those found for the functions previously considered. The differences from hour to hour, especially those chosen by the median, are exceedingly great, the relative differences being here many times greater than those found in the memory tests. Both mean and median agree in showing a large and steady increase during the forenoon, which has ceased, however, by 11:30 A.M. Compared to the efficiency of the morning hours, a decided drop is evident at 1:30 P.M., which is followed by a steady increase until 4:30 P.M.; 5:30 P.M., although lower on the curve than 4:30 P.M., is still very high, but it will be noted that the mean variations for the last hours are very high. On the whole, there is a high correspondence between the general form of the curves for this function and those previously considered.

Table V gives the results when, from the scores just considered, one credit was deducted for each erroneous recognition. It is very probable that this arbitrary method may give a good index of the real efficiency of many individuals. Some subjects work cautiously, making but few erroneous judgments. Others are less careful, marking out almost any figure which seems at all familiar; and, by increasing the number of cancellations, mark out a greater number of the proper figures, in many cases by mere chance, since the numbers of right and wrong figures were equal. The arbitrary penalty has for its basis the fact of equal distribution of right and wrong figures, and one credit is therefore deducted for each error.

TABLE V

The Absolute and Relative Mean and Median of Figures Recognized

(Penalized Score)

	A.M.				P.M.				
Hour.....	8:30	9:30	10:30	11:30	1:30	2:30	3:30	4:30	5:30
Av. No. recognized	10.8	12.5	13.2	12.5	11.5	12.0	13.0	13.0	12.8
Mean variation	2.0	1.9	1.9	1.8	1.9	1.8	1.8	2.1	2.0
Mean, per cent....	100.0	115.7	122.2	115.7	106.5	111.0	120.0	120.0	118.5
Median	11.1	12.0	13.0	12.3	10.6	11.0	13.0	13.5	13.0
Median, per cent....	100.0	108.0	117.0	112.0	96.4	99.0	117.0	121.0	117.0

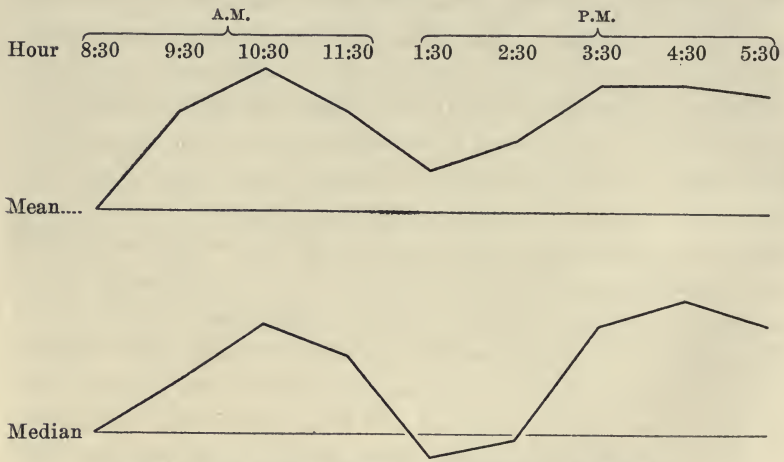

Fig. 5.—The diurnal course of recognition of figures. (Penalized score)

The figures, relatively, are not greatly changed by penalizing the subjects for erroneous recognitions. 11:30 A.M., by virtue of fewer errors, shows a slightly higher efficiency, while 5:30 P.M., on account of more frequent errors, shows less relative efficiency than before. The mean variations of the two last hours of the day remain high. The changes brought about by penalizing the subjects for errors have resulted in making the curves correspond more closely than formerly to the curves of functions considered earlier.

