

II

The Relative Amounts of Fatigue In-  
volved in Memorizing by Slow  
and by Rapid Repetition

BY

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### *Editor's Note*

This paper contains the substance of a thesis which was presented by Josephine Nash Curtis in the June of 1912 to the Academic Council of Wellesley College in partial fulfilment of the requirements for the degree of master of arts. The outcome of the experiments was such as to justify the publication of the thesis only in a greatly abridged form. The work of cutting the text and of making shorter tables has been done by the editor with material assistance from Miss Goss. The editor has rewritten the conclusions *ex radice*.

## II.

# THE RELATIVE AMOUNTS OF FATIGUE INVOLVED IN MEMORIZING BY SLOW AND BY RAPID REPETITION

### INTRODUCTION

In looking over the literature of experimental work in psychology, one can hardly help noticing with surprise how few of the many and detailed memory investigations have aimed primarily to discover the effect of the rate of repetition of the material to be memorized upon the difficulty of memorizing, whether this difficulty be measured by the number of repetitions or by fatigue. The general purport of such work as has been done is to show that a rapid rate increases the number of repetitions necessary for complete mastery, but decreases the total learning time; in other words, that, whereas each slow repetition accomplishes absolutely more, if considered with reference to the amount learned per repetition, each fast repetition accomplishes relatively more if viewed with reference to the amount learned per unit of time.<sup>1</sup>

The object of this paper is to present a comparison of the fatigue effects of memorizing normal series of nonsense syllables by slow and by rapid repetition. The question in regard to fatigue is two-fold: (1) Is fatigue more apparent when the subject memorizes by rapid repetition than when he memorizes by slow repetition? (2) If so, is the fatigue of memorizing at a rapid repetition rate so great as to cancel the time-saving effect of rapid repetition within the limits of a laboratory appointment lasting three quarters of an hour? A question of minor importance concerns the limit at which decreasing the rate of presentation decreases the number of repetitions necessary for

<sup>1</sup> See Ogden, *Untersuchungen über den Einfluss der Geschwindigkeit des lauten Lesens auf das Erlernen und Behalten von sinnlosen und sinnvollen Stoffen*, Arch. f. d. ges. Psychol. 2 (1903), pp. 163 f.; Ephrussi, *Experimentelle Beiträge zur Lehre vom Gedächtnis*, Zeitschrift f. Psych. und Physiol. der Sinnesorgane, 37 (1905), pp. 183 f.; and Ebbinghaus, *Grundzüge der Psychologie*, zweite Aufgabe, pp. 671 f. Cf. also Jacobs, *Ueber das Lernen mit äusserer Localization*, Zeitschrift f. Psych. und Physiol. der Sinnesorgane, 45 (1907), pp. 66 f.

memorizing and the limit at which increasing the rate of presentation diminishes the learning time. Ephrussi raised this question but gave a merely speculative answer.

To answer the first of the two questions primarily at issue, *viz.*, the question as to whether or not fatigue is more apparent when the subject memorizes by rapid repetition, one must solve the difficult problem of finding a simple yet efficient measure of fatigue. So many factors enter into fatigue that it is practically impossible to isolate one and test it, and it seems still more useless to attempt to find one test that measures all the factors at once. Then, too, individuals apparently differ to a great extent, both in the amount of work it takes to fatigue them and in the way in which fatigue affects them. The experimental study in fatigue is further seriously complicated by the methods employed by different experimenters in using the same test. This, indeed, sometimes makes it impossible to compare the results of different investigators. Tests of mental fatigue may be grouped in two ways: in the first place, as physical or mental; in the second place, as extrinsic or intrinsic. In the intrinsic test, fatigue is measured by the speed and accuracy with which the subject performs the same work that has fatigued him; in the extrinsic test, the fatigue is measured by his comparative efficiency in another kind of work. The extrinsic tests actually employed in this investigation were selected rather for their simplicity and variety than because of any unanimity in the conclusions of those experimenters who have used them. Of these the only physical test was with the dynamometer. The mental tests were: reaction time, and speed and accuracy in doing arithmetic.<sup>2</sup>

### *Subjects, Materials and Methods*

The subjects used in these experiments were seven in number,—Miss Gamble, "G."; Miss Agnes Rockwell, "R."; Miss Florence Banks, "B."; Miss Cecilia Hollingsworth, "H."; Miss Evelyn Keller, "K."; Miss Marjorie Sawyer, "S."; and Miss Nathalie Williams, "W." All began work in October, 1911,

<sup>2</sup>For a brief bibliography, including titles of experimental studies of fatigue, see pp. 189-190 below.

except S., who was put in after the Christmas vacation to take the place of a subject whose results proved so erratic as to be absolutely useless for our purpose.

The only subject who had had much experience in such work was G., who was the principal subject of the earlier memorizing experiments in this laboratory.<sup>3</sup> In our work she served as subject two periods each week. It should be noted that in this paper the length of a period, unless otherwise stated, is to be understood as forty-five minutes. In Groups I and II of the following experiments, G.'s periods fell on different days; in Group III they were consecutive. Subjects H., K., and S. were all Wellesley College seniors taking a second course in experimental psychology; W., a junior taking the same course; and B., a senior who had had only one course in experimental psychology. All these subjects served one period a week for the year, except S., whose late beginning has already been mentioned. R., who acted as subject one period a week in Groups I and II and two periods a week (on different days) in Group III, was a senior taking the same second-year course.

In these experiments we used series of twelve nonsense syllables made in imitation of the normal series of nonsense syllables devised by Müller and his collaborators. These series are discussed briefly on page 110 of the preceding paper.

All the series were aurally presented and were learned by the method of complete memorizing. The rate at which a series was presented and recited was regulated by a metronome. The experimenter said "Now" on one beat of the metronome, waited a beat, and then began to present the series. In some experiments, the syllables were given on every beat, in others on every other beat, and in still others on every third beat. When the experimenter had finished reading the series, she waited a beat and on the next beat said "Now." The subject was then expected to repeat the series from the beginning, starting on the next beat but one, after the experimenter's "Now," and saying the syllables at the same rate at which they had been presented. If the subject failed to give a syllable on the proper beat of the metronome,

<sup>3</sup> See pp. 82 f., 119 and 122 f.

the experimenter gave that syllable on the next beat and then presented the remaining part of the series at the prescribed rate. If the subject gave a wrong syllable on any beat, the experimenter interrupted her on the next beat with the correct syllable, accenting it strongly to impress the subject with the fact that she had given a wrong syllable. The experimenter then finished the series, waited a beat, and said "Now" as in the first presentation. Once more the subject tried to recite the series from the beginning and was, if necessary, prompted or corrected by the experimenter as before. This procedure continued until the subject succeeded in repeating the whole series correctly and on the proper beats of the metronome. The experimenter who read the series to the subject also kept the record of her attempts at reproduction by making columns of characters beside the series, each column corresponding to an attempt of the subject.

