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The Measurement of Attention

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CHAPTER I

Introduction

The problem of the measurement of the degree of attention has for some time been recognized by writers of the highest authority as one of the central problems of experimental psychology. There is, consequently, no need to dwell upon its importance. What is believed to be a satisfactory solution of this problem is offered in the following pages.

While the writer is of the opinion that an accurate and practicable method for the measurement of the degree of attention has not hitherto been described, it is only fair to acknowledge that many methods have been proposed. The reader who desires a critical historical study of methods of measurement of attention may be referred to Geissler.[1] In summary, Geissler writes: "We have thus completed our review of the experimental work upon the problem of measuring the attention and may conclude, on the one hand, that, although much effort has been spent upon it, we are still far from a satisfactory solution. On the other hand, we are now better able to judge which paths would seem most promising for future experiments and which should be abandoned."

As regards Geissler's own contribution, the main conclusion at which he arrives is the following: "A very close parallelism was found to exist between introspectively distinguishable variations of attention and corresponding differences in the precision of work performed at these levels, under the condition that the estimation of degrees of attention was made in terms of clearness and that the work itself was not influenced by anything else but change in attention." That a parallelism exists between degree of attention and various kinds of work has long been taken for granted. Indeed, it is hard to imagine any psychophysical work in which attention is a factor, the efficiency of which would

[1] *Amer. Journ. of Psychol.*, 1909, 473-529.

not show variation when attention varied, and which would not accordingly show a parallelism with attention under the condition that "the work itself was not influenced by anything else but change in attention." But Geissler's work experimentally establishes the validity of this assumption.

Concerning the bearing of this correlation between estimated degrees of clearness and efficiency of work upon the measurement of attention, Geissler writes: " . . . we believe that our results have brought us within reach of a new and fairly definite method of measuring attention, for the results have shown that degrees of clearness are just as accessible to introspective determination as variations of the intensity of sensations. . . . There is sufficient warrant in our results for the assumption that continued practice will lead at least to a differential clearness limen which may be just as definite as any other psychophysical limen, while on the other hand, it may be perhaps more difficult to establish the least possible or the highest possible clearness degree for any given mental process. However, the determination of a difference limen for clearness would be the most important step toward an exact measurement of the concentration of attention. It would enable one, by starting with a certain clearness degree of a given mental process under fixed experimental conditions, either to increase or decrease that clearness by just noticeable differences, until the maximum or the minimum of attention to the particular process is reached."[2]

Concerning this differential limen, which Geissler says would be the most important step toward an exact measurement of the degree of attention, all that can be said in reply is that no such limen for clearness has as yet actually been measured, and that Dallenbach[3] in his recent article which is avowedly a continuation of Geissler's work, does not even refer to the matter.

It is perhaps possible that, apart from the matter of a differential clearness limen, use may ultimately be made in the measurement of attention of the high correlation which both Geissler and Dallenbach have found to exist between efficiency

[2] *Op. cit.*, 522-523.
[3] *Amer. Journ. of Psychol.*. 1913, 466-507.

and estimates of clearness. Neither of the authors mentioned, however, deny that efficiency may vary as the result of other factors than attention; nor do they explain any procedure for keeping other factors than attention constant, though their statement of parallelism between estimated clearness and efficiency is limited by the condition that no factor other than attention shall vary.

Both Geissler and Dallenbach have paid so much attention to the matter of devising suitable distractors, that their work has considerable bearing upon the method proposed by Titchener. Titchener writes as follows: "If we knew, for instance, that a certain sensation may exist in ten different degrees of clearness: and if we had at our disposal ten stimuli which, introduced by way of distraction, would reduce this sensation from the corresponding degree of clearness to total obscurity: then we might calculate, from the effect of a particular distractor in the particular case, what fraction of maximal attention the observer was giving to the matter in hand. The method is cumbrous and difficult to work out; but the writer believes that it may, some day, be successfully applied."[4] Such a method evidently requires above everything else a set of constant and reliable distractors. Indeed, while the theory of the distraction method of measuring attention has, in the rough, been known for many years, the rub has always been in finding suitable distractors—or, since as a matter of fact only one, and not a set, is necessary, a suitable single distractor. A method of distraction suitable to the measurement of attention has not hitherto been devised. Geissler found that even the most complex distractors, after a few days' work, were unable to induce great variations of attention,[5] and Dallenbach writes: "In choosing the distractors, our ideal was that of Drew, 'to arrange a series of tasks of increasing degrees of complexity which should from the normal make ever greater demands on the mind until the attention should pass from a fully concentrated to a completely distracted state.' This is the prin-

[4] *A Text-Book of Psychology*, 1909, 296. *Cf.* also his *The Psychology of Feeling and Attention*, 1908, 276-282.

[5] *Op. cit.*, 513.

ciple laid down by Stumpf in his *Tonpsychologie,* and by Titchener in his *Psychology of Feeling and Attention.* The results show that we were not successful in obtaining such a series of graded distractors."[6]

A quite different method of measuring clearness is that followed by Wirth.[7] Wirth's method is exceedingly complicated and utilizes very elaborate apparatus. There exists serious doubt whether Wirth's method accomplishes its aim. Geissler, in a second review[8] of Wirth's method after a reply[9] by Wirth to his first criticism,[10] concludes by still maintaining that Wirth "has failed to solve his problem" [11] and Gruenbaum in a criticism of the work of A. Kaestner u. W. Wirth entitled *Die Bestimmung der Aufmerksamkeitsverteilung innerhalb des Sehfeldes mit Hilfe der Reaktionsversuche,* concludes as follows: "Meiner Ansicht nach ist also weder der Vergleich der Resultate nach beiden Methoden [the reaction method and the differential brightness limen method] positiv ausgefallen, noch eine einwandsfreie Darstellung des Aufmerksamkeitsreliefs gelungen, noch die Durchfuehrung der Aufmerksamkeitsverteilung gesichert gewesen."[12]

Whether the main trouble with Wirth's method lies in his units of measurement or in his method of securing distributed attention, it is difficult to decide. Serious objections may certainly be made to both. Wirth's fundamental proposition, to limit myself to his first method, seems to be that the clearness of any point of the visual field with respect to intensity can be measured by determining, first, the intensive differential limen with maximal attention upon the point in question, and second, the same limen with less than maximal attention to the point in question, i. e., with distributed attention, and third, dividing the first mentioned limen by the second.

[6] *Op. cit.,* 489.
[7] *Philos. Stud.,* 1902, 635-659. *Psychol. Stud.,* 1906, 30-88; A. Kaestner und W. Wirth, *Psychol. Stud.,* 1907, 361-392 and 1908, 139-200.
[8] *Amer. Journ. of Psychol.,* 1910, 151-156.
[9] *Psychol. Stud.,* 1909, 48-72.
[10] *Amer. Journ. of Psychol.,* 1909, 120-130.
[11] *Op. cit.,* 156.
[12] *Zeit. f. Psychol. u. Physiol.,* 1909, vol. 53, 102.

As for the third part of the procedure, I must confess that it seems to me the result of incorrect and confused reasoning. And while this part of Wirth's procedure is unjustified, it is impossible on the basis of the data he presents to outline any other which would give a correct result. In Chapter III it will be shown that a decrease in the favorableness of the conditions of attention, under certain conditions, exerts an absolute effect inversely proportional to the degree of attention, while the relative effect may remain the same. A theoretical explanation of this fact is there given. If such a law as this held under the conditions used by Wirth, one would have to use the difference between the normal and distraction limena, and not their quotient, as the measure of clearness. Wirth takes the quotient, but he has no data which prove the validity of this procedure. It is based on the hypothetical and unsound speculation that all the component factors involved in the discrimination of intensity would vary in the same direction as the result merely of a change in attention. Now either attention alone changed, in which case the non-attention factors involved in the process of discrimination did not change at all, or else other factors than attention varied and it would then be hopeless to attempt to get a measure of attention or clearness from the resulting change in the limen.

Moreover, it is very apparent that a measurement of clearness possessing any accuracy can not be obtained by such a method of securing distributed attention as that used by Wirth. If the clearness of different points in the field of vision is to be determined by Wirth's procedure, it is essential that throughout any set of measurements that are to be compared, the distribution of attention used to secure less than maximal attention shall remain constant. But the distribution was produced solely by the voluntary direction of the subject. It can not be said to have been brought under experimental control. We have no guarantee of its constancy, through a series of measurements, and consequently we can not make a valid comparison of the different measurements. The very great irregularity in the results obtained do not justify any faith in the reliability of such a method of securing a constant distribution of attention. That the method was altogether inefficient is indicated by the result that the clearness of points in the area "attended to" was about as often either high or low as that of points in the area "distracted from," and that no reliable difference existed even *on the average* in the clearness of the points in the areas "attended to" and in the areas "distracted from."

Passing now to the method developed in the following pages, I wish to raise a question which is bound to occur sooner or later and so may as well be considered at the start. How can one claim to have a method of measuring attention when psychologists are not entirely agreed as to what attention is? One may arbitrarily define attention, a procedure which has the advantage of definiteness, or one may argue that the method is valid for any of a number of reasonable and generally accepted definitions of attention. Since what attention is, is more or less of a speculation, I prefer the latter course. It will be assumed that attention is a psychophysical process, the intimate nature of which is still in doubt, but which is known by certain of its functions. By a function of attention is meant something which varies whenever attention varies. Electricity is perhaps a roughly analogous illustration of a process known only by its functions. One of the most commonly accepted functions of attention is clearness. I do not regard clearness as a synonym of attention but as a function of attention. Another function is limitation or narrowing of the field of consciousness. Another function is efficiency in any psychophysical process, that is, the greater the degree of attention, the greater the efficiency, other conditions remaining constant. There are many other functions. Attention may be satisfactorily defined in terms of any of its essential functions. The function by which attention is defined must always vary when attention varies, providing other conditions remain constant.

The function of attention which I have chosen for the purpose of measurement of the degree of attention is efficiency in a psychophysical act. There is no more important function. Efficiency, has, morever, been shown to correlate very highly with clearness by Geissler and by Dallenbach. It is true that the efficiency of any act is determined only in part by attention, but it is not here proposed to measure attention by simple efficiency. The efficiency utilized in the method described in the following pages is efficiency (quickness) in reaction. This particular efficiency has already been found by Dallenbach to correlate highly with clearness. He writes, "Attention may be measured introspectively in terms of attributive clearness. For introspectively distinguished variations of attention (i.e. clearness) are closely paralleled by corresponding differences at the same level in accuracy of work performed, in rate of reaction, and in degree of precision as expressed by the m.v."[13] Consequently, it seems to me that any one who holds any of the generally accepted views of attention can, if he so desires, relate his definition to the method of measurement here proposed in such a way as to allow the validity of the method. I might put the matter in this way: it is generally admitted that an increase in attention shortens reaction time, and I mean by attention whatever is usually meant by it in this statement. Again, intensity of stimulus is generally agreed upon as an objective condition of attention, and I mean whatever is meant by attention when one makes this statement.

A few pages may now be given to a discussion of the general principles involved in a measurement of attention by means of its effect upon, or expression in, efficiency. At the same time, as an orientation to the following chapters, it will be pointed out how these principles have been observed in the present work. In the first place, it is necessary to have some act the efficiency of which varies with the degree of attention. Since it is not necessary that this efficiency shall vary only with variation in attention, there is no difficulty here. Almost any psychophysical act varies with the degree of attention. The act I have chosen to use is the simple reaction. That reaction time varies with the degree of attention has long been known, and is demonstrated over and over again in each of the following chapters. This is a fundamental proposition in the theory of the method here proposed for the measurement of degree of attention, but the evidence in sup-

[13] *Op. cit.*, 507.

port of it [14] is so overwhelming that it is unnecessary to argue the matter. The fact that reaction time varies with attention does not make of it a satisfactory measure of attention. Reaction time varies as the result of variation in other factors than attention: and it is just this fact that makes it so desirable to devise a distraction method. A distractor must be found which acts on attention and on attention solely, one which lengthens reaction time solely by lessening the degree of attention involved in the reaction. After such a distractor is found it is still necessary to determine how the effect of such a distractor varies with variation in the degree of attention. The formulation of the relationship between the distracting effect of the dictractor and the degree of attention against which the distractor acts is a difficult and hitherto unsolved problem. Certain formulations might be arrived at which would not enable us to use the distraction effect as a measure of attention. A significant and useful formulation requires that the subject's efficiency be measured in units which fulfill certain conditions, as will be pointed out later.

[14] Obersteiner, *Brain*, 1879, 439-533.
Buccola, *Rivista di filos. scientif.*, I, 219 ff.
Hall, *Mind*, 1883, 170-176.
Cattell, *Mind*, 1886, 242.
James, *Principles of Psychology*, 1890, vol. I, 427-434.
Dwelshauvers, *Phil. Stud.*, 1891, 217-250.
Swift, *Amer. Journ. of Psychol.*, 1892, 1-19.
Bliss, *Studies from the Yale Psychological Laboratory*, 1893, 16-17.
Sharp, *Amer. Journ. of Psychol.*, 1899, 356.
Binet, *L'Année psychol.*, 1899, 275-282.
Ebbinghaus, *Grundzuege der Psychologie*, 1902, 589.
Wundt, *Grundz. d. physiol. Psychol.*, 5th ed., 1903, vol. III, 441 ff.
Toulouse, Vaschide et Piéron, *Technique de psychologie experimentale; examen des sujets*, 1904, 181-183.
Moore, *Psychol. Rev. Monog. Suppl.*, 1904, **6**, 31-40.
Roehrich, *L'Attention spontanée et volontaire*, 1907, 64.
Pillsbury, *Attention*, 1908, 83.
Kaestner u. Wirth, *Psychol. Stud.*, 1907, 361-392; 1908, 139-200.
Della Valle, *Psychol. Stud.*, 1908, 283.
Meunier et Vaschide, *La psychologie de l'attention*, 1910, 43-47.
Arnold, *Attention and Interest*, 1910, 54-56.
Breitwieser, *Archives of Psychol.*, 1911, **18**, Chap. III.
Grassi, *Zsch. f. Psychol.*, 1911, 46-72.
Dallenbach. *Amer. Journ. of Psychol.*, 1913, 465-507.

While I have hitherto spoken of distractors and distraction methods there is evidently need of somewhat similar but broader terms. The word distraction implies a tearing asunder of attention, part remaining on the objects attended to before the distractor appeared, and part going to the distractor. The current psychological usage of the term distraction implies not only a division of attention but attraction of attention to the distractor; a distractor is also an attractor. While this latter implication is perhaps not a necessary one, the idea of division or tearing asunder seems unavoidably connected with the term. Now a distractor of attention results in a lowering of the degree of attention, because one of the conditions determining the degree of attention is the number of things simultaneously attended to. A distractor, then, means an unfavorable state of one of the conditions of attention, namely, the number of objects simultaneously attended to. But there are many other conditions of attention than the number of things simultaneously attended to: for instance, intensity, familiarity, etc. An unfavorable state of any of these conditions results in a lowering of attention, as does the presence of distractors, but does not necessarily result in a division of attention, and cannot, therefore, be spoken of as a distractor. I propose to use the term "detractor," a term which retains the significance of distractor with respect to the effect of the latter on the degree of attention, without implying division of attention. A distractor lowers the degree of attention by tearing attention asunder. A detractor simply reduces the degree of attention,—no matter how, whether by distraction or otherwise. Distractors are also detractors. A detractor, therefore, is an unfavorable state of any of the conditions of attention. The effects of alcohol upon the nervous system, weak intensity of stimulus and fatigue or lack of interest on the part of the subject are illustrations of detractors. They are conditions which detract from the degree of attention.

In accordance with the terminology suggested above, the method of measuring attention described in the following pages would be called a detraction method rather than a distraction method. The latter term would be misleading. The theory of the method, however, remains in general the same as that of a distraction method, in spite of the slight change in terminology. The important point is that a detractor may lower the degree of attention without bringing about a state of divided attention.

The conditions with which a detractor of attention must comply, in order to be satisfactory for the purpose of measuring attention, have often been discussed, and I shall emphasize here only two of the most essential. The point of first importance is that the detractor shall act solely upon attention. The detraction effect which it produces (measurable in one of the functions of attention) must be due solely to its effect upon attention. Reaction or any other psychophysical act involves other factors than attention. If the detractor affects any non-attention factor it is unsatisfactory for use in the measurement of attention. The second most important condition is that the detractor shall be of such a nature that its magnitude as a detractor remains constant. A detractor which the subject can avoid or not as he will, to even a slight extent, will vary too much in its magnitude as a detractor to be satisfactory. Again if we find that its effect very rapidly wears off we can be sure that it is unsatisfactory. As a matter of fact, as will be shown later, especially in Chapter V, the effect of a suitable detractor remains approximately constant throughout a large number of successive applications, and we may lay down such a constancy as a test of a satisfactory detractor.

The attention that is measured by the detraction method described in the present article, is, as already stated, that involved in a simple reaction. Unfavorable preparatory intervals have been used as the detractor. On this account, my first task was to undertake a careful and extensive investigation of the effect of variation in the preparatory interval upon reaction time. This investigation constitutes Chapter II. The conclusion there reached is that the unfavorable preparatory intervals result in a prolongation of reaction time solely because of their effect as detractors of attention. Unfavorable preparatory intervals further recommend themselves for use as a detractor because they may be varied in unfavorableness and so graduated in magnitude as detractors if so desired, they are accurately measurable and accurately controllable, are unavoidable, do not involve divided attention, and as is pointed out more especially in Chapters III and V, are eminently constant in their effect upon a given attention as long as all other factors remain the same. They may be used to detract from attention in various situations, e.g. in sound reactions or light reactions, simple reactions or recognition reactions, etc., and they may be easily used simultaneously with other detractors.

Having come to the conclusion in Chapter II, that the unfavorable preparatory intervals constitute a satisfactory detractor of attention, I proceeded next to determine how the detraction effect varies with the degree of attention detracted from. This part of the investigation, which I regard as the most important part, is reported in Chapter III. It was necessary to have different degrees of attention, which could be relied upon to remain approximately constant throughout the investigation. I could not obtain these different degrees by the use of my detractor, as my object was to determine how the effect of the detractor varied when applied to various already existing degrees of attention. I might have used subjects of different age, some children and some adults, and indeed did so later (see Chapter V) by way of confirmation of conclusions, but I preferred to produce the different degrees of attention in adult subjects by means of artificially controlling the degree of attention. For this purpose I had resort to a second detractor, or rather, set of detractors, namely, weak intensities of stimulus. Such detractors would be unsatisfactory for the purpose of measuring attention, as they affect other factors than attention, but they condition with great constancy different degrees of attention. Intensity being a condition of attention, a decrease in intensity detracts from the degree of attention. The reaction time is lengthened partly as the result of this detraction from attention and partly as the result of other effects of the decrease in intensity. The important point, however, is that different degrees of attention are secured, a point experimentally demonstrated in Chapter III. Having thus secured different degrees of attention, I applied my detractor to each of these degrees. The most useful formulation of the results from the point of view of measurement of attention is the following law: The absolute increase in reaction time produced by the use of unfavorable intervals as a detractor varies inversely as the degree of attention. This law is arrived at again in Chapter IV and still again in Chapter V. In the work reported in these latter chapters, the different degrees of attention were produced in a variety of ways other than that described in Chapter III. A corollary of this law is that the degree of attention ranks as the reciprocal of the absolute increase in reaction time produced by the detractor. Simple reaction time may vary widely from time to time and from individual to individual without great variations in attention, because the non-attention factors may be different in different cases. In general, of course, some degree of correlation will exist between simple reaction time and degree of attention, but the fact that reaction time will vary as the result of other conditions than attention prevents our using the simple reaction time as a measure of attention. This is why it is necessary to apply a detractor of known magnitude, which acts solely on attention, and then observe the effect of this detractor; in short, to use a detraction method. And this method happens to be feasible because under proper conditions the effect of the detractor varies in an ascertainable way with the degree of attention, as expressed in the above mentioned law.