Table VI shows the amount of errors made at different hours of the day, without regard to the total amount of correct recognitions. The percentage columns show efficiency and do not show the relative number of errors; i.e., the larger this percentage, the fewer the errors.[4]

TABLE VI. ERRORS IN RECOGNITION

SHOWING THE MEAN AND MEDIAN ERRORS MADE, WITH THE RELATIVE EFFICIENCY AT EACH HOUR

	A.M.				P.M.				
Hour.....	8:30	9:30	10:30	11:30	1:30	2:30	3:30	4:30	5:30
Av. No. errors.....	2.31	2.04	1.78	1.93	2.16	2.40	1.90	3.06	2.50
Mean variation	1.13	1.40	1.22	1.76	1.45	1.48	1.27	1.82	1.95
Relative efficiency	100.0	112.0	130.0	120.0	107.0	96.3	121.5	75.5	92.5
Median	2.00	2.00	1.50	1.50	1.80	2.15	1.32	2.30	2.00
Relative Median	100.0	100.0	133.0	133.0	111.0	93.0	151.5	87.0	100.0

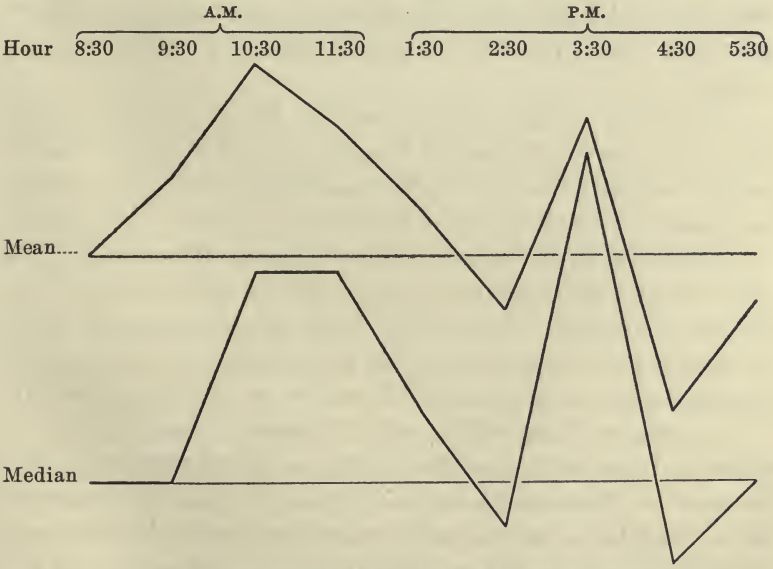

Fig. 6.—The diurnal course of efficiency with regard to decrease of erroneous recognitions

[4] The figures showing the relative efficiency are obtained by dividing the score for eight o'clock by the score for any particular hour.

The number of errors made seems to decrease during the forenoon, the fewest being made at 10:30 A.M., with 11:30 A.M. next in order. During the afternoon the smallest number of errors are made at 3:30 P.M., with a great many in the 2:30 P.M. hour. Although the results are very irregular and the mean variations exceedingly high, there is a slight indication that the hours at which the smallest number of errors were made were the hours of greatest efficiency otherwise.

VI. Tests in Logical Memory[5]

Tests in logical memory, or memory for ideas, have long been used to determine individual differences in mnemonic efficiency, as related to age, sex, training, etc. This test differs from the preceding tests of memory in two respects; first, material which forms a significant whole is used instead of a series of disconnected impressions; and second, the reproduction of ideas rather than the exact reproduction of sensory forms is required. Therefore, this is called a test of *logical* memory, in contrast to *rote* memory.

One of the familiar texts devised by Healy was used, beginning "If a man finds that his house is on fire, he should look to see if it is a large fire, etc."[6] The material is divided into twenty parts, each of which is counted one detail, or "idea." The method of conducting the test was carefully explained. The material was read slowly, and ample time was allowed in which to write the details remembered. One unit of credit was given for the recall of each "idea"; thus an accurate reproduction of all the ideas would give a score of twenty. The results are given in Table VII.

The results of this test for logical memory are quite irregular; mean and median do not harmonize as closely as usual. The increase in efficiency during the forenoon which has generally been found to be the rule, does not appear clearly in this func-

[5] This test was conducted by Miss Ida A. Felt, a graduate student in psychology, who used the data for other purposes.

[6] See Healy, W., and Fernald, G. M., Tests for Practical Mental Classifications, *Psych. Monog.* (1911), no. 54.