Thus, by counting the columns of signs, we knew the number of repetitions necessary for complete mastery, and the characters enabled us to tell at what point in each repetition the subject broke off, and the nature of the failure. An assistant experimenter kept the time, starting the stop-watch at the reader's "Now" and stopping it on the subject's completing a perfect recitation (that is, a recitation correct and given at the proper rate) of the series. This second experimenter also kept the records of the fatigue tests.

Inasmuch as the point at issue was simply to discover which rate of repetition was more fatiguing, it was necessary to eliminate in the two sets of experiments (with slow and with rapid repetition) all differences other than rate which might possibly occasion differences in fatigue. The length of time required for learning a series is possibly an important factor. If, for example, it takes twice as long to learn a slow series as to learn a fast, and if the subject shows more signs of fatigue at the end of the slow, it would be impossible to say how much of the fatigue is due solely to the rate and how much to the fact that the subject's attention has been kept on a stretch for a longer time. It would also be impossible to say whether the results in the case of the "slow" series are influenced through genuine fatigue or merely through ennui. In order to eliminate as far



as possible these difficulties, we endeavored to find two rates of repetition, one fast and one slow, which required approximately the same learning time. This proved not to be difficult, for we found from a few skirmishing experiments with all the subjects that as we increased the rate of repetition from very slow to very fast, the total learning time grew shorter and then again longer. It is evident, of course, that if one finds that a series given slowly takes no longer than a series given rapidly, it must be because the fast series is repeated too fast to save time. The question regarding the point at which increasing rate of repetition ceases to economize time is, it will be remembered, one of the secondary considerations of this study.

Our experiments fall naturally into three groups. In Group I, the preliminary experiments, the purpose was to discover at what two rates the subjects had about the same total learning time. In these we first gave the subjects series, as already described, at the rates 60/100, 60/75, 60/60, 60/30, 60/20 and 60/15. This method of differentiating between rates shows the relationship between the seconds occupied in giving a certain number of syllables and the number of syllables given, the numerator showing the former and the denominator the latter. For example, the rate 60/100 means that at this rate one hundred syllables would be presented in sixty seconds or, in other words, that the twelve syllables were actually presented at the rate of one syllable to every 6/10 of a second. We soon abandoned the 60/100 and 60/15 rates, as we found that the rate 60/100 was obviously too fast to economize time and that the rate 60/15 was obviously too slow to economize the number of repetitions. The sets of rates finally chosen for the different subjects were as follows:

- G. 60/60 — 60/20
- R. 60/75 — 60/20
- B. 60/60 — 60/20
- H. 60/60 — 60/30
- K. 60/75 — 60/30
- S. 60/75 — 60/30
- W. 60/75 — 60/30

As will be seen later, the success of this plan was somewhat impaired by the fact that some of the subjects seemed to be affected at one rate by practice much more than at others.

When the rates to be used were finally determined, Groups II and III of the experiments were performed. In Group II, a number of fatigue tests were made at the beginning of the period, and were interpolated after the memorizing of every two series.<sup>4</sup> The experiments of Group III differed from those of Group II in the facts (1) that only one extrinsic test of fatigue was used, and (2) that a greater number of series were learned at each sitting, and that the subject's gradual loss of efficiency in memorizing was regarded as the chief index of fatigue. In these two groups, all the series presented in one day were given at the same rate. The rate to be used each day was determined according to a compensating program in order to prevent, as far as possible, series given at either rate from having the advantages of practice more than series given at the other rate.

We have outlined our procedure in performing the memory experiments and have differentiated between the three groups into which the experiments fell. We come now to the consideration of the fatigue tests. The results of all previous attempts to measure fatigue have proved so very contradictory that we decided, as already noted, to choose as many and varied extrinsic tests as seemed practicable in consideration of the time and apparatus at our disposal. The tests employed, for a longer or shorter period, were: (1) tests of muscular strength made with two different dynamometers; (2) tactile-reaction time; (3) auditory-reaction time; (4) free-association time; (5) a test of appreciation for rhythm made with a telegraph key, an electric

<sup>4</sup>At the very first, we introduced the tests after every series learned. However, we soon abandoned this procedure as we found that the tests often occupied more time than the learning of the single series, so that the fatigue at the end of a period might be due more to the tests themselves than to the memorizing. Of course, the tests in question, when made at the beginning of the period were not, properly speaking, fatigue tests at all but merely tests of normal efficiency.

pen and a kymograph; (6) a test of the delicate muscular co-ordination involved in needle-threading; (7) tests of speed and accuracy in arithmetical calculation. Tests 5 and 6 were speedily abandoned on account of glaring inconsistencies in the results. The arithmetic tests are the only extraneous tests which proved at all satisfactory. The procedure in the various tests was as follows:

*The dynamometer.*—In this test we used at first a piece of apparatus, consisting primarily of a suspended spring balance, described by Titchener in his "Experimental Psychology, Student's Manual, Qualitative," 1899, page 100, and manufactured by Stoelting and Co. This dynamometer proved useless, for even after limiting the performance so as to require the subject to keep the handle between the second and third joints of her fingers and to keep her feet off the floor (to prevent additional leverage from bracing), we found it impossible to be sure that the subject was using the same set of muscles all the time. The second dynamometer used was one of the elliptical-grip order, manufactured by Thomas A. Upham of Boston. With this instrument the subject was required to use only her right hand and to squeeze as hard as possible, and she was not allowed to stand in making the test.

*Tactile-reaction time.*—In this test we used Sanford's vernier chronoscope as manufactured by Stoelting.

*Sound-reaction time.*—Again we used the vernier chronoscope making the auditory signal by rapping sharply on the releasing key with a piece of wood. We made no specification in either of these experiments as to whether the reaction was to be sensorial or muscular.