Whether the above law governing the relationship between the effect of a detractor upon reaction and the degree of attention detracted from can be generalized depends upon what one understands by an adequate measure of the detraction effect. I can, of course, not be sure how much general validity attaches to a relationship that I have found to exist under certain special conditions. The data of the following pages strongly indicate however the following general law of detraction: The absolute effect of a given detractor varies inversely with the degree of attention detracted from. I am inclined to believe that this law has general validity providing the detraction effect is adequately measured. If the detraction effect used is a lessening in efficiency of some sort, the efficiency must be one that varies very delicately with variation in attention. If the act is a reflex, we cannot use changes in it as a measure of the detraction effect. Moreover, the efficiency must be adequately measured. The average number of points per inning made by a billiard player during an hour may not adequately measure his efficiency. The difficulty of the shots, and the size of the misses, etc., would have to be considered. Another consideration of the greatest importance is that efficiency cannot be adequately measured by the amount done in a given time. Paradoxical as it may sound, the time required to do a given amount is a much more adequate and accurate measure than the amount done in a given time. In measurement by amount done, poor efficiency is not given sufficient chance to display itself. If a person is rather poor and so accomplishes only a small amount in a given time, there is, so to speak, lack of room for a great absolute decrease in this amount done, no matter how much worse the individual becomes. There is no limit on the other hand to the increase in time that he may require to accomplish a given amount of work. There is infinite room for the time to become longer. The general law of detractors that I have stated certainly would not hold if efficiency were measured by amount done in a given time. Suppose, e.g., that a normal individual did 10 units normally and 5 under detraction, in a given time of 10 secs., and that an imbecile, in the same time, did 5 units normally and 2 under detraction. If we called the decrease in amount done the absolute detraction effect, according to the above law the imbecile would have the better attention, as his decrease is only 3 units while the intelligent individual's is 5 units. On the other hand, assuming that the amount done varies in direct proportion to the time allotted, the normal individual would require 10 secs. to accomplish 10 units under normal conditions and 20 secs. under detraction, while our imbecile would require 20 secs. normally and 50 under detraction. If now we measure the detraction effect by the increase in time required to do a given amount of work, according to the law of detraction stated above the normal individual has much better attention, as his time under detraction increases only 10 secs., while that of the imbecile increases 30 secs. The latter procedure may confidently he said, on the basis of the data to follow, to be correct: and consequently it may be further stated that the detraction effect upon efficiency must be measured by the increase in time required to do a given amount (or the increase in average time per unit) or else by some method which complies with the same conditions as such a measurement. A time measurement has the characteristic of being minutely divisible, but much more important is the fact that there is no danger of the efficiency becoming so low or the detraction effect so great, but that a time measurement will always adequately reflect the existing degree of efficiency. Lastly, it must be remembered that a time measurement can not be a satisfactory measurement of efficiency except when the work is done with the sole idea of doing it as quickly as possible, as for example in the case of a "motor" reaction.

The attention measured is, of course, not the "general power of attention" of the individual in question, but the average degree of attention involved in his reactions. Not the attention he "might" give, but the attention actually present. An attempt has been made, however, to show that the measurement may be made independently of the factor of sensory sensitivity, in other words, to develop a method of measuring "attentions," whether of different individuals or of the same individual at various times and under various conditions, which would rank these "attentions" only in accordance with the way in which they differ because of other factors than sensory sensitivity. The results presented in Chapter IV show that this is possible, when we use as the reaction stimulus a change in intensity in place of a given absolute intensity. This is a point of importance in the comparison of different individuals, where considerable differences may exist in sensory sensitivity. It is clearly desirable to be able to compare individuals with respect to attention apart from sensory sensitivity, and to be able by the use of two methods, one which eliminates and one which does not eliminate sensory sensitivity, to determine the effect of sensory sensitivity on the degree of attention. The perfecting of a method of measuring attention independently of sensory sensitivity is also of importance in connection with determining whether individuals rank the same in auditory as in visual attention. Before we can say that the type or quality of mental activity is a condition of the degree of attention we must equate the intensity factor, and this can hardly be done in the case of sight and hearing except by devising methods of measurement which are independent of both intensity of stimulus and the degree of sensitivity of the sense organ. It is intended soon to publish an investigation of the degree of correlation between measurements, made by the same method, of degrees of attention in the same subject in the case of different modes of stimuli, but data on this question are not presented in the present work.

In Chapter V, I have presented the results of a rigorous test of the constancy of the unfavorable preparatory intervals as a detractor of attention under the heading of "Practice". The results obtained here lead to several very important conclusions. The effect of the detractor is shown not to decrease nor to greatly vary as it is used over and over again upon the same individual. This leads to the further very important conclusion that the degree of attention involved in the reaction experiment does not improve with moderate practice. A few further sets of measurement are also included in Chapter V, partly to illustrate the use of the method and partly to confirm conclusions arrived at in the preceding chapters.

While the present work is primarily a study in the measurement of attention, it is at the same time a rather elaborate study of reaction time. The total number of reaction times reported in the following pages is 30,000, taken usually in series of 30. The mere labor of computation of averages and mean variations has occupied many weeks. The particular conclusions arrived at concerning reaction time will be found in the summaries given at the close of each chapter.

CHAPTER II

The Effect Upon Reaction Time of Variation in the Preparatory Interval

While a number of investigators[1] have studied the effect upon reaction time of variation in the preparatory interval,[2] no one has carried out the investigation thoroughly and extensively enough to permit of a full understanding of the whole matter. Only two investigators, Breitwieser and Della Valle, have published systematic investigations on the effect of intervals extending up to, or beyond, 10 secs.[3] I do not dwell on the fact that these two authors give an entirely different picture of the effect of variation of the interval. Breitwieser's contribution is so much more thorough than Della Valle's, that it may, no doubt, be regarded as superseding the latter, even though Breitwieser did not use intervals longer than 10 secs. But from work I had done before Breitwieser's contribution appeared, I knew that by using other series of intervals than the one he used, in the case where the intervals are mixed in irregular order, and by varying the order, I could get results which would greatly change the interpretation one might put upon results obtained from any single set of intervals. As an illustration of

[1] Dwelshauvers, G., "Untersuchungen zur Mechanik der activen Aufmerksamkeit," *Phil. Stud.*, 1891, 217-250.
Moore, T. V., "A Study of Reaction Time and Movement," *Psych. Rev. Monog. Suppl.*, 1904, **6**.
Della Valle, "Der Einfluss der Erwartungszeit auf die Reaktionsvorgänge," *Psychol. Stud.*, 1907, **3**, 294-298.
Breitwieser, J. V., "Attention and Movement in Reaction Time," *Archives of Psychol.*, 1911, **18**, 18-38.
The writer, also, reported some results of a preliminary study of this subject some years ago. *J. of Phil., Psychol. and Sci. Meth.*, 1908, **15**, 413.

[2] By "preparatory" interval, I mean, of course, the interval elapsing between a warning signal of some sort, i.e., a signal to get ready, and the stimulus to which the subjects reacts.

[3] Dwelshauvers, in studying the effect of *omission* of a preparatory signal, used as the intervals between reactions 30, 45 and 60 secs.

what I mean, Breitwieser, using intervals varying in duration, by steps of 1 sec., from 1 to 10 secs., mixed irregularly, found that "an interval of 2 or 3 seconds appears to be in general the most favorable," that is, gives the shortest reaction times. I had already found, using a set of intervals, varying, by steps of 0.5 secs., from 3 to 7 secs., mixed in irregular order, that the interval of 3 secs. was strikingly the least favorable, and in a series varying from 4 to 20 secs., by steps of 4 secs., that the interval of 4 secs. was the least favorable. Remembering that Breitwieser found the average reaction time of 18 subjects only 1σ shorter with a 2 sec. interval than with a 7 sec. interval, it may be said with great certainty that we both obtained perfectly normal and correct results, and that the results of the present investigation are in concordance with those of Breitwieser. Yet on the surface there is enough apparent contradiction to make it imperative to go into the matter more thoroughly.

Moreover, it seems to me that not enough attention has been paid to the different procedures that one may use in studying the effect of variation in interval upon reaction time. It is of fundamental importance to distinguish sharply between that procedure where the same interval is used a number of times in succession, and that in which a number of intervals are mixed irregularly. Some authors have used one of these methods and some, the other. It is true that Breitwieser, though confining himself chiefly to that procedure in which the intervals are mixed irregularly, to some extent used both procedures, but his investigation is not planned with the view of making a careful comparison between the two procedures.

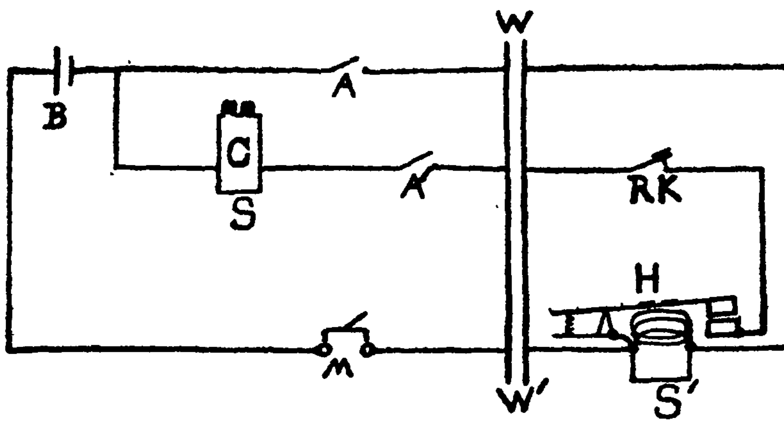
I shall first present the data obtained by using the same preparatory interval a number of times in succession, beginning with the shortest one and passing in regular order up to the longest. I shall reserve the comparison of the results obtained by different procedures until later in this chapter.

The apparatus for these reactions, which were simple, "motor", sound reactions, consisted primarily in a Wundt's sound hammer arranged in circuit with a Hipp's chronoscope and a Scripture's reaction key, the reaction movement being an upward one which broke the circuit. The source of current was a battery of Edison primary cells of about 10 volts. The chronoscope was controlled before each hour's sitting by means of a Wundt's fall-hammer, which in turn was checked about once a week by means of a 250 d.v. tuning-fork. The control was effected partly by regulation of the springs of the chronoscope, but chiefly by means of a slide resistance connected in parallel with the chronoscope. The fall-hammer was adjusted to occupy about 175σ from the "make" to the "break." I found, for the average of ten trials, the mean variation of the time during which the fall-hammer kept the circuit closed, to be well under 1σ, usually about .3σ or .4σ for an average time of 175σ. This, of course, includes the errors due to reading the tuning-fork records. The chronoscope was adjusted at the beginning of each sitting until the constant error for ten readings was not over 1σ (with a mean variation on the average of from 1 to 3σ). I took great pains with this adjustment, and would give up a sitting rather than proceed when the chronoscope was not entirely satisfactory in its readings. The preparatory intervals, which varied from 1 to 32 secs., were regulated by means of a metronome which could be set to make a circuit at any rate from once every second up to once every 7 secs. For intervals longer than 7 secs., I kept the circuit open by means of a key during certain "makes" of the metronome, that is, cut out either the alternate "make" or two or more successive "makes" of the metronome. This was easy for the experimenter to do, since the metronome made a different sort of a sound on the beat just preceding that which brought about the close of the circuit. The beats were audible to the experimenter owing to the nearness of the metronome, which, however, because of being enclosed in a chest, was absolutely inaudible in the neighboring subject's room.

The following diagram shows the disposition of apparatus: the fall-hammer, and the tuning fork, signal magnet and kymograph used in its control, are omitted. In actual work, however, the fall-hammer was never taken out of the circuit.

FIGURE 1

Apparatus for Sound Reactions with Controllable Interval between Signal and Stimulus.



A and A' = switches, operated by experimenter.
B = storage battery.
C = Hipp's chronoscope.
S and S' = slide resistances, used as shunts.
M = metronome, with two mercury cups, the points suspended from the cross-bar entering both cups simultaneously.
W W' = wall separating experimenter's room from subject's room.
R K = subject's reaction key.
H = Wundt's sound-hammer.

After starting the chronoscope, with both switches, A and A', open, the experimenter closed switch A at the moment when the circuit was open at the metronome. Switch A being closed, the next beat of the metronome would close the circuit passing through the metronome and sound-hammer, and so, as the result of the action of the sound-hammer, produce the warning signal. Switch A' being open, the hands of the chronoscope would not start, whether the reaction key was closed or not. When the warning signal had been given, which the experimenter could determine by the sound of the metronome, leaving switch A closed, the experimenter promptly closed switch A' also. Thus, when the metronome "make" occurred again, the resulting action of the sound-hammer produced the sound which served as the reaction stimulus and at the same instant closed the chronoscope circuit. The metronome circuit closed by the metronome "make" remained closed for over 800σ, so there was no danger of the circuit opening at the metronome before the subject had reacted. As soon as the hands of the chronoscope stopped, the experimenter quickly opened both switches and took the reading. In this way the duration of the preparatory intervals was determined accurately, the intervals being given with just the accuracy of the metronome. The intensity of sound used was moderate and remained the same throughout.

Three subjects were used, two advanced students, Sz and Vs, and the writer. The two advanced students had had a moderate amount of practice in reaction experiments at the time of this work, and this practice had included reactions with a wide range of preparatory intervals given in irregular order. They were not especially habituated to a 2 sec. interval. The third subject, the writer, had had a very great amount of practice in a great variety of reactions, usually with a 2 sec. preparatory interval. The reactions were "motor" or "abbreviated" reactions, and all the subjects had previously had practice in this form of reaction. As shown in the diagram of apparatus, the experimenter and most of the apparatus were in one room, while the subject sat in an adjoining, comparatively sound-proof room (this room happened to be a dark-room, but was artificially illuminated).

My reason for choosing the "motor" form of reaction and using it exclusively in the work reported in this monograph, is that I am convinced that the instructions for a sensory reaction are ambiguous, at least when it is held unpermissible in instructing for a sensory reaction to say "React as quickly as possible," on the ground that to react as quickly as possible is to use the motor form of reaction. If the instructions say "Put all attention upon the stimulus," the subject may really succeed and forget to react altogether. What actually happens, therefore, usually, is that the subject attends predominantly to the stimulus, but yet keeps his attention on the reaction enough to enable him to react promptly. But how promptly? Not as promptly as possible, and consequently as slowly and leisurely as he pleases, except in so far as the experimenter gives some incidental suggestion. Breitwieser's remarks are to the point:

"It is practically certain that the attitudes induced by different experimenters, under the name of sensory reaction, have differed. This difference need not have been due to the formal instructions, but the experimenter's own attitude and expectations may have been subtly imparted to his subjects. An exact definition of the sensory attitude cannot, therefore, be expected, but only an indication of some scale along which the attitude may vary. . . . Our results, therefore, suggest that, whereas the motor attitude is a single-minded preparation to react, the sensory attitude is a preparation to observe as well as to react, and that the preparation to observe may interfere in different degrees with the preparation to react, according to the amount of energy which is diverted from the preparation to react into the preparation to observe. In other words, the distribution of attention or of preparatory tension or innervation, varies in an uncontrolled way in the sensory type of reaction."[4] Moreover, as has been emphasized by Ach[5] and others, the sensory form of reaction tends to change with practice into the motor form. Ach also points out that the main distinction between the different forms of reaction depends upon the degree of determination to react as quickly as possible.[6]

The subjects were instructed to react always as quickly as possible, as soon as the stimulus sound occurred. I also emphasized with them that they were to try to do their very best every reaction and were neither to try to do exceptionally well any

[4] Breitwieser, *Op. cit.*, p. 13.

[5] N. Ach, *Willenstätigkeit und Denken*, 1905, p. 108 ff.

[6] "Das Verhalten der Versuchspersonen bei den versichiedenen Reaktionsformen zeigt, dass nicht die Einstellung der Aufmerksamkeit auf den kommenden Reiz oder auf die auszuführende Bewegung das Wesentliche ist, sondern vielmehr den Umstand, wie sich Versuchspersonen bei ihrer Absicht zu den oben (S. 115) gegebenen Aufgabestellungen verhält, also ob sie z. B. die intensive Absicht hat, möglichst rasch zu reagieren (muskuläre-verkürzte Form) oder zu reagieren, nachdem sie den Sinnesreiz vollständig erfasst hat (sensorielle-verlängerte Form). Dabei ist es von untergeordneter Bedeutung wie diese Einstellung anschaulich in Bewusstsein repräsentiert ist, ob sie visuell, durch Fixation der Verschlussplatte, durch inneres Sprechen, durch intentionale Bewegungsempfindungen im reagirenden Muskelorgan oder in anderen Organen, z. B. in den Augenmuskeln u. dergl., gegeben ist." *Op. cit.*, p. 122.

particular reaction or series of reactions, nor to let up at any time and neglect to react as quickly as possible. The reaction movement was always made in very much the same way. The subject placed the middle and forefinger of his right hand on the key at the warning signal, in case they were not already there, and held the key down until the reaction. If the subject at any reaction was not ready or distracted in any way, he signalled at the time to the experimenter and the reaction time obtained was thrown out, whether long or short. The subjects were instructed not to count, as I was afraid they might adopt this method of estimating the longer intervals. Just what difference it would have made, if they had, I do not know. All the subjects reported that they avoided counting.

The subjects were informed of the general nature of the experiment, and knew also the duration of the intervals used and the order in which they were to occur. They were informed that each interval would be repeated 25 times before the next longer one was taken up. They were not called upon to introspect more than to be sure that they followed the instructions. I did not wish them to try to introspectively describe the "action" consciousness. This was not my problem, and I did not want to require anything of the subjects which might distract them from the main task in hand, which was to react as quickly as possible every time the stimulus sound occurred.

The sittings lasted about an hour or sometimes a little longer, and occurred at the same time upon immediately successive days for each subject. Each "Series" in Table I refers to one hour's results of one subject. Each hour's work was as follows: After the control of the chronoscope, 25 reactions were taken with a 1 sec. preparatory interval; then 25 with a 2 sec. interval; then 25 with a 4 sec. interval, and so on up by steps of 4 secs. through a 24 sec. interval, and in some cases through a 32 sec. interval. The return to a 1 sec. interval, as though to repeat the whole experiment, was never made at the same sitting.

In presenting the results in Table I, I have followed the most widely used procedure, and given the average and the mean variation. In taking the averages no results were thrown out merely because they deviated greatly from the average. I may have included in this way a number of mistakes, but the only readings which I threw out (and I threw them all out) were those where I had noted possible error or mistake at the time, or those which were accompanied by a signal from the subject that he was distracted or not ready. In first working up my results

TABLE I

Effect of Variation in Preparatory Interval, Regular Procedure.
N, for each interval of each series = 25. Total number of reactions = 3,825.

Subject	Interval	1	2	4	8	12	16	20	24	28	32
Sz	Series I	159	148	159	198	227	217	240	267	...	...
"		*26*	*25*	*16*	*25*	*24*	*18*	*25*	*27*	...	...
"	" II	140	128	147	173	188	200	200	235	...	...
"		*18*	*17*	*14*	*15*	*15*	*12*	*14*	*20*	...	...
"	" III	140	118	155	166	185	190	209	208	...	...
"		*14*	*12*	*15*	*17*	*17*	*21*	*22*	*25*	...	...
"	" IV	141	125	149	162	182	192	205	208	...	...
"		*16*	*18*	*14*	*15*	*16*	*17*	*20*	*31*	...	...
"	" V	115	125	153	171	178	187	205	220	...	...
"		*23*	*24*	*14*	*17*	*18*	*20*	*20*	*24*	...	...
"	" VI	100	123	157	194	194	216	217	220	...	...
"		*19*	*24*	*17*	*15*	*14*	*29*	*20*	*17*	...	...
"	Average	**133**	**128**	**154**	**177**	**192**	**200**	**213**	**226**	...	...
"	Av. M.V.	*19*	*20*	*15*	*17*	*17*	*20*	*20*	*24*	...	...
Ww	Series I	144	149	142	152	158	172	173	175	...	...
"		*21*	*19*	*12*	*12*	*14*	*17*	*13*	*24*	...	...
"	" II	118	111	111	115	133	138	138	136	...	...
"		*14*	*12*	*13*	*13*	*12*	*18*	*13*	*12*	...	...
"	" III	161	154	154	183	186	183	200	200	...	...
"		*15*	*11*	*11*	*29*	*18*	*20*	*18*	*21*	...	...
"	" IV	171	158	156	183	198	190	198	195	...	...
"		*16*	*11*	*9*	*17*	*15*	*16*	*16*	*17*	...	...
"	" V	162	138	151	156	162	166	167	171	...	...
"		*19*	*14*	*12*	*11*	*12*	*18*	*14*	*13*	...	...
"	Average	**151**	**142**	**143**	**158**	**167**	**170**	**175**	**175**	...	...
"	Av. M.V.	*17*	*13*	*11*	*16*	*14*	*18*	*15*	*17*	...	...
Vs	Series I	169	159	168	180	199	225	240	226	216	220
"		*18*	*13*	*21*	*18*	*13*	*40*	*39*	*40*	*42*	*33*
"	" II	157	146	158	176	194	199	203	219	219	216
"		*16*	*10*	*16*	*23*	*21*	*41*	*23*	*39*	*35*	*30*
"	" III	153	136	139	162	176	191	191	192	192	197
"		*19*	*9*	*14*	*12*	*13*	*18*	*12*	*14*	*15*	*21*
"	" IV	136	114	140	153	169	177	181	184	199	193
"		*11*	*10*	*13*	*14*	*18*	*19*	*22*	*21*	*20*	*16*
"	" V	143	148	160	186	189	198	202	204	218	216
"		*15*	*9*	*15*	*13*	*19*	*15*	*12*	*13*	*27*	*40*
"	" VI	141	133	144	159	175	187	197	201	204	207
"		*11*	*7*	*11*	*8*	*12*	*10*	*26*	*16*	*19*	*15*
"	Average	**150**	**139**	**152**	**169**	**184**	**196**	**202**	**204**	**208**	**208**
"	Av. M.V.	*15*	*10*	*15*	*15*	*16*	*24*	*22*	*24*	*26*	*26*
Average for all subjects		**145**	**136**	**150**	**168**	**181**	**189**	**197**	**202**	...	...