TABLE VII. LOGICAL MEMORY

THE ABSOLUTE MEAN AND MEDIAN OF THE NUMBER OF IDEAS REPRODUCED

	A.M.				P.M.				
Hour.....	8:40	9:40	10:40	11:40	1:40	2:40	3:40	4:40	5:40
No. of subjects....	22	23	27	28	22	22	25	28	26
Av. No. "ideas"....	13.20	14.40	14.20	13.60	12.60	13.10	13.40	13.50	12.05
Mean variation	2.2	1.4	2.4	2.6	2.4	1.9	2.1	1.8	1.5
Mean, per cent....	100.0	109.0	107.7	103.0	95.5	99.3	101.4	102.2	91.3
Median	13.5	14.5	14.0	14.2	13.5	13.5	14.0	13.5	12.6
Median, per cent....	100.0	107.3	103.7	105.1	100.0	100.0	103.7	100.0	93.3

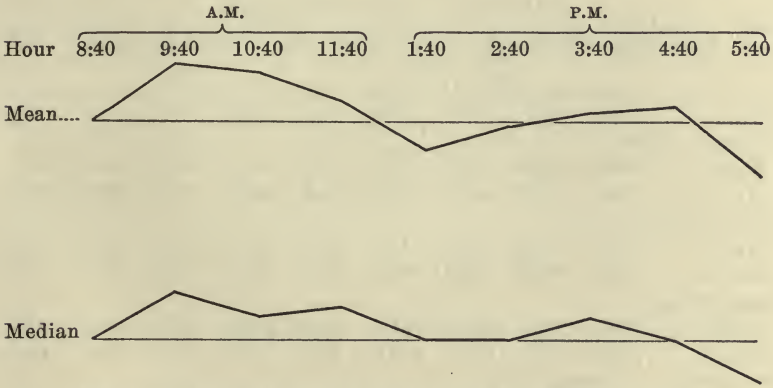

Fig. 7.—The diurnal course of efficiency for logical memory

tion. The maximum of the day appears early, at 9:40 A.M. The mean indicates a superiority of 10:40 over 11:40 A.M., but the median shows the latter hour to be superior. It will be noted that the mean variations for these hours are very large. More uniform and more characteristic results appear in the afternoon curves. The mean shows an increase from a very low efficiency at 1:40 P.M. to an afternoon maximum at 4:40. The latter hour is, however, but very slightly superior to 3:40 P.M. The median indicates a maximum for the afternoon at 3:40 o'clock. The final decrease in efficiency at 5:40 is clear in both cases. The curves

for the afternoon hours, then, conform fairly closely to the curves found in the case of most other functions previously considered, but with regard to the forenoon hours the results are not harmonious.

VII. Summary of Results

The accompanying table and figures show the curves for the various functions that have been considered, grouped for purposes of comparison. The mean and median of each function are given as percentages, and a final average for the mean and median figures of all functions is given.

TABLE IX. ALL FUNCTIONS

The Mean and Median, per cent, for the Various Functions

	A.M.				P.M.				
Hour*.....	8:00	9:00	10:00	11:00	1:00	2:00	3:00	4:00	5:00
Auditory memory.									
Mean	100.0	97.5	98.8	103.3	97.4	94.5	98.2	95.5	93.8
Median	100.0	103.0	103.0	107.0	105.8	103.9	105.8	101.4	101.0
Visual memory.									
Mean	100.0	99.3	101.5	101.5	98.0	100.1	101.7	102.0	100.0
Median	100.0	100.0	103.0	101.5	96.7	100.0	104.0	101.5	100.0
Substitution.									
Mean	100.0	102.7	105.2	104.3	96.0	102.6	101.5	101.2	94.3
Median	100.0	101.2	104.0	103.4	95.5	97.2	97.7	97.7	95.3
Recognition. (Penalized score)									
Mean	100.0	115.7	122.2	115.7	106.5	111.0	120.0	120.0	118.5
Median	100.0	108.0	117.0	112.0	96.4	99.0	117.0	121.0	117.0
Logical memory.									
Mean	100.0	109.0	107.7	103.0	95.5	99.3	101.4	102.2	91.3
Median	100.0	107.3	103.7	105.1	100.0	100.0	103.7	100.0	93.3
Average†	100.0	104.3	106.6	105.6	98.7	100.6	105.1	104.2	100.4

* The hours at which the series of tests were begun is given here. The actual time at which each test was given can be obtained from Tables I to VIII above.