*Free-association time.*—This we measured by a Hipp chronoscope connected in circuit with a fall-screen and a lip-key in such a way that when the screen fell, exposing the stimulus word on an upright tablet behind the screen, the circuit was broken and the chronoscope started. As soon as the subject dropped the lip-key by giving the reaction word, the circuit was made and the chronoscope stopped. The subject G. had difficulty in reading the words at the distance at which it was neces-

sary to expose them and therefore had to have her stimulus words auditory instead of visual. In order to prevent the necessity of rearranging the apparatus for auditory stimuli the experimenter dropped the screen at the same time that she spoke the word. The stimulus words were all one-syllable nouns and only names of visible things were used. The reaction word of the subject was not recorded.

*Appreciation of rhythm.*—It was suggested at the beginning of these experiments that inasmuch as some authors<sup>5</sup> claim that the cause of many factory accidents is the loss of the appreciation of rhythm by the employees, it might be interesting to find whether mental fatigue would bring about any loss in appreciation of rhythm. To test this we required the subject to tap on a telegraph-key connected with a magnet pen which, as the key made and broke the electric circuit, traced a zigzag line on a kymograph. The subject was required to strike the key on certain metronome beats in a somewhat complicated rhythm which she was required to read into the beats of the instrument set at the rate 60/100. The results of the experiment, however, were absolutely negative, *i.e.*, no subject failed at any time to tap at exactly the right moments; and, therefore, no mention will be made of this test in the discussion of results.

*Speed and accuracy in arithmetical calculation.*—The first test was in addition of columns of the ten digits arranged by chance. The subject was required to add as far up a column as she could, in thirty seconds, with certainty of correctness. A record was kept of the number of digits added, the sum obtained, and the correctness of the answer. The second arithmetical test, used only in Group III and the only extraneous test in this period, was in the multiplication of the ten digits arranged by chance to form two five-place numbers. The subject was required to multiply the numbers as rapidly as possible with certainty of correctness, and a record was kept of the time taken and also of any mis-

<sup>5</sup>Bogardus, E. S. *The Relation of Fatigue to Industrial Accidents*, *Am. Jour. of Sociol.*, 17, pp. 220-222; Brandeis, L. D., *Women in Industry*, Decision of the United States Supreme Court in *Curt Muller vs. State of Oregon*, Reprinted for the National Consumers' League.

takes made. The multiplication test was not introduced in Group III after every two series, as were the tests in Group II, but only three or four times in a period.

Our experimental procedure has now been described. The methods used in the calculation of all the results of this investigation were as follows: Results of any one kind for different days of the experimental group were recorded in horizontal lines placed under each other so that the corresponding figures for any given task on all the different days could be readily added and averaged. For example, the numbers of repetitions required by G. for learning the first series given on each day were written in a vertical column; the figures for the second series were written in another vertical column; the figures for the first addition test were written in still another column, and so on. The tables and other numerical statements given in the next section are self-explanatory, except for the use of percentages. The extrinsic fatigue tests varied so much in units of measurement that it was necessary to find some common measure, if the figures for the different tests were to be properly compared. We finally decided upon the following procedure: The first performance of any given kind on each day, *e.g.*, the time taken for a tactile reaction before any memorizing had been done, was taken as the normal performance of its kind and was treated as unity. We next found the percentages of the first result that the figures obtained upon each of the succeeding trials represented. By this method we had all our results in the same terms (*i.e.*, percentages) and were able to compare the changes arising in the results of the various tests.

In most of the tests the results of all the subjects have been averaged together, as well as for each individual, and the results of all the subjects except G. and K. have also been massed apart from the results of these two subjects. The latter procedure seemed admissible in view of the fact that the results of B., H., R., and W. showed about the same trend. The results of G. and K. diverged decidedly and could not be included without obliterating all the significance of the averages.

### *Numerical Results*

In this section the results of the extraneous tests and the signs of fatigue displayed by the changes in the numbers of repetitions necessary for learning the series will be considered. The results of Group II and of Group III will be discussed together as far as possible, since these groups, as will be remembered, differed not in general method or aim, but merely in the extraneous tests used and in the number of series learned in a period. The tentative nature of the first group of experiments has already been stated; the results for each of the many rates employed were few and need no further discussion here.

#### *I. Extraneous Tests*

*Dynamometer tests.*—Tests made with the spring-balance dynamometer (Stoelting's) proved entirely unsatisfactory on account of the different sets of muscles brought into play by the same subjects in different trials. Tests made with an elliptical-grip dynamometer showed for the principal subject G. no consistent change in muscular strength during the process of memorizing. The tests were therefore abandoned at so early a date that the results for the other subjects are too few to be discussed seriously.

*Tests of reaction time.*—The figures for auditory and for free-association reaction time are extremely inconsistent for each individual subject and have therefore been entirely discarded. The results of the tests of tactile-reaction time are parallel to those of the test with the elliptical-grip dynamometer: the subject G. showed no consistent increase or decrease of reaction time when memorizing either with fast or with slow repetition. The results for the other subjects are too few to be presented in detail. It should be noted, also, in regard both to the dynamometer and to the tactile reaction time experiment that the results for G. (in so far as they show anything) and the results for the other subjects (as far as they go) are in direct contradiction to one another. These results, therefore, have also been set aside.

*Arithmetic tests.*—In the addition test the results had to be

calculated in a manner somewhat more complicated than that of the other tests, for we had to take into account not only the number of digits added in the given time but also the sum obtained. This was necessary because it is of course harder to add a number of large digits than the same number of small ones, and if the majority of the digits in a certain column happened to be large, the subject would not be able to add as many as if they had been small, but the sum obtained would be larger. The number of figures added and the sums obtained were added separately; the resulting sums for the different trials were then represented by percentage in the manner described on p. 165, the first percentage of each kind being treated as unity; the two sets of percentages were then averaged and the final average percentages are those taken into consideration. The results of G. diverge greatly from those of the other subjects. In memorizing by fast repetition she shows a steady decrease in the amount of work done, supplemented by a final spurt at the end. In the fourth addition test on each day (the test given after six series had been memorized) her efficiency is only 81% of her average efficiency at the beginning of a sitting. A terminal spurt is manifested in the rise of her efficiency to 88% in the fifth and last addition test. In memorizing with the slow series G. shows practically no change in ability to do addition. R.'s later efficiency percentages are always smaller than her normal and, on the whole, show more deterioration through memorizing by slow repetition. B. shows a steady decrease in amount of work done after the "slow" series and a very decided increase, falling off somewhat at the end, after the "fast." In the fourth of the addition tests, given in the course of memorizing by slow repetition, her efficiency percentage is only 69. In the third of the tests given in the course of memorizing by fast repetition, the percentage rises to 126 dropping to 106 on the fourth and last test. The averages obtained from the results of all the subjects, including G. and K., are worth little, showing merely that the subject's efficiency is never as great in the later trials as in the first, but exhibiting no difference between the results obtained in the course of memorizing with slow repetition and those ob-