I applied Chauvenet's criterion[7] for the rejection of extreme cases, but found it too laborious in view of the fact that its application did not seem to change the general trend of the results. It may be that I have included a number of prematurely begun reactions in the case of the 1 and 2 sec. intervals, but as these intervals were repeated only 25 times, I doubt if many such occurred. Of course a reaction which occurred before the stimulus would not be measured by the apparatus used.

The mean variation is given separately for each day's results. The "Series," each of which represents the data of one day's sitting, are arranged for each subject from top to bottom in the order taken. The average reaction time in thousandths of a second is given first, and the mean variation from each average given immediately below that average in italics. In the lines headed at the left, "Average," is given the average of all the average reaction times of each day; that is, the grand or total average. In the lines below these, headed "Av. M. V.," is given the average of the mean variations of the daily averages. The intervals are given in seconds in the first line of the table.

The data of Table I are represented graphically in Figure 2. The duration of the preparatory intervals is represented by the abscissae and the reaction time by the ordinates. Only the grand average reaction-time for each interval, for each of the three subjects is plotted.

Since the general course of the curve is somewhat similar for each of the three subjects, I have plotted a curve, Figure 3, which represents in graphic form the data for the three subjects regarded as constituting a single group, allowing equal weight to the results obtained with each subject. The numerical data represented graphically in Figure 3 are given in the bottom line of Table I.

That the averages and mean variations given in Table I truly represent the general tendency is shown by comparison with the full distributions of the last 100 reactions to each interval for subject Vs, presented in Table II.

Subject Vs is chosen as typical, and only the last four sittings

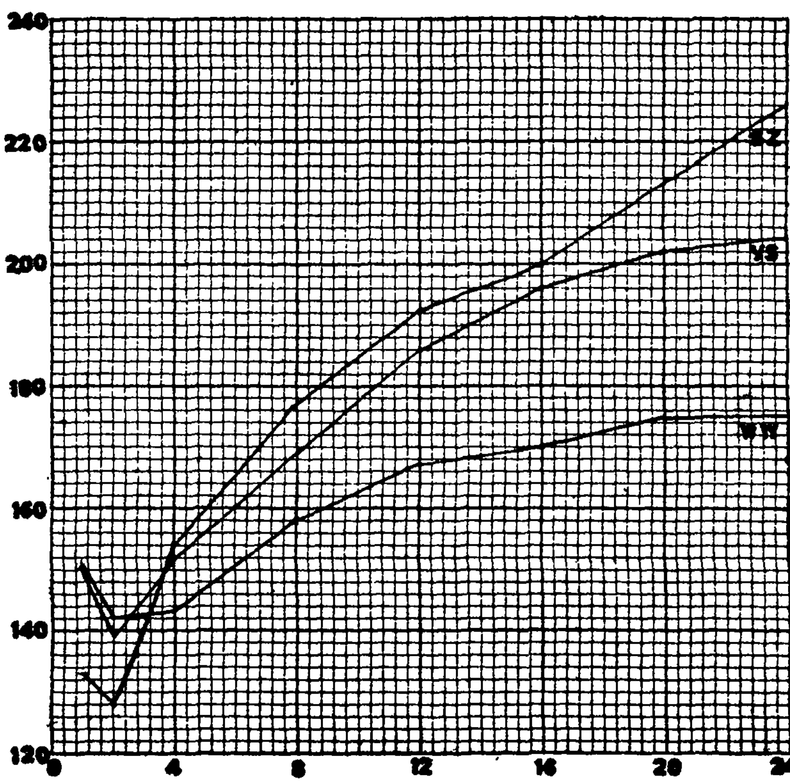
[7] See Merriman, *Method of Least Squares*, 1903, 166.

with each interval are represented, so as to have data which do not represent too widely differing stages of practice. Even then, it must be remembered that each of these four sittings occurred on different days, and since the subject reacts uniformly faster or slower on any given day, a table which mixes the distributions obtained on different days gives a much less narrow range of reaction times for each interval than a table showing the same number of reactions all made the same day. On the

FIGURE 2

Graphic Representation of Effect of Variation in Preparatory Interval, Regular Procedure, for Each of Three Subjects.

The durations of the preparatory intervals are represented as abscissae; the reaction times, as ordinates. SZ, VS and WW stand for the three different subjects, for each of which the curve is plotted separately.



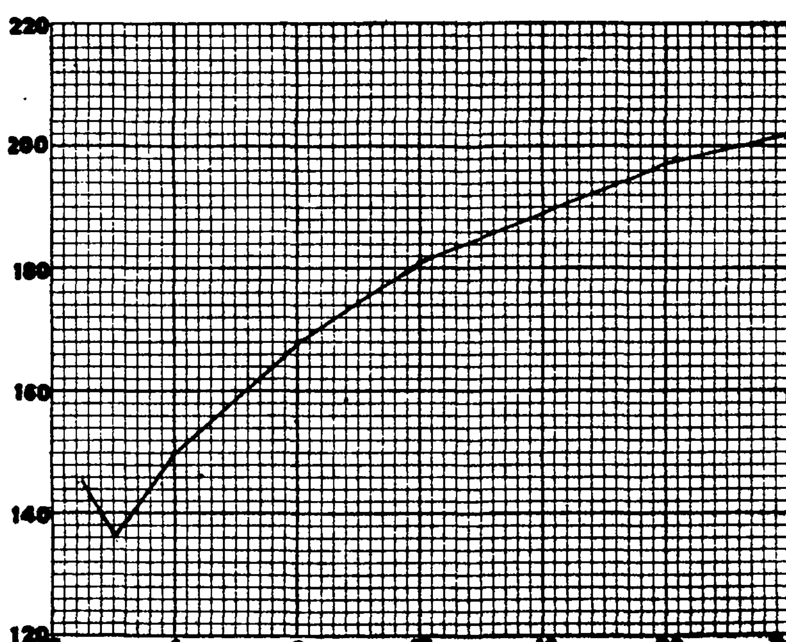
other hand, the *average* is probably all the more reliable, as any peculiarities in one day's results would tend to be eliminated by averaging with results obtained the other days. It is because the results for each day represent different stages of practice that I have not given in Table I the M. V. for the whole number of reactions, but instead, the average of the M.V.'s obtained on separate days.

The conclusions to be drawn from the data of Table I are quite simple, and clearly expressed in the curves of Figures 2 and 3. It must be constantly remembered that the conclusions hold only for the particular procedure used. Data presented later

FIGURE 3

The Curve Obtained by Combining the Three Curves of Figure 2.

The durations of the preparatory intervals are represented as abscissae; the reaction times, as ordinates. The formula for the above experimental curve is $y = A + B . \log x$, in which y equals reaction time and x the duration of the interval, and A and B are constants.



will clearly prove this. The interval of 2 secs. is clearly the most favorable. Subject Ww, however, the writer, who in general was the least affected by the duration of the interval, did practically just as well with an interval of 4 secs. The interval of 1 sec. and, likewise, any increase in the length of interval beyond 4 secs., is definitely unfavorable for all subjects, so that either decrease in the length of the interval to below the most favorable, or increase in its length beyond the most favorable interval, or range of intervals, results uniformly in longer reaction times. The curves of Fig. 2 are, in general, fairly regular, especially when we consider the kind of curves usually obtained in investigations of this sort. They present no well defined inversions and agree roughly with each other in form. It will be observed, however, that the subject who gives the quickest reaction time with a preparatory interval of 2 secs.

TABLE II

Effect of Interval, Regular Procedure, Shown by Complete Distributions of the Reaction Times.

Subject Vs.

Interval	2	4	8	12	16	20	24	28
R. T.								
.30 secs.								1
.29 "								
.28 "							1	
.27 "		1						
.26 "				1	1		1	1
.25 "							2	2
.24 "						1	1	4
.23 "					3	5	1	2
.22 "			2	3	3	19	6	8
.21 "			1	5	10	19	11	17
.20 "		1	4	20	18	18	22	18
.19 "	1	1	6	15	23	18	23	16
.18 "		2	18	23	21	11	16	16
.17 "		7	14	19	9	5	11	9
.16 "	7	17	23	18	9	1	2	2
.15 "	17	16	20	9	1	2	2	1
.14 "	27	23	6	2		1	1	2
.13 "	20	19	5		1			1
.12 "	16	9	1					
.11 "	9	3						
.10 "	1	1						
.09 "	1							
.08 "	1							
Total N	100	100	100	100	100	100	100	100

does not by any means give the quickest with the longer intervals. Indeed, for these three subjects there is an inverse correlation between the reaction time with the 2 sec. interval and that with the longer intervals. That the inverse correlation in the present case is perfect, is not of any real significance, owing to the small number of subjects. The only reliable point, and one of importance, is that a person who reacts relatively quickly with a 2 sec. interval may react relatively slowly with a longer interval, and vice versa.

The curve of Fig. 3 shows the general tendency of all the subjects, and its high degree of regularity shows that the effect of the preparatory interval on reaction time is far from haphazard. Both the general tendency and the tendency in each individual case is for the reaction time to increase at first comparatively rapidly and later comparatively slowly with uniform increase in the duration of the preparatory interval beyond the most favorable range of intervals. By the most favorable range of intervals, I mean those near 2 secs. While 2 secs. is the most favorable interval of any I used, yet undoubtedly intervals very near 2 secs. (extending even up to 4 secs. with subject Ww) would also give very short times, so that the statement that the reaction time increases at first rapidly with increase in duration of interval, does not hold until after not only the one most favorable point is passed, but until after a certain narrow range of very favorable intervals is passed. The mean variations show nothing particularly striking. They run about 10% of the average, and in general increase or decrease in absolute size in accordance with the average.

Since the results with each of the three subjects conform to the same general statement of the effect of the duration of the preparatory interval, I have deemed it worth while to state more definitely the general tendency of the group, as represented in Fig. 3. The mathematical formula for the simplest smooth curve that comes near fitting the experimental curve is $y = A + B. \log x$ in which y equals reaction time and x the duration of the preparatory interval, and A and B are constants. Calculating the reaction time by taking A as 117σ and B as 60σ and using common logarithms, the following comparison may be made of the calculated and the experimentally obtained values. The differences given are obtained by subtracting the calculated from the obtained values. R. T. stands for reaction time (expressed in σ).

TABLE III

Interval (x)	Calculated R. T. (y)	Obtained R. T. (y)	Difference
2 secs.	135	136	+1
4 "	153	150	−3
8 "	171	168	−3
12 "	182	181	−1
16 "	189	189	0
20 "	195	197	+2
24 "	200	202	+2

In view of the close correspondence between the calculated and obtained values it seems safe to state the effect of the intervals longer than the most favorable intervals, upon reaction time, when the above regular procedure is used, as follows: *The reaction time equals a constant plus the product of the logarithm of the interval and a constant.*

From this law it is evident that at least two factors are involved in reaction time. One of these, *A*, is a large constant, in the present instance 117σ. The other, $B \cdot \log x$, is an *additional* factor, which increases in size directly as the logarithm of the preparatory interval. Perhaps the constant, *A*, may be regarded as including certain specific psychophysiological factors which could not very well be supposed to vary with variation in interval, and the second factor, $B \cdot \log x$, as some more general factor including the attention factor, since, as will be pointed out later, attention certainly varies with prolongation in interval.

I have often confirmed the results presented above, as well as the results obtained with the irregular procedure presented later, in a general way, with students in my class in experimental psychology. As these students used a Vernier chronoscope, reading only to 0.02 secs., I do not feel justified in introducing these results as accurate scientific data, but mention the fact merely as confirmatory of the general correctness of the preceding results. I shall, however, present at this point other results which, though taken by a somewhat different method, definitely confirm the data of Table I, and on subjects not represented in that table, two advanced graduate students with a very great amount of practice in reaction time.

The method employed differed from the 'regular' procedure used for the data of Table I in that no particular warning signal was given. The subject was required to react to every sound of the series, the sounds being repeated at a definite rate, so that the subject reacted to each of a series of regularly recurrent sounds.[8] Each sound thus served both as stimulus and as warning signal for the succeeding sound. As there was not time to read a chronoscope between successive reactions, the graphic method was used, with a long-roll kymograph and a 100 d.v. tuning fork. My primary purpose in taking these reactions was to determine whether or not, when the series of sounds was run off regularly in this way, the attention would become adapted to the interval, and if so, for what range of intervals. For example, I wished to see whether the attention could be so adapted to a 5 sec. interval and each sound occur so exactly at the time it was expected, that the reactions would be as short as with the 2 sec. interval. Such a possibility seemed to be suggested by a number of writers on attention and rhythm, and especially by Schumann, in his writings on the perception of time. Schumann,

[8] No data on reaction time with this procedure, so far as I know, have hitherto been published. Binet, however, in a review of reaction technique (*L'Année Psychologique*, 1895, 775), mentions the fact that he used this method in collaboration with MM. Philippe et Courtier.

"Ce dispositif expérimental permet de noter que differentes personnes peuvent aller jusqu 'à des limites differentes pour les intervalles entre deux réactions successives; ainsi la plupart peuvent réagir lorsque le coup de marteau arrive toutes les deux secondes; lorsqu 'il arrive toutes les secondes il est déjà très difficile de réagir à chaque coup, on a une tendance très forte à soulever le doigt simultanement avec le coup du marteau, c'est à dire, à faire des mouvements rhythmiques correspondant aux coups de marteau, il faut exercer un effort d'attention très considérable pour arriver à des reactions aussi rapides; la plupart des personnes échouent apres une dizàine de reactions faites de cette sorte; de plus, les durées des reáctions varient beaucoup et peuvent indiquer le degré d'attention soutenue, et aussi la fatigue.

Quelques personnes puivent faire de bonnes réactions, nullement anticipées, avec intervalles d'une demi-seconde. . . . " *Loc. cit.*

in a discussion of the experiences of surprise and of strain of expectation, which are felt upon listening to a metronome which is beating at "fast" or "slow" rates, writes as follows: "Diese Nebeneindrucke sind jedoch bei den ersten Schlägen einer neuen Schlagfolge subjektiv deutlich. Nach kurzer Zeit passt sich innerhalb gewissen Grenzen die Aufmerksamkeit dem neuen Intervall an, die Spannung der Erwartung, bezw. der Nebeneindruck der Überraschung nimmt immer mehr ab, und jeder Schall wird schliesslich wieder gerade in dem Augenblicke erwartet, in welchem er eintritt."[9] Further, "Die bisherigen Auseinandersetzungen gelten übrigens nur für Intervalle, welche 2 Sek. nicht wesentlich überschreiten. Mit der Zunahme der Intervalle tritt die Einstellung der Aufmerksamkeit immer schwerer ein und die Vergleichung der intervalle wird entsprechend unsicherer."[10]

I sought to obtain an objective test of the validity of these statements by means of reaction time. Since, when the adaptation of attention to the rate of succession of the sounds is perfect, each sound occurs exactly when it is expected, within the range of perfect adaptation there should be no variation in the average reaction time of reactions made to every sound of the series; and if this adaptation of attention becomes constantly less perfect as the rate is made slower than one sound every 2 secs., the reaction time should become constantly longer and the increase in reaction time should measure the lessening in the degree of adaptation of attention.

The subjects were instructed to try to get into the tempo, and the first few reactions were not recorded, the idea being to wait until the subjects were adapted to the rate. I was unable to obtain reactions at a rate faster than one every 2 secs., as with very fast rates it becomes very difficult to keep from beating time instead of reacting. The subjects were instructed to use the "motor" form of reaction. The intensity of the sound stimulus was rather weak in the case of one subject, Hh, and

[9] *Über die Schätzung kleiner Zeitgrössen, Ztscft. fur Psychol. und Physiol.,* 1893, 4, 3.

[10] *Op. cit.,* 7.

very weak in the case of the other, Br. This explains why the reaction times are so long and why the times for Br. are so much longer than for Hh. The idea in using the very weak stimulus, as with Br., was that with a very weak intensity of stimulus, the degree of adaptation of attention would be a relatively more important factor in determining the reaction time, and that consequently variations in the degree of adaptation could be more readily detected. That this surmise was correct is indicated by the marked prolongation in reaction time which occurs with the longer intervals. It is also very clearly proved by the data presented in the next chapter.

TABLE IV

Effect of Variation of Rate on Reactions to Each of a Series of Regularly Recurring Sounds.

N, for each interval, for subject Br, = 75, for Hh, = 30.

The average reaction time for each rate is given in σ. The mean variations are given in italics just below the corresponding averages. The rate, i.e., the interval between successive sounds of a series, is given in secs. in the first line of the table, headed "Interval."

Interval	2	3	3.5	4	5	6	7	8	10	12
Subject Br	198	214		243	260	260		289		299
	31	*19*		*28*	*30*	*31*		*25*		*30*
Subject Hh ...	164		158		172		214		230	
	17		*17*		*25*		*39*		*22*	

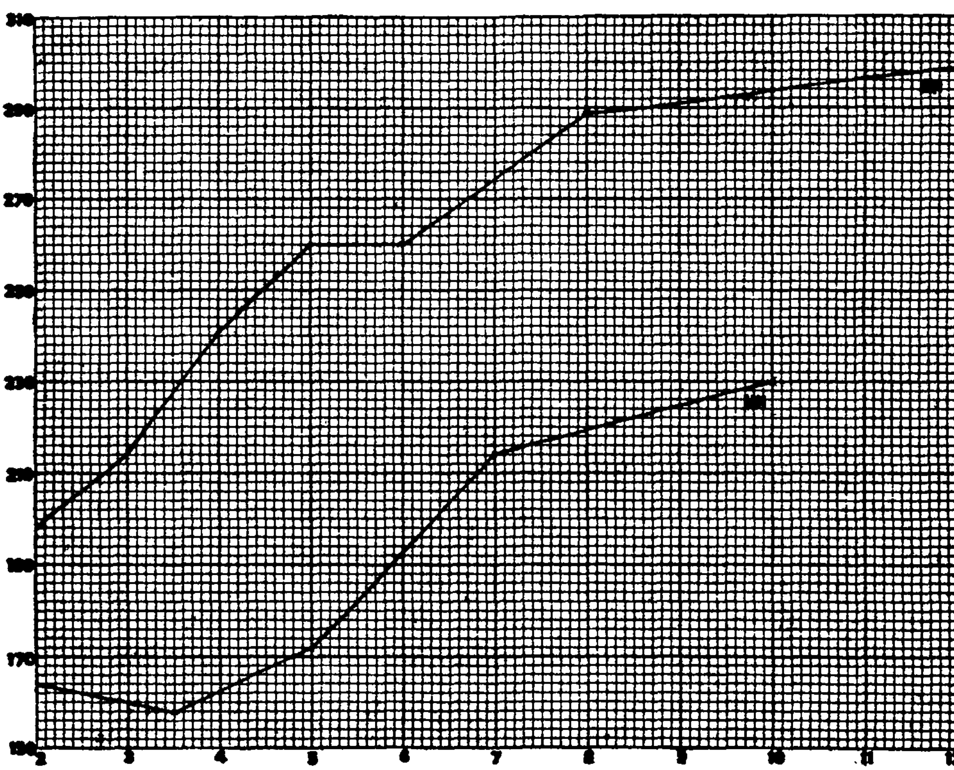
Average reaction time of 100 reactions, subject Hh, with intervals from 1 to 6 secs. inclusive, mixed in irregular order, 234 σ, M.V. 28 σ; for 25 reactions with intervals from 7 to 20 secs. irregularly mixed, 258 σ, M.V. 21 σ.