† Average of means and medians of all functions.

The existence of many irregularities and fluctuations in the various curves is at once evident. Yet when one overlooks these minor differences, it can be seen with equal clearness that there

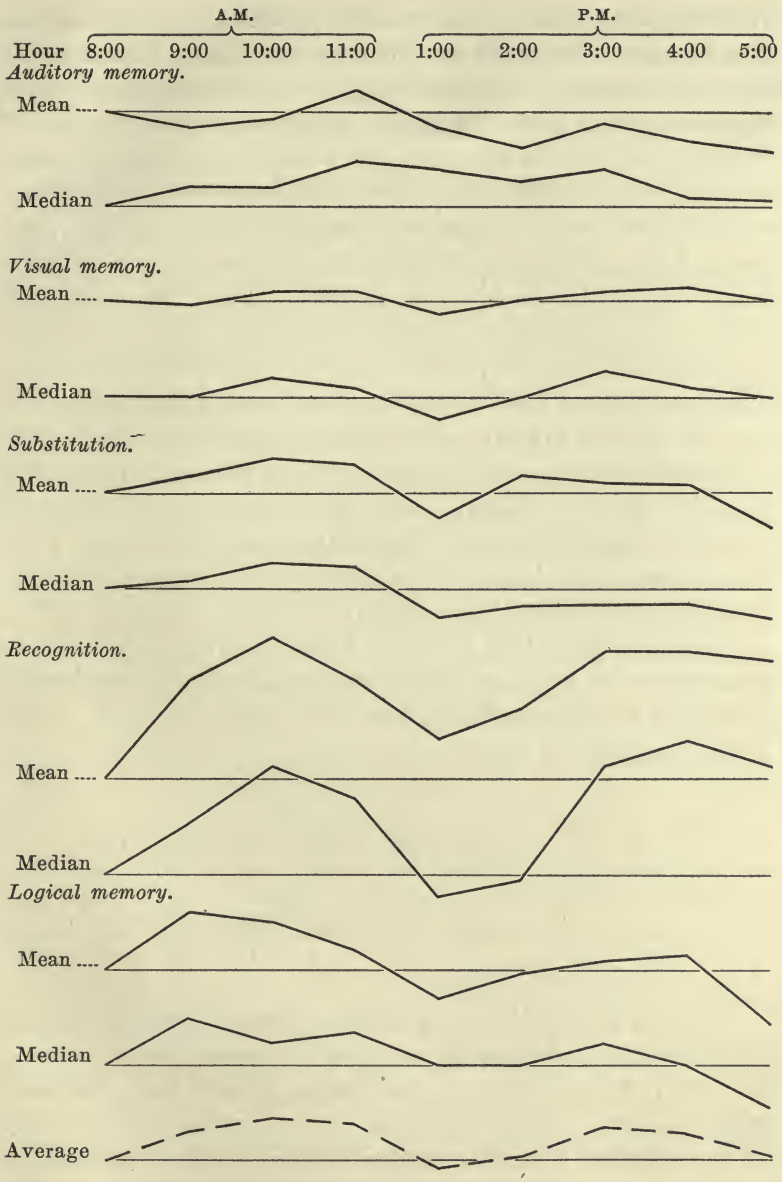

Fig. 8.—All functions. Curves based on Table IX, showing the course of efficiency for all functions

is throughout a great similarity in the general form of the curves. The average curve shows the characteristic trend of all those of which it is made up. Beginning at 8 A.M. the curve moves steadily upward until it reaches a maximum between 10 and 11 o'clock. In the average curve, 10 o'clock surpasses 11 o'clock slightly; a fact which is shown by some of the individual curves, while others show the opposite. Compared to the later afternoon hours, 1 P.M., in the average figure, is very low; in fact, it is the time of minimum efficiency of the day. All of the individual curves agree in showing 1 o'clock to be a poor hour. From the 1 o'clock minimum, the average curve moves upward to an afternoon maximum at 3 o'clock and then tends downward again until the last hour of the day, which shows an efficiency about equal of that of the first morning hour. There are many departures from the central tendency; some curves, for example, show an afternoon maximum at 3 o'clock, others at 4, and in some cases 2 P.M. stands very high; but all show more or less definitely the characteristic wave of efficiency.