tained in the course of memorizing with fast, and showing no progressive change in efficiency in either set of experiments. If, however, the results of G. and K. be excluded from the averages it would seem that ability to add always deteriorates in the case of the slow series while in the case of the fast series it at first increases slightly and then decreases slightly. In the case of these tests, unlike the last two sets or reaction-time experiments, it is admissible to average the results of R., B., H., and W., for all show the same general trend. With one exception (H.) more mistakes were made in the arithmetic when the subjects were memorizing at the slower rate.

The multiplication test was the only extraneous test used in the third group of experiments whereas the addition test was one of a number used in Group II. The use of the multiplication in place of the addition test has the following advantages: (1) Closer concentration is secured; (2) the setting of a relatively difficult example in multiplication demands less space than the setting of a sum in addition. On account of this second circumstance, the figures could be written larger and variations between subjects due to differences in ease in reading the numbers could be avoided. In the multiplication tests we improved upon our procedure in the addition tests by measuring the time required for performing the task set instead of measuring the amount of work done in a given time.<sup>6</sup>

The multiplication test gives, in general, results which differ at many points from those obtained from the addition test. G.'s results show decrease in speed of multiplying after memorizing with rapid repetition and an alternation, probably accidental, between decrease and increase in speed after memorizing with slow repetition. Thus, G.'s results in the multiplication test fall fairly well into line with her results in the addition test. This assertion, however, cannot be made for all the other subjects. For example, R., who in the addition test lost efficiency in the case of both the fast and slow series, here in the multiplication test loses in efficiency in the fast series but gains in the slow, and B.,

\*Thorndike, E. L., *An Introduction to the Theory of Mental and Social Measurements*, p. 14.



who in the addition test lost in the slow and gained in the fast, here, in the multiplication test, gains in both. In the multiplication tests the results of B., H., S., and W. are all fairly consistent with one another and show a gain in efficiency with both the fast and the slow series. K. is, as usual, at variance with the other subjects and shows marked deterioration in the case of both slow and fast series. Thus, the figures from the two kinds of arithmetical tests taken in combination show little or nothing in regard to the fatigue-effects of the two rates of memorizing. G.'s results alone are consistent and, as we shall see, G. is probably the only subject (except perhaps K.) who suffered real fatigue. In the case of the other subjects, the variations are undoubtedly accidental.

The proportions of the total number of examples, done by all the subjects in a period, which show mistakes are as follows:

<i>Slow</i>		<i>Fast</i>	
Example	I, 9%	Example	I, 24%
	II, 22%		II, 24%
	III, 11%		III, 33%
	IV, 8%		IV, 33%

That is, in general there were many more mistakes with the fast rate than with the slow. During the course of the experimental period with the slow series, the number of mistakes increases suddenly and then in the last trial decreases slightly; with the fast series, the number of mistakes made increases slightly. The discrepancies in the results of the extraneous tests are discouraging in view of the fact that the subject G., whose results are more numerous by far than those of any other subject, persistently differs from the other subjects in so far as the latter exhibit any common trend. It was exactly on account of the equivocal results furnished by the extraneous tests in Group II, that the only extraneous test used in Group III was the multiplication test just described. It is to be regretted, however, that the method of extraneous tests was not entirely abandoned, since, as will later appear, the best gauge of fatigue was the gradual deterioration of efficiency in memorizing, and since the interpolation of even one extraneous test gave the subject a change of occupation, arrested fatigue, and hampered us in the use of this intrinsic criterion.

## II. *The Intrinsic Test*

The intrinsic criterion of fatigue is the change in the number of repetitions necessary for memorizing. The more important results of the investigation are presented in Tables 1 and 2. Table 1 exhibits, for the subject G., the numbers of repetitions necessary to learn the series arranged according to their time-position on the different days. Table 2 covers the corresponding results for the other subjects. Each one of these tables contains results from both the second and the third groups of experiments. The abbreviations *s* and *f* as used in the headings of both tables stand respectively for the "slow" and "fast" rates of repetition compared. The numerals in parenthesis after the *s* and *f* stand for the numbers of series represented in the averages.

As recorded in the tables, the results of all the tests seem meagre. It must be remembered, however, that the results have been separated according to their position in the series of tests made on each day (*Zeitlage*) and that, therefore, although really a great many experiments were made, there are but few results of any one kind. The most striking example of this is the work of the subject G. in Group III. G. learned 192 series of nonsense syllables, but the number of series learned at each rate and time-position is only 4. The results of subject G. (found in Table 1), and of R. and B. (found in Table 2) are the most noteworthy because G. and R. had had practice in working with nonsense syllables and so had no difficulty in apprehending them, and because the results obtained from these three subjects are more numerous than the results of H., K., and W. In Group 2, the results of the subjects, taken individually, are inconclusive. G.'s efficiency clearly deteriorated in the course of the period but not uniformly and not at one rate more than at the other. If a few scattering results obtained from R. on days when she happened to learn more series than usual be discarded, it is evident that the subject's ability to learn decreases rather steadily during the course of the day's experiments, with slow repetition, whereas with fast there is at times a slight improvement and at others a deterioration. R.'s loss of efficiency, however, is never as great with the fast series as it is with the slow. B. shows no loss of

TABLE I  
Subject, G

[illegible]

efficiency during the period, but on the contrary an increase with both rates. This increase is greater with the slowly repeated series. The results of H., W., and K. are too meagre to receive more than passing comment. H. shows deterioration during the period with the slow series and, at first, improvement and then deterioration with the fast. W. shows improvement with the slow and deterioration with the fast. K.'s second trial shows, with the slow, an increase in the number of necessary repetitions; with the fast, a decrease. K.'s results for later trials show improvement to about the same degree for both rates. When the results of the subjects are averaged (whether with or without G. and K.) they seem to show that the subject's ability to memorize improves from the beginning of the period with the slow series, while, with the exception of a terminal spurt, it grows less with the fast series. No importance, however, may be attached to this seemingly definite result, for it is evident from Tables 1 and 2 that with such great individual differences an average is meaningless.