The results with this procedure are given in Table IV and Fig. 4. It is evident that there exists no great degree of flexibility in the range of rates to which the attention can become perfectly or maximally adapted. The curves begin their rise with quite short intervals, and rise rapidly, indicating that perfect adaptation cannot be secured with rates slower than one sound every 4 secs. They are not so regular as the curves of Figs. 2 and 3. This is in part due, no doubt, to the smaller number of reactions represented in Table IV, but more largely, I think, to the fact that, in the experiments represented in Table IV, I did not proceed in regular order from the fastest rates up to the slowest, but in a rather irregular order, of which unfortunately I did not keep account. Considerable time, 10-15 minutes, however, elapsed between the series of different rates, so that the effect of order was probably slight compared to what it might have been had the reactions at one rate immediately followed those at another rate. Aside from somewhat lesser

FIGURE 4

Graphic Representation of the Data of Table IV.

The intervals between the successive sounds of a series are represented as abscissae and the average reaction time in σ as ordinates. Br and Hh refer to the two subjects.



regularity, the curves of Fig. 4 agree in a general way with those of Figs. 2 and 3. Both sets of curves show the same marked increase in reaction time with prolongation beyond a certain most favorable interval or range of intervals; and beyond the point where this increase is first noticeable, in both cases, the increase is at first more rapid than it is later, with uniform increase in the duration of the intervals. While in obtaining the results of Table IV no particular warning signal was used, evidently in a regular series of sounds such as is here in question, each sound serves as a warning signal for the next, so that it may be said that the procedure for both Table I and Table IV involved the repetition, over and over again in succession, of the same preparatory interval; and it is this likeness in the two procedures that renders it justifiable to regard the data of Table IV as confirming the data of Table I, and at the same time explains the wide dissimilarity in the results obtained, on the one hand, by either of these procedures and, on the other hand, by the procedure in which the preparatory intervals are mixed irregularly. The prolongation in the reaction time for slower rates shown in Table IV, confirms Schumann's statement that the adaptation becomes much more difficult for rates much slower than one sound every 2 secs.[10a] That there is, however, a very considerable degree of adaptation for intervals considerably longer is shown by the fact that the reaction time does not reach its maximum until very slow rates are reached, with either the procedure of Table I or that of Table IV. The results presented in Table IV are not extended enough to fix the rate required before the reaction time reaches a maximum of slowness, but show that the rate is certainly not less than one sound every 8 secs., and probably well over one sound every 12 secs.; and the results of Table I indicate that the maximal reaction time is not reached until the interval is well over 24 secs. I am inclined to think, therefore, that Schumann's explanation of our estimation of short intervals applies equally well to longer inter-

[10a] For further data bearing on Schumann's theory, see the author's *A Quantitative Study of Rhythm*, *Archives of Psychol.*, 1909, 14, 10, 37, 61-62.

vals, for while it is true that perfect adaptation is not possible much beyond an interval of 2 secs., there is nevertheless a degree of adaptation present, and the degree of this adaptation does not decrease any faster than does the keenness of temporal estimation. It is true that there is less adaptation of attention in the case of a rate of one sound every 8 secs. than in the case of one sound every 2 secs., but the absolute accuracy with which we estimate 8 secs. is much less than that with which we estimate 2 secs. In brief, the degree of adaptation of attention runs parallel to the accuracy of temporal estimation.

In confirmation of this conclusion, I may mention that the feelings of surprise and strain which Schumann mentions as occurring in the comparison of intervals of less than 2 secs., are very marked in much longer intervals. After using preparatory intervals of 16 or 20 secs., an interval of 4 or 8 secs. seems short; and the stimulus coming at the end of this short interval usually produces a peculiar, but very noticeable, feeling of surprise, finds the subject unprepared, and results in a long reaction time. Whether the stimulus coming at the end of any interval produces surprise or is preceded by expectant strain, depends upon the place of that interval in the series of intervals that is being used. A further study of this effect of order of intervals is presented in Tables VI and VII.

Before leaving the question of the bearing of the results of Tables I and IV upon the perception of time, I wish to point out one further conclusion, one which offers an explanation of the law governing the effect of interval on reaction time but at the same time runs counter to a great many published but unproved statements with respect to the perception of time. The results of Table I show that when a regularly repeated preparatory interval is used, the duration of the reaction increases with the longer intervals, the reaction time always equalling a constant plus the product of another constant into the logarithm of the interval. I shall argue further on that this increase in reaction time with the unfavorable intervals indicates that at the time the reaction occurs at the end of these longer intervals, there is not such a perfect readiness to react. The evidence and authority in favor of this explanation is abundant. But, however true this explanation, we have still to explain why there is less adaptation of attention or less readiness. Neither fatigue nor the effects of temporal adaptation offer any adequate explanation. If the subject could estimate the 20 sec. interval with the same absolute accuracy as the 2 sec. interval, however weak, wandering or fluctuating his attention, there is no reason why he could not be just as attentive at the end of 20 secs. as at the end of 2 secs. He would not need to maintain good attention during the whole interval, but only to be ready at the end of it. Consequently, if the interval of 20 secs. was estimated with the same degree of accuracy as that of 2 secs., there can be little doubt but that equally good adjustment of attention could be brought into play at the end of the interval, that is, at the time of the occurrence of the stimulus to which the subject had to react. It is evident then, that while we may offer lack of perfect adaptation of attention, or unpreparedness, as the immediate explanation of the prolongation in reaction time, which, as Tables I and IV show, occurs with the longer intervals, it is further true that this lessened degree of preparedness would not exist if the subject could estimate the longer intervals with the same degree of accuracy as the shorter. Consequently, the prolongation in reaction time indicates the decrease in the accuracy of the estimation of the intervals. As long as the reaction time is not as long as with a set of totally irregular intervals, there is evidently a certain degree of ability to estimate the interval. On the other hand, any prolongation of the reaction time in the case of the longer intervals beyond that obtained with an interval of 2 secs. plainly indicates that the longer interval is not estimated as accurately as is the interval of 2 secs. Since the increase in reaction time is perfectly smooth, gradual and regular from 2 secs. up to 24 secs., it is plain that the accuracy of the estimation of intervals decreases gradually and regularly from 2 secs. up to 24 secs. There is no sense in saying that an interval of 4-5 secs., or of 8 secs. or of 12 secs. is the longest which can be grasped as a single temporal perception.[11] We can

[11] "Im allgemeinen dürfte dann unter günstigen Umständen der Zeitwerth von 4-5 Sec. die obere Grenze bezeichnen, bis zu der eine Zeitvorstellung als

perceive intervals that, at any rate, are quite long. There is no break at 4 secs. or 8 or 12 secs. All that happens between 2 secs. and 24 secs. is that the absolute accuracy of estimation of intervals decreases as the interval increases. The results of Table I show that this decrease in the accuracy of estimation must be regular and smooth from 2 up to at least 24 secs. The increase in reaction time with longer intervals, which indicates the decrease in accuracy of estimation of intervals, is identical with the increase in the product of a constant and the logarithm of the interval. This indicates that the estimation of intervals is in accordance with Weber's law from 2 to at least 24 secs. This law is not proved by the data here presented, of course, since it is not established in accordance with what law the degree of readiness to react varies with variation in the accuracy of the estimation of the interval. But if Weber's law holds for very short intervals as is usually stated,[12] it must hold up to 24 secs., since the same law holds for this whole range of intervals, in the case of what is a function of the accuracy of the estimation of the interval, namely, the reaction time. What the data here presented do prove, therefore, is that the estimation of time follows some regular law which holds without break right through the various intervals so often mentioned as the longest that are "immediately" perceived.

None of the subjects gave the introspection that they ever

Ganzes unmittelbar zusammen gefasst werden kann, wogegen diese Grenze auf höchstens 1.5 bis 2 Sec. herabsenkt, wenn die Zeitstrecke ungegliedert ist." Wundt, *Physiologische Psychologie*, 5th ed., 1903, vol. III, 49.

"As a matter of fact our *direct*, as distinguished from our indirect and inferred, consciousness of time, never exceeds a few seconds. Under favorable conditions it may mount up to 12 secs. or thereabouts, but ordinarily it it much shorter." Angell, *Psychology*, 4th ed., 1908, 191.

"The conscious present varies greatly in objective duration; but there can be no doubt that it may last for a considerable period of time: it is 'now' during the whole hour that we spend in the dentist's chair, or during the whole morning that we devote to some baffling problem." Titchener, *A Text-book of Psychology*, 1909, 341.

[12] "Innerhalb jener beiden Grenzen, dem Indifferenzwerth als unterer und dem Maximalumfang des Bewusstseins als oberer, folgt nun die Unterschiedsempfindlichkeit für Zeitgrössen ziemlich genau dem Weberschen Gesetze." Wundt, *Physiologische Psychologie*, 5th ed., 1903, vol. III, 49.

tried to estimate the interval by means of breathing. This very complicating factor was avoided, presumably, because the instructions were to keep the attention on the reaction. They were not primarily engaged in estimating intervals. Yet they tried to estimate the interval so as to be perfectly ready to react at the exact moment the stimulus was given.

I wish at this point to make a few comparisons between data so far presented and some results that have been obtained by others, whether by procedures similar to the one used for Table I, or by the procedure in which preparatory intervals of different lengths are mixed in irregular order. The results so far presented on the effect of prolongation of the preparatory interval offer considerable contrast and at the same time considerable agreement with results already published by others. The present data show a much more marked prolongation in reaction time as the result of lengthening the interval, and also greater uniformity or smoothness in the curve which represents this prolongation. My results agree with those of a number of investigators respecting the favorableness of the 2 sec. interval. These investigators[18] have all found that some quite short preparatory interval, about 2 secs., is the most favorable; that is, gives the shortest reaction times. Various sets of intervals have been used, but in most cases only a few different intervals, with a maximum interval of only a few secs.; yet there is very close agreement in the results. It may be concluded with a high degree of certainty, that a preparatory interval of from 1 to 4 secs. is the most favorable. There is strong evidence that, in many cases at least, the interval is extremely near 2 secs. Whether there is just one exact interval which may be said to be most favorable, or whether there is a little stretch of intervals lying between 1 and 4 secs. about equally favorable, is hard to determine. The most favorable interval apparently holds for all kinds of reaction times, motor or sensory, simple or discrimination, and for persons of widely differing ages, though the effect of age on the most favorable interval has never been particularly investigated.

[18] Dwelshauvers, *op. cit.;* Moore, *op. cit.;* Della Valle, *op. cit.;* Breitwieser, *op. cit.*

There is less unanimity of opinion concerning what happens when the preparatory interval is increased beyond 2 secs. Della Valle used series of intervals varying by steps of 2 secs. from 2 to 8 secs. for one subject and from 2 to 14 secs. for another. The intervals were mixed in irregular order. He used seven subjects, but publishes, as curves only—no averages or mean variations—the results obtained with two subjects. The number of reactions with each interval was only 10 or 12. These curves show an extremely large and well marked "attention wave," of a period of 4 secs. Thus, in one case, the reaction time at 2 secs. is 122 σ, at 4 secs., 138 σ and at 6 secs., 115 σ. This regular undulation continues, together with a rise in the general height of the curve up to 14 secs. Breitwieser refers to the regularity and uniformity of these fluctuations found by Della Valle as "remarkable," and comes to a conclusion in "entire disagreement"[14] with Della Valle. My results are also in entire disagreement.

The data published by Breitwieser are more complete and reliable and it is worth while to consider his conclusions very carefully. He found, like previous investigators that "an interval of 2 or 3 secs. appears to be in general the most favorable."[15] He found, however, that the influence of interval is slight, when the average of all the subjects is considered, while in the case of the individual records there was a good deal of fluctuation. Speaking of the general average, Breitwieser writes: "The reaction time after one interval differs but little from the reaction time after another interval." In the case of sound the average of all reactions for a 2 sec. interval was 130 σ; for 9 secs., 136 σ; and for 10 secs., 134 σ. In the case of reactions to visual stimuli the average for the 4 sec. interval was 177 σ; for 2 secs., 186 σ; for 9 secs., 196 σ; for 10 secs., 195 σ. In these cases, *the subject never knew which interval to expect.* Ten readings were taken for each interval, but the intervals were given in a promiscuous order. No further indications of the order are given. We may, then, according to Breitwieser's

[14] Breitwieser, *op. cit.*, 37.
[15] *Op. cit.*, 24.

results, sum up the effect of variation in the interval, when the intervals are used irregularly and without foreknowledge of their length on the part of the subject, by saying that in general the most favorable period is from 2-4 secs., but that there is only a very slight lengthening of reaction time as the interval is increased up to 10 secs., or as it is shortened to 1 sec. The change in reaction time with change in interval may, moreover, according to Breitwieser's results, be found to be rather irregular.

In addition to these results Breitwieser used a procedure, in the case of one subject, where the subject knew in advance what length of interval was to occur between the ready signal and the stimulus. The ten reactions with each interval were taken in sequence before passing to another interval. He does not state however, in what order the different intervals were taken. "The results show that foreknowledge of the interval makes the reaction quicker, and much more uniform throughout the range of intervals." "Still, the interval of 1 sec. is less favorable than those of 2 and 3 secs.; and the longer intervals again give somewhat slower reactions. . . . It appears thus that the subject cannot readily adjust himself for the reaction within the first second after the ready signal, and also that he is not likely to be at his best at the end of an interval of over 4 secs."[16] The prolongation of reaction time found by Breitwieser in this case was from 117.8 σ (shortest) at 2 secs. to 132.6 σ (longest) at 9 secs.—much greater than with regular procedure.

We have, then, to distinguish two main types of procedure. First, the method of mixing the preparatory intervals in an irregular order, without foreknowledge on the part of the subject as to the length of the intervals; and second, the method wherein each interval is repeated a number of times before passing on to the next longer interval, with foreknowledge on the part of the subject. As Breitwieser used eighteen subjects with the first procedure and only one, apparently a different one from any of the other eighteen, with the second, it is hard to compare his results on the two procedures. I would like to em-

[16] *Op. cit.*, 30.

phasize, perhaps a little more than Breitwieser himself has done, the greater uniformity obtained by the method of regular repetition with foreknowledge, and also what his results do not show very well, the greater prolongation obtained by the regular procedure as the result of prolongation of the preparatory interval. This effect of method, together with the fact that I extended my intervals up to 24 secs., serves to harmonize my results very well with those of Breitwieser, and explains why I found a more marked and uniform effect as the result of the prolongation of interval.

To make more sure of the effect of the order in which the intervals were given, and of foreknowledge on the part of the subject, I made some additional experiments with the same three subjects, whose results are plotted in the three curves of Fig. 2. As already explained, the procedure used in obtaining the data represented by the curves of Fig. 2 was to give the same interval 25 times in succession, the subject being told beforehand of the length of the interval and of the fact that it would not be changed until he was so informed, and then, after taking these 25 reactions with the same preparatory interval, to pass on to the next longer interval. The first interval used was always the shortest, i.e., 1 sec., and then the intervals were taken in order up to 24 or 28 secs. I now took a large number of reactions in which I mixed up in irregular order intervals varying in length from 4 to 20 secs. I kept track of the order but the subject never knew beforehand which of these intervals would be given. The order in which I gave the preparatory intervals was as follows: 4, 16, 20, 4, 8, 20, 12, 16, 8, 4, 12, 4, 20, 8, 12, 4, 16, 20, 8, 16, 12, 12, 8, 16, 20. This list of intervals is too long and too irregular for a subject to learn. I occasionally changed the order of the first few intervals, however, and further, it is likely that the subjects came to realize that every interval occurred about equally often, and that the same interval was but seldom given twice in succession. The introspections, however, of all three agree that it was never known just how long an interval to expect.

The results are represented in Table V. The average reaction time in σ and the mean variation of the average of all reactions obtained with each interval is given for each of three subjects, under the columns headed R.T. and M.V. The intervals are given in the first horizontal line of the table. The lowest line gives the average of the averages for the three subjects, equal weight being given to the final determinations in the case of each subject.

TABLE V

Effect of Interval on Reaction Time, Irregular Procedure.

N, for each average, for Sz, 125; for Vs, 100; for Ww, 50.
Total No. of reactions = 1,375.

Interval	4		8		12		16		20	
Subject	R.T.	M.V.	R.T.	M.V.	R.T.	M.V.	R.T.	M.V.	R.T.	M.V.
Sz	211	34	207	25	216	22	218	25	232	29
Vs	204	34	199	30	202	33	204	37	213	39
Ww	214	35	199	33	178	24	178	23	170	32
Average	210		202		199		200		205	

The results included in Table V may be best discussed in comparison with those of Table I, in which was used the method of varying the preparatory interval in a regular and known order, from shortest to longest, repeating each interval a number of times as already described. To facilitate this comparison the average result for each interval with each procedure is given, and the general tendencies represented by these averages are plotted as curves in Fig. 5.

Comparison of the Effect of Regular and Irregular Variation of Preparatory Interval on Reaction Time.

Interval in secs.	2	4	8	12	16	20
R. T., Regular Procedure	136	150	168	181	189	197
R. T., Irregular Procedure		210	202	199	200	205

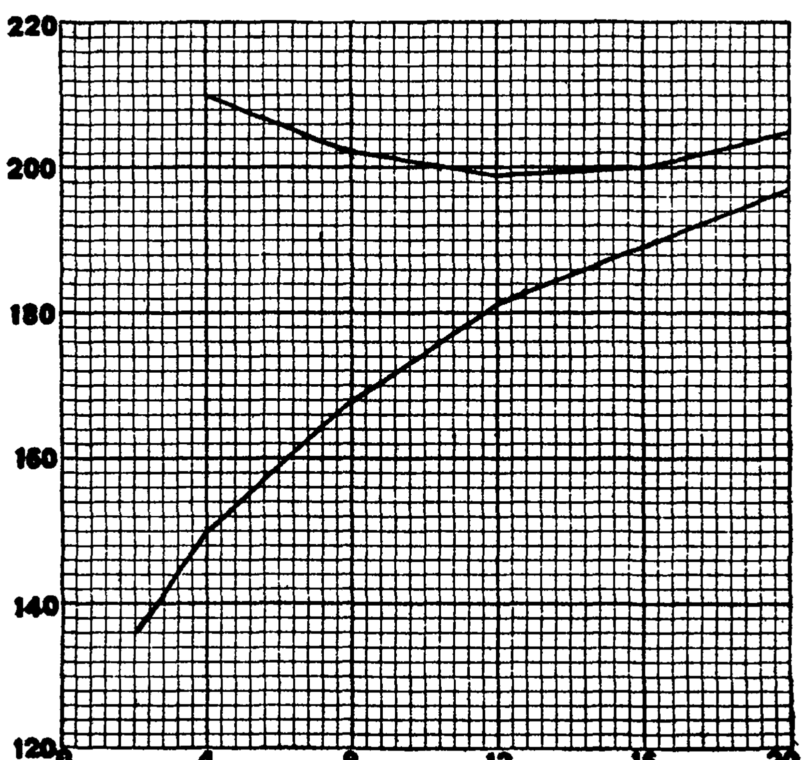
There are some interesting differences in the results obtained by the two procedures. In the regular procedure the reaction time increases, rather uniformly, at first faster than later, as the duration of the preparatory interval is increased beyond 2 secs. With the irregular procedure, the effect of variation in the preparatory intervals is very much less marked. In the regular procedure the difference in time between the 2 sec. interval reaction time and the 20 sec. interval reaction time is 61 σ, whereas with the irregular procedure the maximal difference (between the reaction times with a 12 sec. interval and that with a 4 sec. interval) is only 11 σ.

Yet a rather definite effect of the variation in interval is evident even in the case of the irregular procedure. The shortest

FIGURE 5

Graphic Representation of the Effect of Regular and Irregular Variation of Preparatory Interval on Reaction Time.