In an earlier section (p. 325), a table was made showing the distribution of the individuals taking part in the experiment according to their preferred hours for study. A part of the table is reproduced here.

	A.M.					
Hour	6:00	7:00	8:00	9:00	10:00	11:00
Inds.	36	42	109	137	87	38
	P.M.					
Hour	1:00	2:00	3:00	4:00	5:00	6:00
Inds.	5	2	2	11	12	5

In the light of the results we have just obtained, it appears that the subjects' estimates of their best hours are very often incorrect. Too few chose the best hours, 10 or 11 A.M.; too many chose too early an hour; and very few appreciate the efficiency of the afternoon hours, noticeably 3 o'clock. The conclusion is that one's subjective feelings with regard to the time of greatest efficiency are not reliable indications of real efficiency. The

organism may be able to produce the greatest amount and the best quality of work at a time when feelings of fatigue and kindred factors lead us to believe that our efficiency is low.

VIII. Comparison with Results Obtained by Other Investigators

The literature of the subject of diurnal variations in efficiency can be found in summarized form in two monographs.[7] But briefest mention can be made here of a few of the more extensive pieces of work.

Marsh, in tests of arithmetical ability, memory, attention, and perception, found that, as a rule, the mid-day periods (12:00–2:00 P.M.) were superior to the afternoon periods (4:00–7:00 P.M.), which were superior to the morning periods (7:00–9:00 A.M.). Winch[8] found memory better in the late forenoon (9:45–10:05 A.M.) than in the afternoon (4:00–4:20 P.M.); and better in the afternoon than in the early morning. Robinson,[9] in arithmetical work, found a rise in efficiency during the forenoon, culminating at 10:30 A.M., with a noticeable drop at 12:30 P.M., and a subsequent rise until 2:00 P.M. Hollingworth,[10] in tests for various functions, found a low efficiency at the beginning of work, then a gradual increase followed by a period of low efficiency. Hollingworth's results and his interpretation of them are not in accord with the present findings. The present writer, in his earlier study,[11] obtained results from tests on school children which agree in most respects with the present findings.

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[7] Marsh, H. D., The Diurnal Course of Efficiency, *Colum. Univ. Contr. Philos.*, vol. 14 (1906), no. 3. Gates, A. I., Variation in Efficiency during the Day, etc., *Univ. Calif. Publ. Psychol.*, vol. 2 (1916), no. 1.

[8] Winch, W. H., Mental Fatigue in Day-School Children as Measured by Immediate Memory, *Journ. Ed. Psych.*, vol. 3 (1912), pp. 18–29, 75–82; Mental Adaptation during the School Day, *Journ. Ed. Psych.*, vol. 4 (1913), pp. 17–28, 71–84.

[9] Robinson, L. A., Mental Fatigue and School Efficiency, *Publ. Winthrop Norm. and Indus. Coll. S. C.*, vol. 5 (1912), no. 5.

[10] Hollingsworth, H. L., Variations in Efficiency during the Working Day, *Psych. Rev.*, vol. 21 (1914), pp. 473–492.

[11] *Loc. cit.*

The curve of efficiency found by Robinson, characterized by an increase during the forenoon, a fall following the lunch hour and a subsequent increase in the afternoon, is borne out by the present findings, as are also the results of Marsh, showing the superiority of the mid-day period over afternoon and morning periods, and Winch's results, showing a relatively great efficiency in the late forenoon. The present piece of work has produced no evidence in support of Hollingworth's results.[12] However, when heed is given to numerous factors, such as climate, habits of life, the character of tests employed, the methods of testing, and so on, which may differ with the different investigations, it is not surprising that they should lack entire harmony. On the contrary, the degree of uniformity which does exist is surprising.