It will be remembered that in the experiments of Group II, a number of fatigue tests were interpolated after the memorizing of every second series. This fact justifies the suspicion that a or most of the subjects were spared real fatigue by the change of occupation. In the experiments of Group III, which have now to be considered, larger numbers of series were memorized without the interruption of a fatigue test. The multiplication test when it occurs, divided the series into groups.

In Group III, in considering the variations in the number of repetitions necessary for memorizing the series, the results will be treated first just as those from Group II were treated, and then afterwards, changes grosser than those from one single series to another, *i.e.*, changes from one set of series learned between two multiplication tests to another such set, will be discussed. The subject G., who was working a double period, learned twenty-four series a day. The number of series learned between the interpolated tests was six. This division into sets is plainly shown in Table 1 and the numbers of series in each set are averaged separately. In the case of the other subjects, the multipli-



cation tests divided the series memorized into halves or thirds. This division could not be shown in Table 2 but is indicated below in the text.

Treated by the first method, G.'s results are inconclusive. With two exceptions (series 7 in the slow set and series 9 in the fast), this subject on the average never learns any of the later series in the period in fewer repetitions than she needed for the first series. Her ability to memorize, however, does not deteriorate in any regular way. For the first fourteen series learned in a day greater deterioration is shown, in general, with the slowly repeated series, whereas for the last ten of a day's series greater deterioration is shown, in general, with the rapidly repeated series. The subject's explanation of the figures will be given in the paragraphs devoted to introspection.<sup>7</sup> R.'s results are apparently more positive. With one exception (series 6 in the fast set) her results show that the first series of a day is learned with fewer repetitions than are any of the succeeding series. The loss of ability to memorize, however, is always greater, for the slow series than for the fast. B.'s results show that her efficiency increases at first with both rates and decreases at the last with both rates. Much greater variations from the average number of repetitions required for learning the first series are shown in the slowly repeated series than in those repeated rapidly. H.'s results for both rates, except for a slight improvement in series 2 of the fast set, show deterioration during the course of a period's memorizing. This subject, however, shows practically no difference between the effects produced by the two rates, for both show a great loss of ability about the middle of the period and a final spurt at the end. H.'s slow series give results which are slightly more variable than those of her fast series. W.'s results show, with two slight exceptions, improvement during the course of a day's experiments. Her results for the slow series are much more variable than her results for the fast, and the improvement in ability to memorize is much more marked with the slow series. K.'s results, as first calculated, are inconclusive. The subject, however, changed her

<sup>7</sup> Cf. pp. 31-32.

method of memorizing during the course of the experiments, and, if the results obtained under this new method alone be considered, we find a very decided improvement during the period, except for the last series with the fast rate. The results for the slowly repeated series are much more variable than those for the series rapidly repeated. The results of S. show with both rates an increase, during the period, in the number of repetitions necessary, or, in other words, a decrease in ability. In general this change is more marked with the slow series but the difference is slight.

From the comparisons just made we gain very few conclusions. The most important is that with nearly all the subjects the results for the slow series reach values which differ more from the normal than the values for the fast series differ. The results for the different subjects may be contrasted as follows: G., B., and H. show no decided difference in the effects of the two rates, although B. improves with both rates and G. and H. deteriorate with both. R. and S. show greater deterioration with the slow rate though they also lose in efficiency with the fast. W. shows greater improvement with the slow rate though some improvement with both. K., like B., improves about equally with both rates except for a drop at the very end of the period when memorizing at the fast rate.

The results of Group III will now be treated by the second of the two methods mentioned above, the massing method. In order to compare the changes in efficiency caused by memorizing at the different rates, by larger steps than from series to series, the results of all the series which any subject learned between two successive multiplication tests have been averaged together and treated like the results of one series. This method of treatment gives the general trend of a period's work and avoids the confusion introduced by the more accidental variations in the individual series. It is unfortunate that the space available in Table 2 did not permit us to indicate the divisions for the subjects other than G. or to interpolate the group averages in the fashion in which the divisions and averages have been given for G. in Table 1. For the subject R. the size of

the group is five; for B., four; for H., four; for W., four; for K., three; and for S., four. The group averages in order are: for R., in the slow series, 3.8 and 4.3, and in the fast series, 11.1 and 10.7; for B., in the slow, 3.4, 3.5 and 3.8, and in the fast, 7.4, 6.9 and 7.5; for H., in the slow, 7.3 and 8.6, and in the fast, 12.6 and 13.6; for W., in the slow, 7.4 and 7.2, and in the fast, 13 and 13.3; for K., in the slow, 8.5 and 9.9, and in the fast, 18.3 and 19.4; for K. with her "new method," in the slow, 8, 6.8 and 10.5, and in the fast, 16.2, 17.7 and 15.7; for S., in the slow, 5.1, 6.6 and 5.9, and in the fast, 11.5, 12.8 and 12.5. When massed in this manner, G.'s results show deterioration with the slow rate, becoming less marked as the period advances, and with the fast, at first practically no change and then great deterioration. R. shows a decided loss of ability with the slow series, a slight gain with the fast. B. shows steady deterioration with the slow rate, and with the fast, at first an improvement and later, a condition nearly normal. H. shows deterioration with both rates, but this is more marked with the slow. W. shows a slight gain in ability with the slowly repeated series, a slight loss with those rapidly repeated. K.'s results (if those obtained with the new method only be considered) show at first improvement and then deterioration with the slow and exactly the opposite with the fast. S.'s ability at first decreases to practically the same degree with both rates, and then decreases much more with the slow.