The durations of the preparatory intervals in secs. are represented by the abscissae and the rection time in σ by the ordinates. The upper curve represents the results obtained with the irregular procedure, and the lower one, the results obtained with the regular procedure.



reactions are obtained not with the intervals nearest 2 secs., but with an interval towards the middle of the series used, in the above case 12 secs. Subjects Sz and Vs give the shortest reactions with intervals somewhat shorter, and subject Ww with intervals somewhat longer, than the middle interval. The intervals lying on either side of that giving the shortest reaction time, in general, tend to give longer reaction times, but this increase in length is more noticeable in the direction of the shortest intervals, and indeed not at all noticeable in the case of subject Ww in the case of the longest intervals. I have obtained similar results even when the shortest interval used was 3 secs., a very favorable interval with the regular procedure. When mixed irregularly with a series of longer intervals, the 3 sec. interval gave a longer reaction time than any of the others, so that while it is a very favorable interval with the regular procedure, it may be a most unfavorable with the irregular. A great deal depends upon the order in which the intervals are mixed, but often the most striking effect of interval when the irregular order is used is to make the reactions with the shortest interval the longest. From a variety of experiments I have made (some of which are presented below), I believe this lengthening of reaction time with the shortest intervals will hold for any series of fairly short intervals, whether the shortest interval be 1 sec., 2 secs., 4 secs., or longer. Another striking point is that the irregular procedure gives much longer reaction times. The difference is especially marked in the case of the intervals down towards 2 secs., and becomes less so as the interval increases in length. The difference in time for the same interval, in the case of the two procedures, grows less and less as the interval increases in length, as the result of the increase in the length of the reaction time with the regular procedure, but it still holds up to 20 secs. that the regular procedure gives the shorter times. The course of the two curves in Fig. 5 indicates that with long enough intervals the regular procedure would give just as long reaction times as the irregular; that is, that the curves would at some point coincide. At what point this would occur is hard to estimate, but it is rather surprising to find it well above 20 secs. As near as I can estimate, the curves would coincide at an interval somewhere about 32 secs. It has to be taken into account that introducing longer intervals into the irregular series would probably raise the general level of the reaction times obtained from the series. This makes it rather difficult to give a general answer to the question at what duration of interval the regular procedure would give as long times as the irregular. It depends somewhat on the length of the irregular intervals.

Before attempting to explain the differences in the results obtained with the regular and the irregular procedures, I shall present some data showing how important the order of the intervals is, when they are mixed irregularly. Using the irregular procedure, it seemed to me that I could obtain the longest time with any interval I chose, by arranging the intervals in the proper order. That this can always be done is improbable, even when the subject's individual tendencies are known, but it is nevertheless certain that the order makes a very great difference. In Tables VI and VII are given the results obtained on several subjects together with the procedure used. The intervals are given in the top line of the table in secs. in regular order. In Table VII the irregular order actually used is given. Only ten reactions were taken with each interval in each procedure, so these results are not very reliable. The mean variation is omitted; it is of no particular importance here and would probably add confusing figures.

TABLE VI

Effect of Order of Intervals: Results Arranged in Regular Order, Obtained by Both the Regular and the Irregular Procedure.

Subject	Procedure	3	5	7	10	13	16	19
W	Regular	99	102	122	123	137	145	135
"	"	86	94	117	127	129	140	151
" (Series A)	Irregular	166	146	165	140	152	125	143
K	Regular	125	126	144	142	162	158	164
" (Series B)	Irregular	226	194	185	163	165	216	191

Interval		3	3.5	4	4.5	5	5.5	6	6.5	7
M	Regular	113	129	136	138	138	142	147	143	157
" (Series C)	Irregular	138	145	146			139		140	144
" (Series D)	"	220	189	168	174	168	159	162	174	158
C (Series E)	"	226	218	184	205	206	194	195	209	195

Table VII

Results with Irregular Procedure, with Intervals Arranged in the Order Used.

Order of Intervals	5	10	19	7	3	13	16
Subject W (Series A)	146	140	143	165	166	152	125
Order of Intervals	13	19	5	10	16	3	7
Subject K (Series B)	165	191	194	163	216	226	185
Order of Intervals	6.5	4	3.5	3	7	5.5	
Subject M (Series C)	140	146	145	138	144	139	

Order of Intervals	6.5	3	5.5	3.5	4	5	7	6	4.5
Subject M (Series D)	174	220	159	189	168	168	158	162	174
Subject C (Series E)	209	226	194	218	184	206	195	195	205

Table VI merely confirms the results already presented. Where the regular procedure occurs, it shows the regular increase in time with increase in the duration of the preparatory interval. Where the irregular procedure is used, it shows the greater absolute length of the general run of the reaction times, and shows the longest reaction times with the shortest interval. Only in one irregular series, series C, subject M, is the shortest reaction time obtained with the shortest interval, and the order of intervals used in this series was planned with the object of placing the shortest interval in the most favorable position for it in the series, namely, immediately after the intervals which had most nearly the same length.

Table VII shows in the case of four subjects just what the effect of order of intervals was, as the intervals are arranged in the table, from left to right in the order they were given. It is rather hard to explain each individual time in the table. A good deal must be allowed for accidental variation. Also, the general rule must be borne in mind, that, with the irregular procedure, the middle intervals give the shortest times, while the longer intervals give slightly longer, and the shortest intervals the longest times. This has already been shown in Table V. It is well shown by subject K, series B, in Table VI. The order of the intervals, however, is a complicating factor. In the case of the subjects of Table VII, the most marked effect of order seems to be that the reaction time to any interval is shortened when preceded by an interval of nearly the same or shorter length, and that it is lengthened when preceded by a considerably longer interval. Table VII bears this out, though it is probably hardly worth while to consider each individual reaction time. The explanation would probably be that there is adaptation on the part of the subject not only to the general trend of the series, but that the last interval has a little more effect upon his attitude than less recent intervals.

Let us suppose, for example, that the subject does not get quite ready in time for the stimulus in the case of the shortest preparatory intervals, because of a tendency to adapt to the intervals of middle or slightly shorter length, and further that the interval to which his attention tends to adapt itself is determined largely by the last preceding interval. If the last preceding interval were a long one, he would tend not to be ready so early as if this preceding interval were a short one. This would make his reaction to a following short interval somewhat longer because of lack of adaptation, or unreadiness. On the other hand, if the preceding interval had been one of the same length, the stimulus at the end of the next interval would be more apt to find the subject just ready. Or if the preceding interval had been shorter, the subject would be ready too soon, but would attempt to maintain his adaptation, perhaps increase it, so that if the next interval were not *too* long, the stimulus at the end of it would probably find the subject quite ready, and give a comparatively short reaction time for that interval. In other words, the results of Table VII on the effect of order are readily understood if we assume that the subject gets perfectly ready to react in time only for stimuli which follow intervals as long or nearly as long as the middle interval of the series: that this is an energy-saving habit which he more or less unintentionally acquires as he becomes familiar with the general run of the intervals; but that this habit is slightly modified by each interval that comes along. This modification is of such a sort that each time he tends to get ready earlier or later than usual according to whether the last preceding interval was shorter or longer than the middle intervals. This amounts to saying merely that the subject's most recent reaction experiences have somewhat greater weight in determining his present behavior, in the way of getting ready, than the more remote ones of the series, though all contribute.

Now I would like to be understood as expressly denying that the effect of order of intervals must necessarily be such as I have claimed it to be with the subjects of Tables VI and VII. That my surmises concerning these subjects are correct is borne out by the fact that experimenting with them I was able to arrange series so as to have the interval of 3 secs. give the shortest reaction time—instead of what is easier, to have it give the longest—this, with series of intervals in which 3 secs. was the shortest interval. An instance of this is found in Table VI, series C and D, subject M. But it is highly probable that other subjects would behave differently. Getting an idea of the nature of the order, they might learn to expect a shorter interval after a long, and not to expect two short ones in succession, etc. Some subjects might be always well prepared for the longest intervals of the series, since after they once knew the limits of the series, if the stimulus had not come after a considerable wait, they could be pretty sure that it was just about due. The effect of order is, no doubt, very complicated, and some subjects would quite certainly behave very capriciously as regards it. At the same time it is highly probable that the process of adaptation as I have described it is very common and one of the chief factors determining the effect of the order of the intervals upon reaction time. This seems likely as the same phenomenon is widely found in the estimation of time. After leaving a long interval, especially one we have had to listen through attentively, a short interval seems unusually short, and vice versa. After working as subject with preparatory intervals of 16 and 20 secs., and then coming back to intervals of 4 secs., I have found them apparently so short that I have gotten up and gone out to see whether the experimenter had not made a mistake and used a 2 sec. interval instead of the 4 sec. one that I desired. The bearing that these results on the effect of interval on reaction time have upon the psychology of time perception, and their similarity to those obtained by Schumann with very short intervals, I have already pointed out. Following the general lines of Schumann's theory, the above-mentioned underestimation of the 4 sec. interval would be due to the fact that the stimulus at its end comes before one is ready for it, and there is a feeling of surprise. The longer interval is overestimated because we get ready too soon for the sound terminating it, and having gotten ready, we have to try to maintain our readiness until it does come. There thus results a feeling or a sensation of strain.[17]

I now feel that I have presented fairly fully the facts of the effect of variation in interval on reaction time. I desire next to take up the explanation of these facts, and especially the explanation of the prolongation in reaction time which occurs as the preparatory interval is changed from 2 secs. to longer intervals, or when a number of preparatory intervals of wide range in duration are used in irregular order. I shall argue that this prolongation is due to the fact that, under the circumstances under which it occurs, the attention of the subject is not maximally adjusted or adapted for the task in hand. This argument is fully justified by the existing literature, though my own observations are sufficient to convince me of its correctness.

As already stated, previous investigators have come to the conclusion that a preparatory interval of 2 secs. gives the shortest times. What explanation do they offer? It will be seen that there is quite uniform opinion that it is a matter of attention. The underlying thought, throughout, is that it takes about 2 secs. for the individual to get as ready as he can get, to adapt or adjust his attention or to obtain a maximum of attention, and that after 2 secs. the degree of attention decreases, either regularly or in a wave-like manner. In the cases where no warning

[17] Wundt writes as follows: "Unerwartete Eindrücke können nun, auch wenn sie von mässiger, ja sehr geringer Stärke sind, eine dem Schreck verwandte Wirkung hervorbringen." *Physiologische Psychologie*, 5th ed., 1903, vol. III, 433. I include any inhibition effect that surprise may have as part of the story when I say that the reaction is longer because the subject is not ready. It is only because of the lack of a suitable preparatory adaptation of attention that the surprise occurs.

signal at all or irregularly mixed preparatory intervals are used, the maximum adaptation of attention will only seldom coincide with the occurrence of the stimulus.

Wundt, in discussing the commonly obtained result that a preparatory interval of from 1 to 2 secs. gives the shortest times, writes: "Ist die Zeit kürzer, so kann eine hinreichende Spannung der Aufmerksamkeit nicht mehr eintreten, ist sie länger, so machen sich die oben bemerkten Schwankungen geltend."[18] The undulations of attention referred to are those constituting the classical "attention wave." The conception is that after maximal strain of attention is once secured, if the subject has longer to wait, the attention begins to oscillate, and at the same time decreases somewhat in general level.

Pillsbury writes as follows: "It is found that unless the attention is aroused by a suitable signal, given about two seconds before the stimulus that is to call out the reaction, that the movement does not reach its maximum quickness. The signal gives the highest degree of adaptation of the attention, and so is but a sub-head under the preceding" [the effect of attention upon the rapidity of movements]. "It is also significant that the period by which the signal must precede the stimulus is nearly half of the length of an attention wave, so that part of the adaptation may consist in the time it takes for the attention to rise to its highest point."[19]

Ladd and Woodworth in their chapter on the temporal relations of mental phenomena offer only the following explanation of the effect of the preparatory interval, namely, that a shorter preparatory interval than 2 secs. does not allow the subject to prepare himself fully for the stimulus, "while a longer period than 2 secs. allows more time than is needed and so affords a chance for wandering of the attention."[20]

Dwelshauvers entitles his study of reaction time "Untersuchungen zur Mechanik der activen Aufmerksamkeit."[21] He

[18] Wundt, *Physiologische Psychologie*, 5th ed., 1903, vol. III, 434.
[19] Pillsbury, *Attention*, 1908, 82.
[20] Ladd and Woodworth, *Elements of Physiological Psychology*, 1911, 482.
[21] *Phil. Stud.*, 1891, 217-249.

found that an interval of 1.5 secs. gave shorter reactions, especially in the case of sensory reactions, though in the motor as well, than did an interval of 3 or 6 secs., the 6 sec. interval giving the longest. He also found that longer reaction times occurred without any signal than with a signal. The following quotations contain his explanation. "Die Reagenten erklärten, dass 1½ und 3 Sec.-Intervalle sich als sehr bequem erwiesen zur gehörigen Spannung der Aufmerksamkeit; 6 Sec.-Intervalle dagegen kamen ihnen unangenehm und ermüdend vor."[22] "Das Signal begünstigt im allgemeinen die Anpassung der Aufmerksamkeit. Die Reactionen, welchen ein Signal vorangeht, sind daher durchweg kürzer."[23]

Bliss, in speaking of the effect of a warning signal writes that the effect of the signal on the reaction time depends on the interval between the signal and the stimulus. "If the interval is too short there is not time enough to concentrate the attention and the warning hinders the reaction instead of helping it. If the time is too long the effect dies away, as the mind is unable to keep its maximum attention for more than 1 or 2 secs."[24]

Moore writes: "The study was commenced with those factors which have been supposed to affect reaction time by their influence on the attention."[25] Among these factors that affect reaction time by influencing attention, the first that he mentions is the duration of the interval between the preparatory signal and the stimulus. His results indicate that when the preparatory signal comes 2 secs. before the reaction stimulus, the conditions are slightly more favorable for reaction time than when it comes at either 1 or 3 secs. before. Moore also studied the effect of an irregular preparatory signal, and found it to consist in a very marked prolongation of the reaction time. In way of explanation, he writes as follows: "The difficulty under which the

[22] *Op. cit.*, 226.

[23] *Op. cit.*, 229.

[24] *Investigations in Reaction-Time and Attention, Yale Psychological Laboratory Studies*, I, 1893, 16-17.

[25] *A Study of Reaction Time and Movement, Psych. Rev. Monog. Suppl.*, 6, 1904-1905, 31.

attention labors in preparing for a reaction when the preparatory signal comes at 1 or 3 secs. beforehand, is certainly slight if compared with the strain of keeping in readiness for reaction when the warning signal is given at irregular intervals or not at all. At the end of such a series of experiments there is a feeling of relief which is indicative of the strain under which the attention was laboring. Previous investigators have found that the efforts of a subject to keep his attention focused were not successful and that the time of reaction was considerably lengthened."[26]

Vaschide and Meunier[27] are very explicit in interpreting the prolongation in reaction time produced by irregular intervals or the omission of a preparatory signal as due to the lack of accommodation of attention. In discussing Wundt's results which show that shorter reaction times are obtained with a preparatory signal than without such, they write: "La raccourcissement du temps de réaction ne peut s'expliquer dans ces cas que par une *tension préparatoire de l'attention.*"[28]

"L'indétermination de l'excitation, soit quant au temps, soit quant à l'intensité, est aussi a considérer. . . ."[29]

"Toutes ces prolongations du temps de réaction semblent avoir origine dans une prolongation de la *durée de l'aperception,* rien ne prouvant véritablement une modification des temps psychophysiques et physiologiques."[30]

These authors seem so convinced that the prolongation in reaction time resulting from the absence of a signal is due to the effect upon attention, that they reproduce the proposals made by Vaschide in his joint publication with Toulouse et Piéron, *Technique de Psychologie expérimentale,* concerning the experimental procedure to be followed when one uses reaction times to obtain an appreciation of the subject's power of attention.[31] This

[26] *Op. cit.,* 33.
[27] *La Psychologie de l'Attention,* 1910.
[28] *Op. cit.,* 21.
[29] *Ibid.,* 20.
[30] *Ibid.,* 21.
[31] . . . "lors qu'on emploie la mesure du temps de réaction à l'appréciation psychologique de l'attention."—*Ibid.,* 44.

procedure resembles that which I have used in the present work, and in brief is as follows: First, 25 simple tactile reactions, with a 2 sec. preparatory interval. Second, 25 simple tactile reactions, without preparatory signal, the stimuli following each other at intervals of irregularly varying length. As the intervals between the stimuli, it is proposed to use the following ten in the order given, the intervals being given in secs.,—5, 10, 10, 5, 10, 15, 5, 5, 10, 5. The maximum and the minimum reaction times of each series is to be noted, but the relative mean variations, that is, the ratios of the mean variations to the averages is regarded as a more precise measure of attention. The difference between the average of the reactions with a 2 sec. interval and of those without a preparatory signal is also suggested as a measure of attention. Choice reactions are also proposed, the same procedure being followed with them as with the simple tactile reactions.

Breitwieser writes as follows: "The most favorable interval must lie between intervals that are less favorable. *A priori,* the concept would seem to be justified beyond question; for, if a subject is not already fully prepared to react on receiving the ready signal, some time must be required for him to reach his maximal degree of preparedness; and again, this maximal degree of preparedness can scarcely be maintained indefinitely." He writes that the subjects often said they found it hard to hold the attention steadily for the longer intervals. That Breitwieser regards the degree of attention as the source of variation in reaction time with variations in interval is shown further by the fact that he uses his results to conclude against an attention wave, concerning which he writes as follows: "Now it would seem that the reaction time ought to be a fairly delicate indicator of flucutations of attention, or of readiness to react; if it indicates so clearly the existence of a most favorable interval, it ought also to indicate the existence of any physiological rhythm of a regular and universal character, exercising an influence upon cerebral efficiency. Our results seem to justify a conclusion adverse to such a rhythm, so far as it could be expected to appear within a space of 10 secs." ". . . our experiments have discovered one type of wave which does remain constant; but this is a very simple type, consisting simply in the occurrence of a most favorable interval."[32]

The above citations are sufficient to show what is usually regarded as the explanation of the prolongation in reaction time which results when long preparatory intervals or none at all are used in place of one of about 2 secs. If the conclusions of the authors I have cited are correct, we must evidently regard it as established that one cannot maintain a maximum adaptation of attention for more than a few seconds, if indeed that long, and further that any letting up of this adaptation will show itself in the reaction experiment by longer times. I think it may be said that there is unanimity of opinion that the prolongation produced in reaction time by unfavorable intervals is due to a lesser degree of adaptation or adjustment of attention. This unanimity of opinions seems to be well justified, not only from theoretical considerations, but on the basis of the experimental evidence. The experimental evidence consists in the introspections of the subjects who have participated in experiments on the effect of variation in interval. Whenever reported, these introspections have been to the effect that with long preparatory intervals or without a preparatory signal, it was impossible to know just when to get most ready, to know just when to expect the stimulus, just how near it was to the time to react, that it was a great strain trying to pay attention through a long interval and that with long or irregular intervals the maximum readiness to react was seldom and only accidentally secured. The maximum degree of attention may at times exist for particular reactions, but more often does not and so, on the average, longer times are obtained.

At this point it is, perhaps, necessary to raise the question whether readiness to react really means adaptation of attention. I believe that this is in agreement with prevalent terminology. The greater the attention to anything, the greater its clearness.

[32] *Op. cit.*, 35-38.

But adaptation of attention is a process implying certain adjustment or accommodation of the nervous system, and secondarily of muscles. With the greater clearness there must go a change in the nervous system. And in expectant attention preparatory to a reaction, there must be an adaptation of the nervous system for the execution of the reaction rather than for the performance of some other action. In short, while increase in clearness is a striking result of attention, increased efficiency is also a result. Everyone admits, it seems to me, that increasing the degree of attention shortens reaction time, and the reaction being a process involving the nervous system, this would not happen unless with higher degrees of attention there occurred an accommodation of some sort of the parts of the nervous system involved both in attention and in the reaction. By adaptation of attention, I mean this nervous process together with the mental parallel. I conclude, then, that it is an established fact that reaction time varies with the degree of adaptation of attention that exists at the time of the occurrence of the stimulus, and that the effect on reaction time of variation in the preparatory interval is due solely to the variation in the degree of adaptation of attention.

With respect to the prolongation in reaction time with the regular procedure, shown in Table I, where each day's work began with the shortest interval and ended with the longest, it might be objected that the subjects reacted more slowly in the case of the longer intervals simply because they had become fatigued by the previous reactions. That this was not the case is certain from results I have obtained with other subjects by the same procedure in which a similar prolongation in reaction time with prolongation in the preparatory interval was found. But in these subjects, after finishing with the 20 sec. interval, without pause except to notify the subject of the change in interval, I proceeded to a regularly repeated 2 sec. interval. It was found that these reactions to the regularly repeated 2 sec. interval, at the end of the hour's work, and after many reactions with the long intervals, gave a shorter average reaction time than the reactions with the 2 sec. interval at the beginning of the hour.