IX. Conclusions

The facts that have been brought forth by this study indicate the existence of a diurnal course of efficiency in an important type of mental activity. From the early morning the efficiency of the organism begins to increase, culminating in a maximum in the late forenoon, followed by a decline immediately after the noon meal, with a subsequent rise until the middle of the afternoon, or a little later, and a final drop in the late afternoon.

Such is the broad rhythm found with fair regularity for groups of individuals. But it must be admitted that within this general trend exist numerous variations among the individuals. Differences in daily habits of life, in the physical and mental make-up, and in external conditions account, in a large measure, for such variations. Each individual, to profit most thoroughly from the knowledge of the nature of his daily rhythm of efficiency, should determine it by experimental methods for himself.

The demonstration of such a diurnal rhythm carries with it the suggestion that psychological and physiological investigators

[12] Hollingworth's results have been discussed in the writer's earlier paper.

should take into consideration more carefully than heretofore the fact of periodicity in individuals. The results of experiments conducted at different hours of the day are in danger of being disturbed by large errors due to diurnal fluctuations. One who reads the literature of years of investigation for the purpose of measuring mental fatigue can readily see the possibility that diurnal variations in efficiency have probably been a prominent cause of conflict in the findings.

Yet the application of the fact of diurnal rhythms to the problem of fatigue is difficult. This is due to the fact that the curve of efficiency, as we have found it, is influenced by the effects of fatigue, incitement, adaptation, and other factors. The subjects working at 10 A.M. in our experiments were doubtless laboring under greater fatigue than those who worked at 8 A.M., yet in spite of greater fatigue their efficiency was higher. If they had been equally fresh, their efficiency might have been considerably higher still. Just what part fatigue, feelings of fatigue, lack of interest, adaptation and such factors play, it is impossible to say.

The fact is significant that the hours of greatest efficiency are those at which fatigue, it would seem, should be very great. We have found in the present study, moreover, that most persons, basing their judgments largely on their subjective feelings, did not select as their best hours for study those which actually stood highest in efficiency according to the tests. Thorndike,[13] in summarizing the investigations bearing on this point, concludes: "The feelings of fatigue, from what we know of them, thus seem to be a very poor symptom of the loss of ability." An opportunity is afforded us to profit by such information. The feelings of weariness which become more insistent as we indulge them might be made more and more to disappear, provided the organism is in healthy condition, if we work on in spite of them. A man must be trained to meet situations where he must put forth more than the customary amount of effort. He should, by practice in the voluntary disregard of mere feelings of fatigue, learn the limits

[13] Thorndike, E. L., *Educational Psychology*, vol. 3, part 1, p. 107.

of his ability and by so doing attain greater assurance, and, by virtue of this, greater efficiency.

The drop in efficiency following the mid-day meal has been the most consistent aspect of the curve that has been found. No exception to this rule occurs in the case of any function, and the average results show that the minimum efficiency of the day occurs at this hour. Since the returns for labor at this time are relatively so small, it would seem that an hour or two, following the noon meal, could be wisely spent for rest or recreation. *Plenus venter non studet libenter* is a maxim to which the student should give more heed. Such was Offner's firm conviction when he wrote:[14] "It is, accordingly, one of the most justifiable demands of school hygiene that the afternoon session . . . should begin, at the very least, two hours after the noon meal, i.e., at 3 o'clock and not at 2 o'clock." Such an implication is not altogether clear, however, because the exact causes of diminished efficiency at this time cannot be accurately determined. The physiological effects of the mid-day meal are, perhaps, not the only influences at work. It may well be that relaxation or mere cessation of work causes the state of adaptation, attained during the forenoon exercise, to subside; and high efficiency can again be attained only by means of another process of "warming up." If such is the case, the exact time at which work is renewed would not be so important a consideration. It was found, moreover, in the earlier investigation,[15] that efficiency in functions of the motor type was quite high soon after lunch. Such school subjects as drawing, painting, modeling, writing, manual arts and the like might be profitably pursued during the early afternoon hours.

[14] Offner, M., *Mental Fatigue,* translated by Whipple (1911), pp. 88–89.
[15] Variations in Efficiency, etc., *Univ. Calif. Publ. Psychol.,* vol. 2 (1916).

Transmitted October 28, 1915.