From this comparison it is evident that, when considered by large steps, the results of four of the seven subjects (R., B., H., and S.) show greater deterioration in the case of the slow series. R. and B., indeed, show deterioration with the slow rate, whereas with the fast rate the ability to memorize actually improves. W.'s variations from the normal are probably too small to have any meaning at all. G.'s results present a very interesting point. It is evident that during the first part of the work for the day (which in the case of G. alone lasted two consecutive schedule periods in Group III, instead of one period) G. behaved like the majority of the other subjects. In other words, if G. had served as subject for only one period at a time her results would have



TABLE 3

[illegible]

agreed with the others. The following question then arises: Is the change in G.'s ability during her second laboratory period a characteristic of G. alone, or would this change appear with the other subjects if they memorized series for two consecutive periods? This question, unfortunately, cannot be answered. The reasons for the peculiarities of K.'s results will be considered in the discussion of individual differences.

It is evident that the showing of the series, when grouped, often differs somewhat from the showing of the series treated separately. One reason for this, doubtless, is that many subjects learn the second and third of a day's series more quickly than they learned the first. When the series are taken separately this change in ability stands out as an improvement. When the series are grouped this increase in speed simply raises the average of the first group of series, *i.e.*, of the normal, and so makes any deterioration in the later series more marked.

Table 3 will show at a glance the general trend of all these results. It will be convenient for the reader to turn frequently to this table in reading the following paragraphs, which deal, largely on the basis of introspection, with the individual differences between subjects. Two of the signs which are used explain themselves. *Plus* (+) indicates *improvement*, and *minus* (—) indicates *deterioration*. The question mark (?) stands for *no decisive change in efficiency*.

### *Introspective Results*

In this discussion, introspective statements of the subjects will first be summarized. An attempt will then be made to explain some of the individual variations in the numerical results in the light of this introspective testimony. The introspective statements of the subjects relate to the following points:—the subject's sensorial type of memorizing, method of grouping, use of auxiliary (mnemonic) associations, preference as to the rate at which the series were presented, and opinion as to which rate required greater concentration of attention and which was more fatiguing.

As to the image types to which the subjects belong:—B. and

S. claim imagery almost purely visual, although from the rest of B.'s introspection it seems probable that auditory-kinaesthetic imagery also was important.<sup>8</sup> W. appeared to use visual imagery except when the syllables "came mechanically," that is, when speech movements appeared to be preceded by no anticipatory imagery. G. visualized the syllables as patches of color on which occasional traces of written letters appeared in black. (G. has colored hearing in a marked degree). However, she also made constant use of auditory-kinaesthetic imagery which was more noticeable in the case of the rapidly repeated series than in the case of those slowly repeated and which served to distinguish between syllables of nearly the same color. This subject noted a tendency to grasp the last two or three syllables of a series merely in auditory-kinaesthetic terms and to recite them in virtue of a "kind of echo." H. "tried to visualize" the syllables which did not readily suggest auxiliary associations. The syllables which did suggest such associations she apparently learned in auditory-kinaesthetic terms, visualizing only the persons or objects which figured in the mnemonic devices. R. learned principally; and K. wholly, in terms of auditory-kinaesthetic imagery.

As regards grouping, all the subjects attempted, more or less, to grasp the syllables in sets shorter than the series. G., K., and S. always divided the syllables into groups of four. H. arranged the syllables in five groups, with four in the first group and two in each of the others. B. grouped the syllables, when she first began to serve as subject, but soon discarded this procedure. B., usually, but not always, grouped the syllables by fours, and W. grouped the first four together and, if the series happened to be particularly hard, also grouped the other syllables by twos. As regards spatial projection, all the subjects testified more or less to having visual schemes into which they fitted the syllables. G., except in Group III, visualized the syllables as arranged in a row from left to right; in Group III she purposely changed from a single horizontal line to three vertical columns each formed of four patches of color. This change was made in order to make the spatial position of the syllables more marked

<sup>8</sup> Cf. statement of preference for fast series on p. 180.

as compared with one another. The subject used this scheme as much in the fast series as in the slow, but had, in the case of the fast series, greater difficulty in fitting the syllables into the proper places. The subject said that, in the case of the fast series, putting the syllables into their proper places was like sorting dishes and setting them in their places upon the shelves of a china closet. H. thought of the syllables as arranged in a row from left to right. S. said she projected the syllables on the wall in three columns of four syllables each.

Auxiliary associations were used by all the subjects. These associations consisted in general of "stories" woven about the series and names of people connected with syllables having a somewhat similar sound. G. memorized to considerable extent without use of such associations but always fell back upon them in case of difficulty and was, therefore, more apt to use them in the case of fast series than in the case of slow. B. also used auxiliary associations more in the case of the rapidly repeated series. R. and H., on the contrary, used them more in case of the slowly repeated series.

With respect to preferences for one rate over the other, it should be noted that R., B., W., and K. preferred the fast series; G., S., and H., the slow. R. and H. were particularly strong in their preferences. The reasons given by R., B., W., and K. for the choice of the rapidly repeated series are as follows: R., "It takes no effort to associate the sounds. They run in together and don't need auxiliary associations." (R., it may be noted, often sighed, when learning slow series, and complained of the monotony.) B., "The fast series are easier to connect with a story." (The subject probably meant that the syllables in the fast series were more suggestive of a sentence.) W., "The words say themselves. With the slow rate I had more time to think, and as soon as I thought very hard, I was lost." K., "The slow series gave me time to forget." In the words of B., W., and K., there are indications of perseveration, kinaesthetic or auditory-kinaesthetic, in the case of the fast series. The reasons given by G., S., and H., for the choice of the slowly repeated series are as follows: G., "With the slow series I could fit the

syllables more easily into my scheme. Moreover, the syllables, which always appear in consciousness as spots of color, sometimes lag, and in the case of the fast series refuse to form in the mental field of vision before the metronome beat on which they are due. This experience is attended by very unpleasant organic sensations localized about the heart." G., however, confessed to having, not infrequently, the feeling of fright also, when learning the slow series. G. was ordinarily able to learn a slowly presented series in two repetitions and, realizing this fact, she felt considerable anxiety to keep the repetitions, at least on the average, at two. If, in any case, she exceeded two repetitions she tried desperately to learn the next series at the first hearing. S., "The slow series gave more time for recall and the experimenter pronounced the syllables more clearly at this rate." H., "I preferred the slow series because I had more time to work out my schemes for remembering." On the basis of these statements and of the other introspective data, it seems fairly clear that the subjects who prefer the fast series are, in general, those who are greatly assisted by kinaesthetic or by auditory-kinaesthetic perseveration, whereas those who prefer the slow series are, in general, those who rely chiefly upon visual imagery deliberately recalled.