As regards the irregular procedure, any idea that the reactions with the irregularly mixed intervals were longer than those with a regularly repeated 2 sec. interval on account of a state of fatigue upon the part of the subject should be dispelled by the results presented in Tables XVII and XVIII, Chapter V. These tables present reaction times with the regularly repeated 2 sec. interval taken both before and after reactions to a set of irregularly mixed intervals. While the irregular intervals give very much longer reaction times than the regularly repeated 2 sec. intervals, there is very little difference between the reaction times with the 2 sec. intervals before and after work with the irregularly mixed intervals.

In the preceding pages a good deal has been said about the effect of adaptation to one set of intervals upon the reaction time obtained with other intervals. The question may arise whether the prolongation in reaction time with the longer intervals may not be due merely to the previous adaptation to the shorter intervals. This seems improbable from certain theoretical considerations and impossible on the basis of an experimental test reported below. The study of the effect of order already presented shows that the reaction time to any interval is not lengthened, but if anything shortened, when it is preceded by an interval of nearly the same length or slightly shorter. And in the regular procedure all intervals are preceded by intervals of the same length or else by intervals only slightly shorter, as the change from the short intervals to the longer is made by small steps. It is only when an interval is preceded by longer ones that a marked prolongation is apt to occur in the reaction time obtained with it. This is the reason why, in using the regular procedure, I did not proceed in inverse order from the longest intervals back to the shortest. Such a procedure with some subjects results in a prolongation in reaction time obtained with the shorter intervals. In other subjects it does not. In general, the effect of order is greatly reduced when the subject has foreknowledge of the length of all preparatory intervals.

In order to determine experimentally whether the prolongation in reaction time with increase in the duration of the interval could possibly be due to the effect of adaptation to the shorter interval, the following experiment was made. With subject Sh, a practiced subject, the regular procedure, as it has already been described, was used on the first and third days. Intervals up to 20 secs. were used. On the second and fourth days, only reactions with the 20 sec. interval were taken. With the regular procedure the reaction times for the 2 sec. interval averaged 128 σ and for the 20 sec. intervals 178 σ. On the days when only 20 sec. intervals were used, the average reaction time for the 20 sec. interval was 173 σ, and for successive series of 25 reactions the averages were 180 σ, 186 σ, 163 σ and 170 σ. The reaction time with the 20 sec. intervals was then, on the average practically as long on those days when it was not preceded by shorter intervals as on those when it was. This result proves clearly that unless we assume the effect of adaptation to the short interval used on one day to hold over to the following day, the lengthening in reaction time with the longer intervals in the case of the regular procedure could not have been due to any effect left upon the subject by the preceding shorter intervals. We have here, also, further proof that the lengthening in reaction time with the longer intervals in the case of the regular procedure is not produced by fatigue resulting from the preceding shorter intervals, as the reaction time with the 20 sec. interval is just as long when not preceded by any shorter intervals.

Some authors have spoken of the inhibitory effect of feelings of surprise or of strain when the stimulus comes either before or after it is expected, and such undoubtedly occur, as I have myself already pointed out. But the phenomenon evidently depends upon adaptation of attention. Surprise occurs if the stimulus comes before maximal adaptation of attention and a feeling of strain if it does not come until after this maximum. It would be incorrect, therefore, to say that these feelings cause the lengthening of reaction time with long or irregular preparatory intervals. Both the time of reaction and the feelings of surprise or strain depend upon the fact that the subject did not expect the stimulus at the right time. Moreover, in a routine reaction experiment, where the subject is fully instructed beforehand, and sounds of moderate intensity are used, the "surprise" is a very mild experience. So far as my own experience is concerned it seems very much the same thing to me, in this case, to say that the sound surprised me and to say that it came before I was expecting it. The feeling of strain, in the case of the longer intervals, may at times be more definite; but this merely indicates the difficulty of maintaining a high degree of adaptation of attention for any length of time. I sometimes feel, especially when I am out of practice, a high degree of strain right at the time of reaction, with a 2 sec. interval, and yet give shorter reactions than with long intervals when no great strain was experienced. Strain would seem if anything to be correlated with high degree of accommodation of attention, but at any rate could certainly not explain the lengthening in reaction time with the long or irregular intervals.

There is, however, one other factor than accommodation of attention, as I have already mentioned, which plays a very important rôle in the effect of variation in interval, wherever the regular procedure is used. This is the perception of time.[33] With a regularly repeated interval the subject soon learns when to expect the stimulus, provided he can learn the interval. It it not necessary to raise the question as to what intervals may be estimated with the greatest accuracy relative to their length. But it is evident that short intervals of about 2 secs. may be estimated with much smaller absolute error than long intervals. It is quite certain that from about 2 secs. up, through the range of intervals used in this research, the absolute size of the error would more or less regularly increase, whether according to Weber's law or not. Now we do not know just how long it is possible to maintain a maximum degree of adaptation of attention. It takes about 2 secs. to reach this maximum, and it probably is not maintained for more than 1 sec.[34] Now some

[33] See G. Duechler, "Beiträge zur Erforschung der Reaktionsformen," II Abhandlung, *Psychol. Stud.*, 1913, 128–129.

[34] "If the stimulus be absolutely simple and one is careful to record each

people are, of course, able to estimate an interval of 2 secs. more accurately than others, but it is rather doubtful if any normal individual would estimate this interval so inaccurately that the stimulus, coming at the end of a regularly repeated 2 sec. interval, would not find the subject at his maximum of adjustment. In other words, I do not believe any subject would err in his estimation of an interval of 2 secs. by an amount greater than the time that it would be possible for him to maintain an approximately maximal adjustment of attention. We have not yet data by which to answer this question with certainty, but I think for all practical purposes at least, we may assume that with a regularly repeated 2 sec. interval any normal individual, and probably also almost any abnormal individual, would be able to adjust himself to the reaction to as great a degree as is possible for him at all. With longer intervals, at any rate with intervals over 4 secs., since above this length of interval the reaction time is quite certainly longer, the case is different. Subjects would not be able to judge these intervals accurately enough to be always sure of reacting with a maximal degree of attention. The more inaccurately they estimated the interval, that is, the less accurately they could tell just when the stimulus was due, the less perfect would be the adaptation of attention, on the average, at the time of the reaction. As the absolute inaccuracy of their estimations of the intervals would increase with the length of the intervals, it is evident that the longer the interval, the lower would be the degree of attention, on the average, at the time of the reaction. This would explain the rather gradual and regular prolongation in reaction time with increase in length of interval, when the regular procedure is used.

Now individuals would differ in their ability to estimate these intervals, and thus with the longer intervals differences in the ability to estimate intervals might play an important part in explaining differences in the amount of prolongation of reaction time with prolongation of interval. Since the duration of maxi-

appearance of something else, it seems that one can hold attention strictly to a single thing for less than a second." Pillsbury, *The Essentials of Psychology*, 1911, 123.

mal adaptation of attention under given reaction conditions would be very nearly a constant no matter what the duration of the preparatory interval, and since the errors in estimating intervals on the other hand would increase in absolute size with their length, inaccuracy in estimating the intervals would become more detrimental to the likelihood of securing maximal adaptation of attention the greater the length of the interval. And the less the likelihood of maximal adaptation of attention, the less would be the degree of attention on the average, actually met with by the stimulus. So that while I believe that with an interval as short as 2 secs., estimation of time would not be a factor of any importance in causing individual differences, since with it all subjects would secure maximal adjustment, it would quite certainly have influence in the case of the longer intervals.

Theoretically speaking, it would be hard to say that there would be any interval so long that a further increase in its length would not result in still longer times. The longer the interval the greater would be both the mean variation and the absolute temporal range of the distribution of a number of estimates of its length, and the greater the range of distribution of these estimates, the smaller the proportion which would fall within the limits of that duration for which a maximal adaptation can be maintained, and the more frequently would the lesser degrees of attention occur at the moment of reaction. But as already shown, the reaction time increases only slowly after very long intervals are reached. This is probably because the very long intervals are estimated so poorly that very little adaptation of attention is possible anyway,—the subject realizes that it is hardly worth while to attempt to hold himself in special preparedness at any particular instant, and consequently adaptation of attention becomes practically insignificant in amount. So that all the extremely long intervals would probably give about the same reaction time because no particular adjustment would be possible, and a few seconds more or less would make but little difference. We can thus understand why the curve showing the prolongation in reaction time with increase in the duration of the preparatory interval rises at first faster and then slower, with regular increase in the duration of the preparatory interval. Adjustment is considerable at first and interfered with to a considerable degree by slight increases in the absolute variability of the estimations of the interval. But with longer intervals there is less adaptation anyway, and there is consequently less detrimental effect from further increases in the absolute variability of the estimations of the intervals.

It is thus evident that time estimation has a great deal to do with the prolongation in reaction with prolongation in preparatory interval in the case of the regular procedure. In the case of the irregular procedure, on the other hand, where the different intervals are mixed irregularly, the perception of time is of negligible importance, for in this case, there is no interval to be estimated. With the irregular procedure, there is no great degree of adjustment to any interval, as is shown by the comparative equality of the times for the different intervals, and by the fact, already mentioned, that the general run of the reaction times is much longer with the irregular than with the regular procedure. There is quite likely to arise, however, a tendency on the part of the subject to be slightly more prepared, on the average, for the intervals of about the middle length of the series used, and so to be slightly less prepared for the stimuli following the shortest intervals. The effect of the order of stimuli I have already discussed.

I believe now that I have offered the correct general explanation of the effects of variation of interval, and the differences in the effect of the two procedures, which I have referred to as the regular and irregular. I have only to mention the increase in reaction times with intervals shorter than 2 secs. I am not particularly interested in this point, but the generally accepted explanation is, of course, that the process of accommodation or adaptation of attention requires about 2 secs. to reach its maximum degree.

I wish lastly to refer to the use of long or unfavorable intervals as detractors.[85] If we regard a regularly repeated 2 sec. interval as the most favorable, regularly repeated long intervals

[85] For definition of this term, see introductory chapter, p. 9.

or irregularly distributed intervals would be unfavorable, and the effect of the latter, which is to produce a lengthening of the reaction time, may be regarded as a detraction effect. If the explanation that I have given of their effect is correct, it is evident that in the case of the irregular procedure, where perception of time does not enter as a factor, we are dealing with a very pure form of detraction from attention. That is, the prolongation in reaction time is due to the fact that we place the subject under conditions which are not the most favorable for a high degree of adaptation of attention to the reaction. In the case of long intervals with regular procedure detraction is involved, but dependent upon the ability to estimate intervals. The quickness of the reaction is varied by operating upon the subject's estimate of intervals as well as upon the degree of his attention. With the irregular procedure, however, the prolongation is due entirely to the fact that there is less adaptation of attention. Consequently, if we wish to use unfavorable intervals as a detractor, evidently we must use the irregular procedure, except in the case where no comparisons are to be made between different individuals.

To sum up, a regularly repeated 2 sec. interval gives the maximal adaptation or adjustment of attention of which the individual is capable. A given set of totally irregular intervals varying from 4 to 20 secs. constitutes a definite obstacle to the attainment of this maximal adaptation. Such a set of intervals produces prolongation of reaction time solely by its effect as a detractor from attention. We have here, then, a satisfactory method of detraction.

This method of detraction has advantages which make it far superior to any of the distractors of attention hitherto used as detractors.[36] It is well known that no satisfactory *dis*tractor has yet been found.[37] In any case where there is divided atten-

[36] Külpe: "It is clear that the mere employment of distracting stimuli of a certain intensity or number is absolutely no guarantee that a corresponding distraction of the attention has actually been accomplished." *Outlines of Psychology,* 1901, Trans. by Titchener, 429.

[37] Geissler found that even the most complex combination of distractors, after a few days' work failed to induce great variations in attention. *Op.*

tion it is impossible to determine what proportion of attention is involved in each of the different processes. As regards other detractors, such as drugs, fatigue, etc., we have none so far as I know that can be shown to act exclusively on the process of attention, nor could we rely on such to constitute always the same amount of detracting influence. We get in many cases, undoubtedly, detraction from attention, perhaps principally that, but other detrimental effects as well, so we cannot say how much of the decrease in efficiency of the tested function is due to decrease in degree of attention and how much to an effect upon other factors than attention. Similarly with weakening the intensity of the stimulus. Intensity is undoubtedly a condition of attention, and in decreasing the intensity of the stimulus we decrease the degree of attention, other things equal, involved in its perception. But this lowered intensity of stimulus may cause prolongation of reaction time for other reasons than that of consequent lowered attention, as, for example, a longer latent period in the stimulation of the sense organ.[88] While unfavorable preparatory intervals may be the best detractor hitherto employed for the purpose of measurement of attention, nothing that has been said should be interpreted as meaning that other equally good detractors may not be discovered. The writer is at present engaged in an investigation in which a quite different sort of detractor is used,—used, however, in accordance with the main principles established in the following chapters.

SUMMARY

It is necessary in reaction experiments to distinguish sharply between two principal procedures: the first, that in which the same preparatory interval is used a number of times in succession, and change from one preparatory interval to another made in regular order from the shortest to the longest; and the sec-

cit., 513. More recently Dallenbach has come to the following conclusion: "The difficulty of obtaining a graded series of distractors is very great. In our experience, the action of the distractors is not constant, but varies from day to day, and from observer to observer." *Op. cit.*, 507.

[88] Piéron, *Recherches sur les lois de variation des temps de latence sensorielle en fonction des intensités excitatrices, L'Année Psychol.*, 1914, 17-96.

ond, that in which a number of preparatory intervals of widely different length are mixed in irregular order.

The effect of variation of the preparatory interval on reaction time, when the first procedure is used, may be summarized as follows: Intervals very near 2 secs. are the most favorable. As the interval is shortened below this most favorable region, or lengthened beyond it, the reaction time increases in a marked manner. The increase which occurs with prolongation in the preparatory interval beyond the most favorable is at first rapid, but becomes less and less marked with further increase in the duration of the interval. This increase continues to intervals over 24 secs., and is in accordance with the law, $y = A + B. \log x$, in which y = reaction time, A and B are constants, and x = the duration of the preparatory interval.

With the second procedure, that in which a number of preparatory intervals of widely different length are mixed in irregular order, little difference in reaction time occurs with the different intervals, and the reaction time obtained with each interval depends largely on the order in which the intervals are given and on the individual characteristics of the subject. A noticeable general tendency exists, however, for the longest reactions to occur with the longest and with the shortest intervals of the series, especially however with the shortest intervals, and for the shortest reactions to occur with the intervals of medium length.

An interval of about 2 secs. with the first procedure gives the shortest reaction times for any individual obtainable under any conditions. Even when the same preparatory interval is repeated a number of times in succession, maximal adaptation of attention is impossible if the interval varies much from 2 secs.

The average reaction time for the whole series, using the second procedure, of irregularly mixed and widely differing intervals, is as long as that with a very long (over 24 secs.), regularly repeated interval.

The marked prolongation in reaction time which occurs as we change from a regularly repeated preparatory interval of 2 secs. to a set of widely different irregularly mixed intervals is due solely to the fact that in the latter case the reactions occur with less adaptation of attention to the reaction. We have, therefore, in the method of using an irregularly mixed series of widely different preparatory intervals, a method of securing less than maximal adaptation of attention, that is, a method of detraction from attention. This detraction not only acts solely on the attention, but is eminently controllable, and very uniform in its action on a given subject.

Incidentally, the data of this chapter have an important bearing on the perception of time. Since, with the regular procedure, the increase in reaction time is regular and in accordance with the same law from 2 secs. up through 24 secs., and since the increase in reaction time with this procedure is dependent upon the decrease in the absolute accuracy of the estimation of the intervals, it follows that the absolute accuracy of the estimation of intervals decreases in accordance with a law which holds without break from 2 secs. up through 24 secs. It is consequently incorrect to say of any interval less than at least 24 secs. that it is the longest which can be grasped as a single temporal perception.

CHAPTER III

The Law of Detraction

In the last chapter I arrived at the conclusion that the use of an irregular series of widely different preparatory intervals or of regularly repeated but long preparatory intervals produced a marked prolongation of the reaction time beyond that obtained by the use of a regularly repeated 2 sec. interval; and that this prolongation was due to the lessened average degree of adaptation of attention which occurs as the result of the use of irregularly mixed or long preparatory intervals. The amount of the detraction effect produced by the irregular series of intervals is measured by the increase in reaction time beyond that obtained with a maximum adaptation of attention, that is, with a regularly repeated 2 sec. interval. Having concluded that we have here a satisfactory method of detraction from attention, I naturally took up next the investigation of the behavior of attention under detraction.

A condition could hardly be spoken of as a detractor from attention, unless, other conditions constant, it resulted in lessened efficiency in the processes to which the attention in question attached. Most writers insist that in a detraction method of some sort lies the best hope of obtaining a practical method of measuring attention, provided that suitable detractors (hitherto usually thought of as distractors) can be found. But how the decrease in efficiency, which measures the detraction effect, is to be used in measuring the degree of attention, has, it seems to me, never been worked out. It is true that some law of detraction has often been assumed or implied, though comparatively seldom stated. The implication usually has been that the better the attention the less would be the detraction produced by a stated detractor.[1]

[1] A good statement of a law to this effect is given by Deuchler in a footnote summing up some of the most important laws of attention. "Je groesser die

That a given detracting condition produces an effect varying inversely as the degree of attention against which it is directed seems fairly plausible, perhaps, but I hesitated to accept a law like this for use in the measurment of attention until it had been experimentally established. It is worth while to know how to prove even that which seems axiomatic, and the law of the relation between the degree of attention and the effect of a given detractor is far from axiomatic. That the matter has never been thoroughly thought out is indicated by the fact that no mention is usually made as to whether equal relative decreases in efficiency or equal absolute decreases, produced by a distractor, would indicate equal degrees of attention; and this point is, of course, of fundamental importance in any practical measurement of attention. Some writers seem to imply that we should take the percentage of decrease, but why should we do so? We wish to use detraction effects as measurements of attention. These effects may be equal relatively and widely dissimilar absolutely, or equal absolutely but widely dissimilar relatively. How then are they to be used as measurements of attention? This question, I believe it will be readily admitted, is one whose answer is not self-evident; and even after the experimental work reported in these chapters, I feel capable of giving an answer that will hold only for a particular kind of procedure, a particular kind of detractor and a particular kind of measurement of the efficiency of the function in which the effect of the detractor becomes noticeable. As I wish at this point merely to indicate that a problem demanding experimental solution exists, and that the problem is an intricate one, I shall reserve my answer to the same until after the presentation of data.

The problem of the relationship between the degree of atten-

Aufmerksamkeits Intensitaet bei der Einengung oder bei der Konzentration ist, desto groesser ist der Widerstand gegen innere oder aeussere Stoerungen." *Beitrage zur Erforschung der Reaktionsformen, Psych. Stud.*, 1913, 223. *Cf.* also Kuelpe, "The attention to a definite content is regarded as inversely proportional to the magnitude of the distraction." *Outlines of Psychology,* trans. by Titchener, 1901, 428. "Distraction" as here used by Kuelpe evidently means the distracting effect produced by a "given" distracting condition or set of conditions.

tion and the effect of detracting conditions is a problem of the relationship between two variables. One of these variables is the degree of attention operated upon, the other is the amount of detraction effect produced by a given detractor. We ought to have, therefore, not only a reliable detractor, which would affect solely the degree of attention, and which would produce a measurable detraction effect, but also different degrees of attention which would be measurable, since we cannot plot a relationship between two variables unless we can measure each. Since my ultimate problem is just that of the measurement of different degrees of attention, it may be readily imagined that it was impossible to have such an ideal set of conditions. The detractor I used was reliable, acted solely on attention and produced very exactly measurable effects; but for the different degrees of attention, I had to be content with ranking them in order.