It is evident that preference for one rate of memorizing over the other was not always coupled with better sustained efficiency in learning at the preferred rate. Although K. and W. both preferred rapid repetition, both showed greater deterioration when learning at this rate, and although H. and S. preferred slow repetition, these subjects showed a greater deterioration in learning the slow series. The deterioration of H. and S., in the slow series, may have been due to the fact that the difficulty of the task was not sufficient to keep their attention at high level. R., W. and K., who preferred the fast rate, expressly said that with the slow rate, their minds tended to wander. G., who preferred the slow series, showed in the first of her two periods greater deterioration with these series. G. explained her deterioration during the first period as follows: At the beginning of each sitting, when her mind seemed "like a freshly washed black-

board" on which every impression stood out distinctly, she could always learn a series with a relatively small number of repetitions (a *very* small number, usually two in the case of the slow series). However, when a number of series had been learned so that the mental blackboard seemed "clouded with erasures of every other series," the number of repetitions suffered an increase, which in the case of the slow series was large in relation to the very small number necessary at the beginning. (If the number of repetitions be two, an increase of one, the smallest increase possible, is an increase of fifty per cent.) Thus, two factors probably come into play in producing the appearance of greater deterioration during the first period in the case of the slow series: First, the arithmetical fact just stated, and second, the greater effort which the subject made to learn the slow series with a very small number of repetitions. This last circumstance may have brought about a genuine and considerable loss of efficiency.<sup>9</sup>

In regard to the feeling of fatigue, direct testimony is meagre. Only three times did any subject report feeling much fatigue at the end of the period. One day early in the year B. remarked that for the past two weeks she had been learning at the slow rate and that at that rate she had made a story, as she went along, to fit the syllables. When, however, on the day in question she had changed to the fast rate, she had become nervous, and at the end of the period felt weak and rather "seasick." The numbers of repetitions required for learning the successive series on that day were: 11, 6, 5, 6, 5, 5, 7, 5, 6, 8, 12, 7. G. reported marked fatigue on two days on which she learned twenty-four and twenty-eight series, respectively, at the fast rate. At the end of one of these periods this subject said that she felt weak and dizzy. The numbers of repetitions required for that day were: 5, 8, 4, 5, 5, 3, 4, 5, 4, 5, 4, 6, 6, 7, 4, 7, 5, 7, 8, 9, 4, 7, 3, 4. The day on which G. complained most of fatigue the following numbers of repetitions were needed: 3, 5, 8, 5, 6, 7, 4, 6, 3, 4, 9, 8, 6, 8, 7, 8, 6, 4, 5, 5, 8, 6, 4, 7, 4, 9, 8, 7. The subject began the work of this day in a condition of slight general fatigue. By the second set of six series her head began to swim and she felt more

<sup>9</sup> Cf. pp. 174 and 176 above.

and more weak and dizzy until the third set of six series when she felt faint and sick. In the fourth set she felt better than in the third, but toward the end began to feel numb and tremulous, and her heart began to beat irregularly. In the last set G. felt better, but was almost too exhausted to complete the arithmetic at the end. Symptoms of fatigue persisted two or three hours after the experimental sitting. In view of this experience of G., we may safely say that her deterioration in the second period when learning by rapid repetition was due to genuine fatigue. Although K. did not complain of being tired, yet she was in delicate health throughout the year and suffered from time to time with severe neuritis. It is also worth noting that W. had a nervous breakdown before the end of the year. K. and W., it will be remembered, both preferred the fast series and yet showed greater deterioration in these series, which obviously put a greater strain upon the attention. On the whole, the introspection of the subjects, taken together with the small amount of deterioration which their work at each sitting exhibited, seems to show that G. (in the second of her learning-periods) and possibly K. and W. were really tired but that they were the only subjects who were fatigued at all. Such loss of efficiency as occurred in the other cases, if due to fatigue, was not due to a fatigue marked by unpleasant subjective symptoms.

*Data in Regard to Practice, Momentum, and Initial and Terminal Spurt*

The main part of the discussion of the results of this investigation is now finished, but before summarizing the conclusions two other points of no small importance must be considered: (1) the influence of practice upon memorizing by the two rates of repetition, and (2) indications of initial spurt, of momentum, and of terminal spurt as they appear in the third group of experiments. It is impossible to trace these factors in Group II because at each sitting the memorizing was so broken up by the interpolation of fatigue tests.

*Practice.*—In the discussion of the method of making the experiments, the statement was made (page 161) that we tried to

use two rates of presenting the series which would take approximately the same total learning time. As the experiments continued it became evident that most of the subjects improved in memorizing at the fast rates more than they did at the slow rates. Inasmuch, as at the beginning of Group II, series presented at the different rates occupied practically the same total learning time, the differences in the times occupied in Group III show the extent of the influence of practice. In Group III, G. learned a slow series in about 129 seconds on the average, and a fast series in about 110 seconds. For the other subjects the corresponding figures are as follows: R., 187 and 149; B., 175 and 133; H., 237 and 224; K., 279 and 261; K., new method, 258 and 226; W., 230 and 186; S., 174 and 168. The difference in the total learning times necessary for the rapidly and slowly repeated series is very marked with all subjects except S. It must be remembered, however, that S. had served as subject at least ten weeks less than the other subjects had served, and therefore practice in her case naturally would be less marked. An important feature in the practice gained with the memorizing was improvement in apprehension, *i.e.*, in ability to grasp the syllables when presented to the ear. This improvement was particularly noticeable with the fast series. Therefore, the effect of practice was more marked with this rate. Thus, practice in some cases defeated the intention of the experimenters to equalize the actual expenditure of time in memorizing fast and slow series. The inequality of learning time for the two sets of series suggests an unfortunate possibility in regard to the figures which evince deterioration in efficiency. Some of the subjects showed greater loss in the slow series and some in the fast. It may be that the slow series tended to fatigue the subjects R., B., and W. in virtue of the long continuance of the strain upon the attention. This supposition is borne out by the fact that these subjects expressed a distaste for the slow series. On the other hand, the fast series may have tended to fatigue other subjects in virtue of the high degree of attention demanded and the emotional excitement involved in "catching" the syllables. The comparative degree of fatigue in the two kinds of attention-strain



may be a matter of individual differences and these individual differences may obscure the main issue in regard to the fatigue effects of memorizing by slow and by rapid repetition.