The different degrees of attention in order to be satisfactory for my purpose had to be produced with steadiness and reliability, so that I could be sure of what the detractor was working on throughout a long series of measurements. The ordinary detractors which are also distractors, such as some simultaneous mental process, would not do for this purpose, i.e., securing steady differences of attention, as it is well known that they are unreliable.[2] The method of obtaining different degrees of attention which I finally decided upon as the first to try out, is one which is very simple. I again resorted to the use of a detractor which was *not* at the same time a distractor. As has already been pointed out, one such detractor, when the task in which attention is involved is a simple reaction, consists in preparatory intervals other than regularly repeated 2 sec. intervals, the best thing being a set of widely different irregularly mixed intervals, though regularly repeated long intervals may also be used, as long as no comparison between individuals is desired. Now there are conditions of attention, in the reaction, other than a 2 sec. preparatory interval. And if the phrase so often used "conditions of attention" means anything, it means that when the conditions

[2] See Titchener, *The Psychology of Feeling and Attention*, 1908, 278.

of attention are fulfilled, other conditions constant, a higher degree of attention is secured than when they are not fulfilled. Of all the conditions of attention, there is none more generally recognized than intensity of stimulus.[3] In spite of the fact that intensity of stimulus is so universally admitted to be one of the conditions of attention, it is still possible that some will hesitate to accept it at its full significance as such. Intensity is a condition which, as Kuelpe puts it, is primarily valid for the phenomenon of involuntary attention.[4] And the mistake of identifying attention with secondary attention is not uncommon, even with the professional psychologist.[5] But we cannot but admit that intensity of stimulus is a condition of attention and that when other conditions are equal, more or less intensity will bring about a greater or less degree of attention. Consequently, by using different intensities of stimulus in the reaction time experiment we secure different degrees of attention.

It is true that the evidence cited in support of the generally accepted statement that intensity of stimulus is a condition of attention consists chiefly in casual observations.[6] We do not

[3] "Ein intensiver Eindruck wird in der Regel, sofern nicht besondere Dispositionen entgegenwerken, klarer appercipirt als ein schwacher." Wundt, *Physiologische Psychologie*, 5th ed., vol. III, 1903, 340.

[4] "But we also distinguish different *degrees* of attention, according to the intensity of the concentration or the steadiness of its hold upon the various contents. We must, therefore, so far as we can, elucidate the conditions of these degrees of attention. . . . All these conditions including intensity of stimulus are primarily valid for the phenomenon of involuntary attention. But they are also of influence upon the voluntary form of the process, as is shown in the increased ease or rapidity with which the attentive act is accomplished under their direction. And they enable us at the same time to explain the relative vividness, the greater or less degree of attention in the individual case." Kuelpe, *Outlines of Psychology*, trans. by Titchener, 1901, 437.

[5] "This mistake of identifying attention with secondary attention, is especially natural to the man of science, who is always puzzling and searching. So it comes about that psychologists have proposed to measure the degree of attention by measuring the degree of effort, which accompanies it." Titchener, *A Text-Book of Psychology*, 1909, 294.

[6] Titchener writes ". . . the appeal to casual introspection is a confession of scientific weakness, and the remark applies in the present instance. . . . The general dependence of clearness upon intensity of stimulus is an evident

know how the degree of attention varies with the degree of intensity, but however this may be, it seems a conservative assumption that differences in intensity great enough to produce very large modifications in reaction time will condition different degrees of attention. It is known that reaction time does not ordinarily vary much with medium ranges of intensity, especially in the case of sound. Wundt explains this relative constancy of reaction time for medium intensities as being due to the constancy of attention,[7] and apparently concurs with Martius, who explains the slowing in reaction time with weak intensities as due to a lesser degree of adaptation of attention.[8] There may, then, be some ground for the belief that the degree of attention is different whenever we have as the result of differences in intensity of stimulus a difference in reaction time. The quickness of reaction to visual stimuli, in turn, up to moderate intensities has been found to vary, roughly, with intensity, in about the same way as apparent intensity varies with variation in intensity of stimulus.[9] In so far then as a parallelism exists between the variation in reaction time with intensity and the variation in

fact, but it is a fact that we must leave in the rough." *The Psychology of Feeling and Attention*, 1908, 189-190.

[7] Die eroerterte zwischen den Grenzen des Minimal und Maximal-reizes bestehende durchschnittliche Constanz der Reactionszeit zeigt deutlich, dass diese wesentlich von psychophysischen, mit der Aufmerksamkeit im Zusammenhang stehenden Vorgaengen abhaengt, und dass auf sie die Leitungsverhaeltnisse in den Nervenfasern, die, wie die Untersuchung der Leitungsgeswindigkeit zeigt, keineswegs unabhaengig von der Reizstaerke sind, wahrscheinlich keinen erheblichen Einfluss haben." *Physiologische Psychologie*, 5th ed., vol. III, 1903, 430.

[8] "Der Grund der Zunahme der Reactionszeit bei abnehmender Reizintensitaet, wie sie bei sorgloser Ausfuehrung der Reaction ueberall auftritt, liegt in der Schwierigkeit der Perception schwaecherer Eindruecke und in der langsameren Coordination von Eindruck und Bewegung.

Zur Annahme, dass rein physiologishe Gruende in den Leitungsvorgaengen die Reactionszeit der schwaecheren Eindruecke verlangsamen, liegt kein directer Anhaltspunkt in dem Reactionsversuchen vor." Martius, *Philos. Stud.*, 1892, 486.

[9] ". . . the conclusion may safely be drawn that the time of reaction tends to increase arithmetically as the intensity of the stimulus decreases geometrically." Froeberg, *The Relation Between the Magnitude of Stimulus and the Time of Reaction, Archives of Psychol.*, 1907, 15.

the degree of attention with intensity, to an equal extent would a parallelism exist between degrees of attention and apparent intensity, in so far as both were determined by the intensity of stimulus. Now, I should not regard it at all safe to assume anything so definite as a parallelism between the degree of attention and apparent intensity, but believe that enough parallelism exists between reaction time and the degree of attention, in so far as both are dependent upon intensity of stimulus, so that it is safe to assume that a *decrease in intensity sufficient to give a large decrease in reaction time will also condition a lower degree of attention.* That this assumption is correct is clearly demonstrated by the experimental data presented later.

In this connection, it may be pointed out that in view of the fact that the preparatory interval in reaction time may be manipulated in such a way as to constitute a reliable and constant detractor from attention, we have here not only a procedure for determining whether intensity is a condition of attention, but also a method of measuring its strength as a condition of attention. Here is a method suited to a large field of quantitative investigation. We use a fixed detractor from attention, a detractor, it must be remembered, which produces its effect by acting exclusively upon attention, and then vary any other factor we wish. If the variation of this other factor produces variation in the effect of our fixed detractor it is a condition of attention. Its strength as a condition of attention is indicated by the amount of the change variation in it produces in the amount of detraction effect produced by our fixed detractor. I have experimented in this way with respect to intensity of stimulus, and have obtained a result which clearly demonstrates that intensity is a condition of attention.

The procedure, then, for determining how the effect of a given detractor of attention varies with the degree of attention was as follows: Four different intensities of light stimuli were used, and in the case of each intensity the detraction effect produced by unfavorable preparatory intervals was determined. It was assumed that degrees of intensity of stimulus sufficiently different to give marked differences in reaction time would condition different degrees of attention, and that the highest degree of attention would be obtained with the greatest intensity of light. In the selection of the four widely different intensities of light stimulus, the simple reaction time with a regularly repeated 2 sec. interval served as a guide. I tried to obtain intensities which, with a preparatory interval of 2 secs., gave reaction times differing by about equal amounts from each other.

Now while intensity is a condition of attention, it has not been shown that variations in intensity affect no other factor in the reaction than the factor of attention. But the point is that different degrees of attention are secured; and since the detractor used detracts from attention *only*, it would not have a different effect in the case of the different intensities except in so far as it operated upon different degrees of attention. Variation in anything else than attention would not change the effect of the detractor. The application of the given detractor of attention could produce different results in the different cases, only providing it met with different degrees of attention. Whatever other differences than differences in attention might exist, it is the attention component solely that would be acted upon by a detractor which detracts from attention.

The best method of using unfavorable preparatory intervals as a detractor is to use an irregularly mixed series of widely different intervals. But it is also true, that regularly repeated long intervals produce a lengthening of the reaction time, and that the immediate cause of this lengthening is a lessening of the degree of adaptation of attention. The method of regularly repeated long intervals is unsatisfactory as a method of detraction providing we wish to compare the attention of different individuals, because differences in individuals' capacities to estimate long intervals would come in as a serious complicating factor. In the case of a single subject, however, the capacity to estimate intervals may be regarded as a constant factor, or at any rate one which is not likely to change markedly or suddenly with variation in the intensity of stimulus. This method of using long regularly repeated intervals is, therefore, a satisfactory method of detraction in the case of a single individual. The prolongation in reaction time is always due to a lesser degree of attention. If the interval cannot be estimated accurately enough for the subject to know just about when the stimulus is due, he will be less ready to react when the stimulus comes; in other words, the stimulus will meet with a lower degree of attention. In an experiment like the present, which aims at an understanding of the effect of intensity on the detraction effect of unfavorable preparatory intervals, it seemed better to work out the whole curve in the case of each intensity, of the effect of prolonging the preparatory interval, than to use merely one set of irregularly mixed intervals. The effect is in this way shown more in detail.

While I have stated my problem as the measurement of the effect of a given detractor upon four different degrees of attention, with the object of determining how the detraction effect may be used to measure the degree of attention, the study actually made may also be stated simply as one in reaction time. So stated the problem would run: How does the effect of variation in the preparatory interval vary with variation in the intensity of the stimulus? It is the problem of the effect upon reaction time of combined variations in intensity of stimulus and duration of preparatory interval, and is one that has not hitherto been systematically investigated. As will be seen, the effect of the two factors working in combination is not merely the sum of the effect produced when each acts separately.

As regards the apparatus and procedure, the arrangements were similar to those described in the last chapter in connection with Table I, a Hipp's chronoscope being used, with the same storage battery and control apparatus. The stimulus, however, consisted in a light in place of a sound. For the purpose of exposing this stimulus a stereopticon lantern was used. I experimented with the Bergstroem apparatus,[10] but found a stereopticon more satisfactory. The projection screen consisted of a ground glass plate

[10] Bergstroem, *Pendulum Chronoscopes and Accessories for Psychological Experimentation*, *Psych. Rev.*, 1910, 1-18.

fixed into a small window that had been built into the wall between the dark room in which the subject was placed, and another room in which were the experimenter, the stereopticon and the chronoscope. Felt screens arranged all about the glass plate between the two rooms and about the streopticon cut off all light falling upon the glass plate except that projected through the lenses of the stereopticon. A stereopticon slide was made by pasting black paper entirely over a colorless cover glass, except for a very small square aperture in the middle. At the short distance used between stereopticon objective and the screen, the image of this square when projected upon the screen had a size of 2.2 cms. by 1.2 cms. The exposure of the image was controlled by means of a Seashore tachistoscope, placed in the path of the rays of light, not far from the nodal point. If the shutters of the tachistoscope opened just the slightest bit the image was visible. The shutters of this instrument are held closed by an electro-magnet, and when the circuit through the magnet is broken, pulled open by springs, and in the case of the lower shutter, by gravity also. By attaching light glass pointers to the shutters and having them mark on a kymograph alongside a 250 d.v. fork and a signal magnet, I found that the time required for the upper shutter to open completely was 20σ and for the lower, 14σ: but the time from the break of the current, registered by the signal magnet, till the time when the shutters had opened far enough to expose the image was only 8σ. The exposure of the light was delayed, then, 8σ after the breaking of the electric circuit which held the shutters together. From this constant error 2σ was deducted, as the latter constant was found to be the time elapsing from the moment the break occurred in the tachistoscope circuit to the moment the make occurred in the chronoscope circuit. This left a net constant error in the reaction times of 6σ, which was deducted from all averages obtained. This constant error, while measured with all possible exactness, is probably of little or no importance, in view of the fact that it is only the comparison of reaction times under different conditions that is here in view, not the absolute times.

Since it was desirable to use a different current for the tachistoscope than for the chronoscope, a rigid double switch was used, constructed in such a way that as one half the switch opened the tachistoscope circuit, the other half, insulated from the first, closed the chronoscope circuit.

To obtain different intensities of light, tungsten lamps were substituted as the source of light in place of the carbon arc of the stereopticon. Four different intensities were used, the different intensities being obtained with a 250-watt, or a 40-watt, all-frosted bulb, placed at suitable distances back of the stereopticon lenses. The intensity of the image upon the projection plate was not measured, as the variation in reaction time with intensity was not my problem. The reaction time itself served me as an index of the intensity. I used two subjects with all four of the intensities.

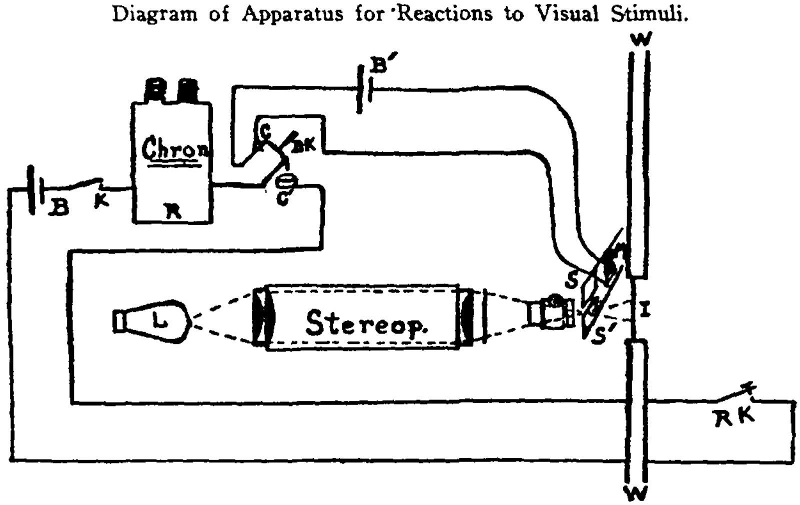
The subject sat 4 ft. away from the image, and straight in front of it, at a table upon which was clamped the reaction key: The room was a fairly "sound-proof" dark-room, but was illuminated, somewhat dimly, by a single 40-watt all-frosted bulb situated about 20 ft. behind the subject. The object of this illumination was to render visible to the subject a black fixation cross drawn in ink upon the ground glass screen at the exact place where the light stimulus appeared. The image appeared and disappeared with all imaginable suddenness, except when the intensity was very faint, in which case it sometimes seemed gradually to grow into its maximal brightness. The subject sat in the dark room for fifteen minutes before beginning to react, so as to become fairly well adapted to the degree of illumination, and thus avoided the risk of a change in the apparent intensity of the light stimulus as the result of changes which might occur in the state of adaptation of the retina. The instructions (one subject was the writer) were for the "motor" form of reaction. This form was chosen for the reasons stated in the last chapter, and in the present instance for the additional reason that both subjects were highly practiced in this form of reaction, and could be expected to stick very closely to a stereotyped form of reaction throughout the entire experiment.

The warning signal was a very short ring of a damped electric bell. The experimenter determined the interval between warning signal and stimulus as accurately as possible by counting the beats of a metronome. All the manipulations of the experimenter were absolutely inaudible to the subject in the dark-room, thanks to the fact that the ground-glass screen was built right into the wall separating the two rooms.

A diagram of the apparatus is given in Fig. 6.

FIGURE 6

Diagram of Apparatus for Reactions to Visual Stimuli.



B = storage battery.

B' = origin of the tachistoscope circuit, a circuit shunted off from a 110 volt direct current supplied by the university.

K = key, non-essential, but convenient.

Chron. = Hipp's chronoscope.

R = slide resistance connected in parallel with the chronoscope.

C and C' = contacts for double key.

DK = double key.

M = electro-magnet controlling tachistoscope shutters.

S and S' = tachistoscope shutters.

L = tungsten lamp.

Stereop. = stereopticon.

I = oblong image on ground glass plate. This image constituted the stimulus.

WW = wall separating the experimenter from the subject.

RK = subject's reaction key.

The double key, DK, when raised to touch the contact C, closed the tachistoscope circuit, which passed through the electromagnet, M, holding the shutters SS′ of the tachistoscope closed, and thereby cutting off the image of light at I. The slightest

TABLE VIII

The Effect of Variation in Intensity on the Effect of Variation in the Preparatory Interval, in the Case of Reactions to Light with the Regular Procedure.
Subject Vs.

N, for each interval of each series = 25. Total No. of reactions = 3700.

Interval		1	2	4	8	12	16	20	24	28
Bright...	Series I....	218	211	214	238	265	288	291	299	300
"		*24*	*10*	*20*	*14*	*27*	*20*	*27*	*26*	*29*
"	" II...	198	193	205	231	247	271	274	292	291
"		*11*	*11*	*11*	*28*	*16*	*22*	*24*	*23*	*29*
"	**Average....**	**208**	**202**	**210**	**235**	**256**	**280**	**283**	**296**	**296**
Dim.....	Series I....	285	287	287	326	354	390	400	406	391
"		*23*	*23*	*19*	*34*	*32*	*61*	*43*	*43*	*49*
"	" II...	270	284	303	328	375	388	384	403	408
"		*26*	*23*	*25*	*36*	*51*	*63*	*58*	*58*	*49*
"	" III..	265	280	308	335	383	444	438	438	445
"		*19*	*17*	*27*	*31*	*49*	*76*	*98*	*52*	*70*
"	" IV...	294	303	301	333	384	397	392	400	402
"		*22*	*35*	*11*	*23*	*52*	*31*	*33*	*36*	*21*
"	" V....	314	298	328	356	385	413	419	425	438
"		*23*	*15*	*19*	*25*	*43*	*71*	*54*	*48*	*51*
"	**Average....**	**286**	**290**	**305**	**336**	**376**	**406**	**407**	**414**	**417**
Quite dim	Series I....	313	348	370	423	477	467	518	480	471
"		*21*	*36*	*36*	*55*	*95*	*78*	*90*	*83*	*56*
"	" II...	280	297	333	358	459	452	418	476	485
"		*48*	*38*	*37*	*25*	*72*	*58*	*36*	*41*	*52*
"	" III..	316	329	330	378	432	500	468	495	501
"		*17*	*15*	*21*	*46*	*54*	*83*	*67*	*69*	*71*
"	" IV...	315	304	402	405	416	436	449	446	499
"		*23*	*31*	*76*	*56*	*34*	*36*	*64*	*48*	*86*
"	" V....	320	328	363	435	447	443	527	483	505
"		*35*	*44*	*50*	*41*	*52*	*39*	*88*	*39*	*69*
"	**Average....**	**309**	**321**	**360**	**400**	**446**	**460**	**476**	**476**	**494**
Very dim	Series I....	372	368	398	453	671	611	651	654	...
"		*59*	*48*	*75*	*49*	*141*	*174*	*149*	*140*	...
"	" II...	355	400	421	625	611	641	696	655	...
"		*47*	*61*	*71*	*111*	*115*	*117*	*127*	*139*	...
"	" III..	389	426	485	467	472	582	581	595	...
"		*61*	*61*	*81*	*66*	*98*	*111*	*75*	*94*	...
"	" IV...	325	373	419	484	488	505	458	528	...
"		*27*	*49*	*70*	*78*	*80*	*101*	*52*	*89*	...
"	" V...	385	365	395	480	513	499	523	543	...
"		*93*	*53*	*73*	*86*	*100*	*92*	*91*	*99*	...
"	**Average....**	**365**	**386**	**424**	**502**	**551**	**568**	**582**	**595**	...
Average for all intensities............		292	300	325	368	407	429	437	445	...

downward movement of the key, DK, broke the tachistoscope circuit, and made the chronoscope circuit through the contact C′, thus causing the shutters to fly open and the image to appear at I at the same moment that the chronoscope circuit was made. The time between the break at C and the make at C′, however, was long enough to be measurable, and was found to be about 2 σ, already mentioned as a constant error.

With each of the four intensities reactions were taken with preparatory intervals varying from 1 to, usually, 28 secs. Twenty-five reactions were taken in succession with each interval, beginning with the shortest interval and going up to the longest and then stopping for that day. Each Series in Tables VIII and IX gives the results for one day's sitting. The intervals are given in secs. in the first line of the tables, headed Interval. The

TABLE IX

Same as Table VIII, but Subject Ww.

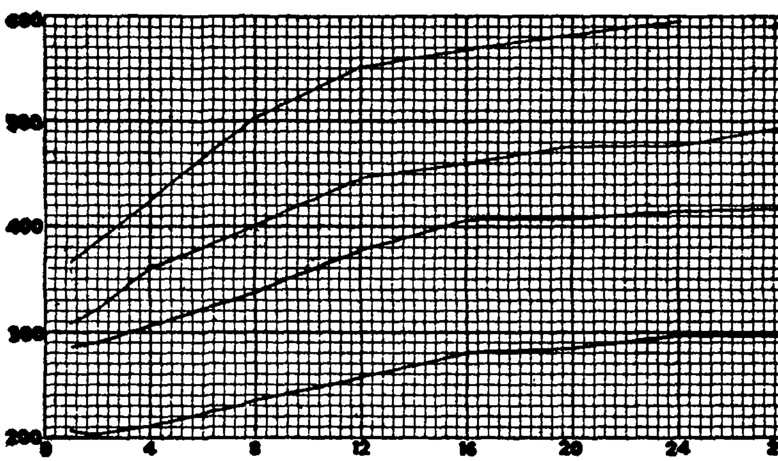
N, for each interval of each series = 25. Total No. of reactions = 1675.