*Initial Spurt, Gathering Momentum, Decreasing Momentum and Terminal Spurt.*—Most experimenters seem to agree in spite of the varying methods used and the different conclusions drawn that mental activity shows a well-marked periodicity. There is no fixed normal type of daily rhythm, each person being apparently a law unto himself. Nevertheless, as to quantity, in any piece of steady work, most subjects exhibit the following stages: initial spurt, or else preliminary inertia with gathering momentum, decreasing momentum, and terminal spurt. If a pause or change of occupation is introduced in the course of the experiment, the work immediately after the interruption is often better and but very seldom worse than the work just before it. The quality and the quantity of work do not always vary in the same direction and degree. In general, in the period of decreasing momentum, the third of the four stages just mentioned, the changing relations between quality and quantity of work exhibit three chief moments: (1) quantity increases, quality decreases; (2) quantity also decreases; (3) with some subjects the quantity gets less and less, with others it increases under nervous excitement until exhaustion is reached. These phenomena can be traced only in the experiments of Group III and in this group only when the results are treated by the massing method.<sup>10</sup> In general, the slow series with all the subjects show the same trend in their variations—for the second of a set, a decided loss of ability; for the third, a decided improvement over the second (in the cases of H. and W. the results of the third series show higher ability than even the results of the first); for the fourth, loss of ability much less marked than that for the second series. G. and R. are the only subjects having a fifth or sixth series in a section. G.'s results show a yet further deterioration of efficiency for the fifth series, and an improvement for the sixth. R.'s results exhibit improvement for the fifth series. The results for the fast series show more individual variations than do those

<sup>10</sup> See pp. 172 and 175 above.

for the slow. All subjects except W. show loss of ability for the second series, and no subject shows marked recovery before the fourth series. With the fourth series the results of R., B., and S. show improvement over those of the second and third series, but the results of G., H., and W. show still greater deterioration. G. shows increase of ability with the fifth series and a slight decrease with the sixth. R.'s figures for her fifth series are indecisive.

These results therefore exhibit: (1) in the case of the slowly repeated series the stages of initial spurt, with most subjects, gathering momentum; and with G. and R., terminal spurt; (2) in the case of the rapidly repeated series with all except W., initial spurt; with G., R., B., and S., late in the group, gathering momentum, and with G. and R., decreasing momentum. It is, of course, possible that all the subjects would have shown all the stages if all the sections had contained enough series.

These results are important in showing the disadvantages of extraneous tests, for in the sets of series between the tests the subjects seem to pass through most of the stages of efficiency. These stages, particularly that of initial spurt, evident immediately after the extraneous tests, obscure the general trend of the fatigue effects which might appear in the course of the period.

### *Conclusions*

The first conclusion to be drawn from the investigation as a whole is that the extraneous tests proved distinctly unsatisfactory. The arithmetic tests appeared most reliable, the multiplication tests showing fewer individual variations than any of the others. This may be due to the fact that this was the only one which was used after the subjects had had considerable practice. It is possible that the other extraneous tests would have exhibited fewer individual variations if they, also, had been used in Group III. It is puzzling that there should be deterioration in muscular strength and loss of efficiency in adding with most of the subjects, when the numbers of repetitions necessary for memorizing showed so little variation. We must conclude either that the variations in the strength of the grip and the speed of arith-

metrical calculation were due to factors other than fatigue (a supposition which discredits their reliability as fatigue-tests), or that fatigue manifested itself in these extraneous tests before it was apparent even in the numbers of necessary repetitions.

A second conclusion is that the extraneous tests were not merely in themselves unsatisfactory but that they were also subversive of the main purpose of the investigation. Whatever advantages these tests may have in indicating fatigue is more than counterbalanced by the fact that they furnish change of occupation and retard the onset of the condition which they are supposed to test.

A third conclusion is that the subjects (G., H., and S.) who made much use of visual imagery in these experiments preferred the series learned by slow repetition, whereas the subjects (B., R., and W.) who appear to have been greatly aided by auditory-kinaesthetic perseveration preferred the series learned by fast repetition.

The fourth and main conclusion is negative, for as regards the chief issue our results are altogether indecisive. If we had not used the subjects G. and K., we should doubtless have supposed it perfectly clear that memorizing with slow repetition is more fatiguing than memorizing with rapid. The results of these two subjects, however, prevent the drawing of such a conclusion. There are three possibilities in the interpretation of the numerical results: (1) that none of the subjects were fatigued at all; (2) that all of the subjects were fatigued, but were affected in different ways; (3) that some only of the subjects were fatigued. From the consideration of our introspective results it is clear that the first of these possibilities was not realized, for B. and G. reported feeling greatly fatigued at the end of certain laboratory periods. The second of the possibilities—namely, that all the subjects were fatigued, but were affected in different ways—can scarcely be true, for the subject S. declared that neither rate fatigued her and that she would have enjoyed learning twelve more series each day. Furthermore, except in the cases already described in detail, the subjects practically never made remarks indicating that they were tired or even bored.

If, then, any reliance is to be placed upon the introspective testimony of the subjects, the conclusion must be drawn that only some of the subjects were fatigued. It is, therefore, evident that the second of the two main questions formulated on page 157 needs no discussion but must be answered with an emphatic negative. The fatigue of memorizing at a rapid repetition-rate is not so great as to cancel the time-saving effect of rapid repetition within the limits of a laboratory appointment lasting three quarters of an hour. Except for K. and for W. such fatigue as appears in a three-quarters-of-an-hour period is more evident in the case of the slowly repeated series than in the case of those rapidly repeated. Moreover, with W. and K. the fatigue (shown by the increase in the number of necessary repetitions) is far too small to counterbalance the gain in economy of time.

The final conclusion of the investigation is this: the problem is one which cannot be solved without much more experimental work. The results of those of our subjects who were certainly tired seem to show that rapid repetition is somewhat more fatiguing than slow, but before the statement can be substantiated it will be necessary to perform many experiments in which the periods of memorizing are long enough to tire the subjects. Such experimental conditions are hard to secure during the college year, for few of the available subjects are willing to be incapacitated for several hours from further academic work.

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