Interval		1	2	4	8	12	16	20	24
Bright.....	Series I.......	197	202	218	228	238	251	266	256
"		*14*	*11*	*14*	*15*	*18*	*23*	*18*	*23*
"	" II......	184	173	198	210	236	243	242	258
"		*16*	*9*	*16*	*18*	*28*	*20*	*25*	*16*
"	**Average**......	**191**	**188**	**208**	**219**	**237**	**247**	**254**	**257**
Dim.......	Series I.......	271	253	270	335	342	376	362	371
"		*32*	*12*	*19*	*25*	*28*	*25*	*21*	*25*
"	" II......	258	244	268	279	300	327	350	353
"		*18*	*14*	*13*	*14*	*30*	*24*	*24*	*20*
"	**Average**......	**265**	**249**	**269**	**307**	**321**	**352**	**356**	**362**
Quite dim..	Series I.......	338	322	356	433	434	462	491	...
"		*30*	*24*	*26*	*42*	*49*	*49*	*53*	...
"	" II......	320	316	330	373	401	434	426	...
"		*35*	*29*	*26*	*38*	*56*	*45*	*40*	...
"	**Average**......	**329**	**319**	**343**	**403**	**418**	**448**	**459**	...
Very dim ..	Series I.......	375	327	436	510	549	578	613	...
"		*36*	*65*	*59*	*53*	*107*	*82*	*113*	...
"	" II......	396	354	428	478	520	555	679	...
"		*58*	*36*	*68*	*93*	*61*	*61*	*125*	...
"	" III.....	356	326	416	531	566	595	622	...
"		*54*	*42*	*80*	*95*	*104*	*98*	*80*	...
"	**Average**......	**376**	**336**	**427**	**506**	**545**	**576**	**638**	...
Average for	all intensities..	290	273	312	359	380	406	427	...

average reaction time and the mean variation in σ, are given in each case, the mean variation in italics under the corresponding average. The intensities are stated merely as bright, dim, quite dim and very dim. A more accurate idea of the intensity may be gained by a glance at the reaction time obtained with the 2 sec. interval. The results of Table VIII are shown in graphic form in Fig. 7, and those of Table IX, in Fig. 8.

FIGURE 7

Graphic Representation of Table VIII.



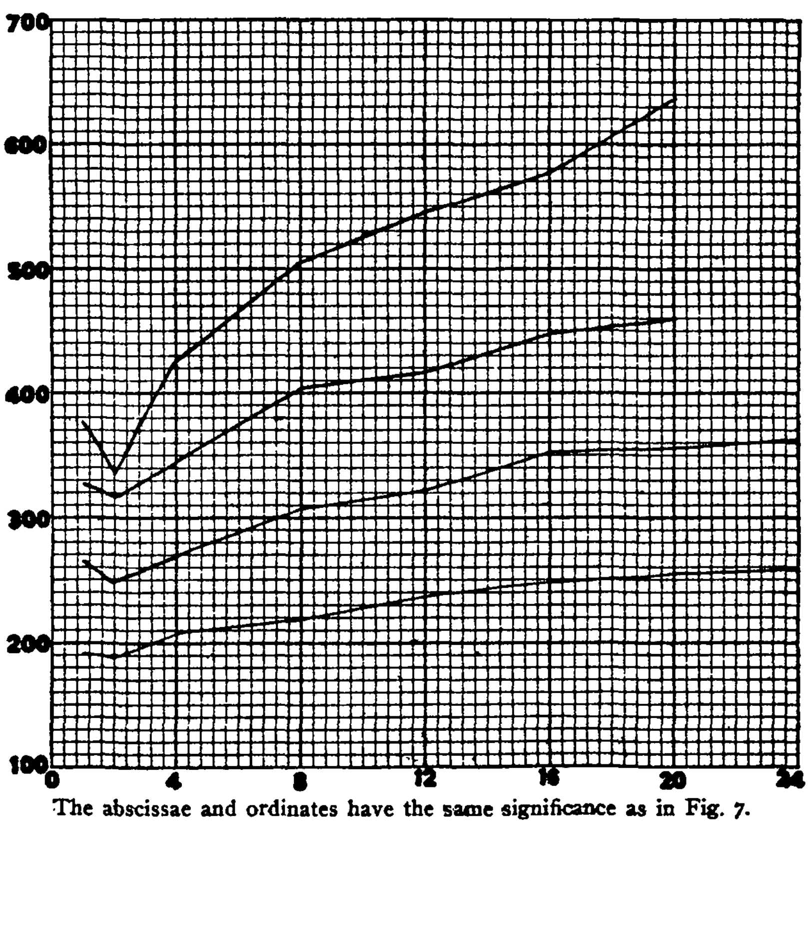
The abscissae represent the duration of the preparatory interval in secs., and the ordinates the average reaction time in σ. Each curve represents the results obtained with one intensity of stimulus, the lowest curve corresponding to the greatest intensity and the uppermost curve to the weakest intensity.

The results presented in Tables VIII and IX and in Figs. 7 and 8 lead to a number of interesting conclusions. Studied merely for the effect of prolongation of the preparatory interval on the reaction time, they show in the case of each intensity the same general effect that has already been described as indicated by the results of Table I (Chapter II). In the case of each subject, with each intensity, the effect of prolongation of interval beyond the most favorable point is to produce a marked and regular increase in reaction time, and this increase occurs at first at a more rapid rate than later. Since the curves with each intensity have the same general form, I have plotted in Fig. 9, separately for each subject, the average of the results obtained with all four intensities. This gives two curves, of a high degree of reliability, showing how interval affects reaction time, taking the average for four different intensities of stimulus. The curves for the two subjects are very similar to each other and also very similar to the curves of Fig. 2, Chapter I, which show the effect of interval on sound reactions for each of three subjects.

The curves for each subject are in accordance with the formula, already arrived at in Chapter I, $y = A + B. \log x$, in

FIGURE 8

Graphic Representation of Table IX.

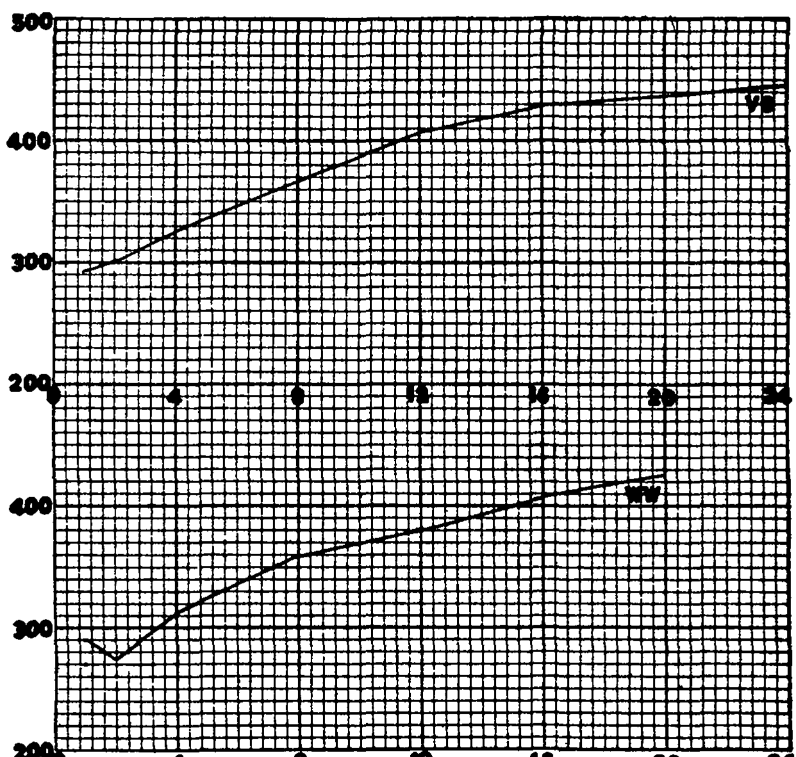


The abscissae and ordinates have the same significance as in Fig. 7.

which y is the reaction time, x is the duration of the preparatory interval, and A and B are constants. In other words, the reaction, for any preparatory interval of 2 secs. or over, is equal to a constant plus the product of another constant into the logarithm of the interval. The deviations of the reaction times experimentally obtained from those calculated in accordance with the equation are shown, for each subject, in Table X. In the

FIGURE 9

Graphic Representation of the Average Reaction Time for All Intensities for Each of Two Subjects.



The abscissae and ordinates have the same significance as in Figs. 7 and 8. The uppermost curve is the curve obtained by combining the four curves of Fig. 7 and the lower curve that obtained by combining the four curves of Fig. 8.

column headed D are given the differences obtained by subtracting the calculated values from those experimentally obtained. R. T. stands for reaction time (expressed in σ).

TABLE X

Subject Vs.

$A = 227\ \sigma$, and $B = 163\ \sigma$.

Interval (x)	Calculated R.T. (y)	Obtained R.T. (y)	D
2 secs.	276	300	+ 24
4 "	325	325	0
8 "	374	368	− 6
12 "	403	407	+ 4
16 "	423	429	+ 6
20 "	439	437	− 2
24 "	452	445	− 7

Subject Ww.

$A = 218\ \sigma$, and $B = 157\ \sigma$.

Interval (x)	Calculated R.T. (y)	Obtained R.T. (y)	D
2 secs.	265	273	+ 8
4 "	312	312	0
8 "	359	359	0
12 "	388	380	− 8
16 "	406	406	0
20 "	422	427	+ 5

It will be observed that the calculated and experimental values differ but slightly, and that the differences between the two values varies irregularly from plus to minus. The one notable discrepancy is in the case of the reaction time with a 2 sec. interval, subject Vs., which, as obtained experimentally, is 24 σ longer than the calculated. But there can be little doubt that the experimental value obtained with this interval really is too long, because it is also longer than the reaction time obtained with this subject with a 1 sec. interval, and there is no doubt that normally the reaction time is shorter with a 2 sec. preparatory interval than with one of only 1 sec. The latter statement is not only generally true, but was found true for this particular subject in the work reported in Chapter II. The fact that in this particular case the reaction time with a 1 sec. interval was shorter than with a 2 sec. interval, I would explain, then, as due to too long a value obtained with the 2 sec. interval, rather than too short a value with the 1 sec. interval. Why the reaction time obtained with the 2 sec. interval is too long, I do not know, but a plausible explanation may be that the subject felt that the reaction was so easy to perform quickly with this length of interval, naturally the easiest, that he did not try as hard as in the other cases.

From the three tables, I, VIII and IX, we may conclude that the effect of the interval upon reaction time follows the same general law whether we use auditory or visual stimuli, and no matter what intensity of stimulus we use. Moreover, the results show that the unfavorable intervals constitute a highly reliable detractor from attention. The same procedure was used day after day, and while it is true that not enough series were taken with any one intensity to determine definitely the effect of practice, no definite decrease in the efficiency of the unfavorable intervals as a detracting condition was noticeable. A special study of the effect of practice is presented in a later chapter, but to be able to take 3700 reactions with one subject without noticing any failure on the part of the long intervals to produce their usual detraction effect is encouraging.

The main object of the experiments described in this chapter, however, was not to determine how reaction time varies with prolongation of the preparatory interval. That was, indeed, sufficiently worked out in Chapter I. But the results included in the present chapter lead to a number of interesting conclusions on other points. The data given in Tables VIII and IX may be looked at in either of two ways. They may be regarded as showing how the prolongation produced by the longer intervals varies with the variation in the intensity of the stimulus, or as showing how the prolongation produced by decreasing the intensity of the stimulus varies with variation in the duration of the preparatory interval. A summary of the data included in Tables VIII and IX from each of these two points of view is given in Tables XI and XIII. Table XI is designed to show how the effect of lessening the intensity of the stimulus varies with prolongation in the preparatory interval, while Table XIII is intended to show how the effect of the long preparatory intervals varies with the intensity of the stimulus.

In the interpretation of each of these tables, I shall follow the same general procedure. I shall first discuss them simply as experiments in reaction time. I shall then discuss them as showing the effects of a given variation in objective conditions upon different degrees of attention. That is, in the case of Table XI, I shall assume that different degrees of attention are brought about by the use of different durations of the preparatory interval, so that I may then consider how the effect of a decrease in the intensity of stimulus upon reaction time varies with the degree of attention; and in the case of Table XIII, I shall assume that different degrees of attention have been brought about by the use of different intensities so that I may then consider how the effect upon reaction time of prolongation of the preparatory interval varies with the degree of attention. And, lastly, I shall consider what conclusions may be drawn by regarding unfavorable variations in the objective conditions as detractors of attention. In all cases I shall consider only the effect of prolongation in the interval beyond 2 secs. The shortening of an interval to below 2 secs. is not strictly comparable in its effect to lengthening it beyond that, and the two sorts of results, therefore, cannot be considered together. As I have used only one interval shorter than 2 secs., I hardly have enough data to make a special study of the effect of shortening the interval to below the most favorable, and this is especially true since the two subjects I used show considerable difference in the relative effect of the 2 sec. and the 1 sec. intervals.

In Table XI, taking the reaction time with the bright stimulus as a standard, I have summarized the effect of decreasing the intensity in the case of each duration of preparatory interval. The preparatory intervals are given in secs. in the first line of the table. Immediately below are given in σ the reaction times with the bright stimulus, that is, the brightest of the four used, for each interval. As an expression of the result obtained by the use of weaker intensities, I have given in the line below, the average of the reaction times obtained with the three weaker intensities. Calling the reaction time for the brightest intensity B, and the average of the times for the three weaker intensities W, the quantity W-B is the absolute prolongation in reaction time produced by the decrease in intensity. As the different intensities were each constants, this decrease in intensity is, of course, to be regarded as a constant. While it is true that the times given in line W are the averages of three weak intensities, I shall speak of the average as that obtained merely by the use of weak intensities, and of the difference W-B as the effect of a given decrease in intensity. The result obtained with the brightest intensity relative to that obtained with the three weakest is shown in the ratio B/W. In so far as the ratios B/W are constant, then, the relative effect of the decrease in intensity is independent of the duration of the preparatory interval.

If in Figs. 7 and 8, which represent by curves the effect of variation in the preparatory interval in the case of four different intensities, one should combine the upper three curves, i.e., those for the three weakest intensities, into one curve, by taking at every point the average height of the three, then the quantities W-B of Table XI would represent the difference between the height of this combined curve and the lowest curve, at each of the points corresponding to the various preparatory intervals used.

A study of the table shows that the absolute prolongation produced by the weaker intensities increases with regularity and in a marked manner with increase in the duration of the preparatory interval. This is shown by the regular increase in the quantity W-B with increase in the duration of the preparatory interval. In Figures 7 and 8 it is shown by the fact that the distance apart of the upper three curves and the lowest increases as they extend to the right.

The increase in the effect of variation in intensity with increase in the duration of the preparatory interval is represented graphically in Figure 10. The two dotted curves show the relation for each of the two subjects individually and the continuous line curve that for the two individuals taken together as a single group. It is true that there is considerable difference between the effects in the two subjects, and yet enough general agreement so that it is worth while to deduce the general tendency shown by both, as expressed in the continuous line curve representing the average result. The formula which seems best to suit this curve is $y = A + B. \log x$, in which y is the increase in reaction time produced by the use of weaker intensities, x the duration of the preparatory interval, and A and B are constants. Taking A as 93 σ and B as 96 σ, the calculated values of y come out very close to those experimentally obtained, as is seen from Table XII in which the values of y are given in σ. In column D are given the differences obtained by subtracting the calculated values of y from the experimentally obtained values.

Table XII shows that the deviations of the experimentally obtained from the calculated values are extremely slight and irregular in direction. The absolute increase in reaction time, then, produced by a given decrease in the intensity of the stimulus increases with the duration of the preparatory interval; the effect of the given decrease in intensity of stimulus increases at first

TABLE XI

(Derived from Tables VIII and IX)

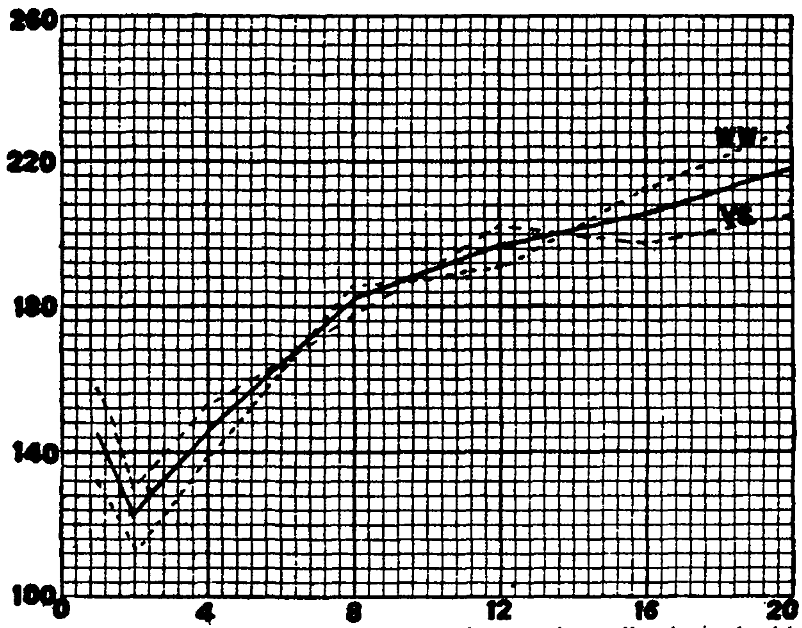
Showing how the Prolongation in Reaction Time Produced by Decreasing the Intensity of the Stimulus Varies with Variation in the Duration of the Preparatory Interval.

Interval		2	4	8	12	16	20	24
Subj.	R.T. (B)	202	210	235	256	280	283	296
Vs	" (W)	332	363	413	458	478	488	495
"	W-B	130	153	178	202	198	205	199
"	B/W	.61	.58	.57	.56	.59	.58	.60
Subj.	R.T. (B)	188	208	219	237	247	254	...
Ww	" (W)	301	346	405	428	459	484	...
"	W-B	113	138	186	191	212	230	...
"	B/W	.62	.60	.54	.55	.54	.53	...

more rapidly than later as the duration of the preparatory interval is regularly increased beyond 2 secs.; and, lastly, stated in a

FIGURE 10

The Variation with Increase in the Duration of the Preparatory Interval in the Increase in Reaction Time Produced by a Decrease in Intensity of Stimulus.



The two dotted curves represent the results experimentally obtained with subjects Ww and Vs. The heavy line curve represents the average result for the two subjects. The abscissae represent the duration of the preparatory interval while the ordinates represent the absolute difference between the reaction time with the brightest intensity and the average reaction time for the three weaker intensities.

TABLE XII

Interval (x)	Calculated y	Obtained y	D
2 secs.	122	122	0
4 "	151	146	− 5
8 "	179	182	+ 3
12 "	197	197	0
16 "	208	205	− 3
20 "	218	218	0

more definite, mathematical way, the absolute increase in reaction time produced by a given decrease in intensity of stimulus increases with increase in the duration of the preparatory interval beyond 2 secs. as a constant plus the product of another into the logarithm of the duration of the interval. The fact that there is a *plus* in the equation indicates, it seems to me, that we should distinguish two effects of the decrease in intensity. In the first place there is a constant effect, corresponding to constant A, one which does not vary with the duration of the preparatory interval, and one which, therefore, does not vary with attention. This may be regarded as the effect of intensity upon factors *other* than attention, all of which remain constant with variation in preparatory interval alone. In the second place there is, in addition, an effect represented by the magnitude $B. \log x$, which varies directly as the logarithm of the preparatory interval, an effect, therefore, which varies with the degree of attention, and which becomes greater as the degree of attention becomes less.

As rgards the relation between the reaction time with the weaker intensities and that with the highest intensity, that is, the relative effect of a given decrease in intensity, it will be observed that this tends to remain constant. This is shown by the relative constancy of the ratios B/W in Table XI. This constancy is quite marked throughout for subject Vs, and from the 8 sec. to the 20 sec. intervals for subject Ww. The constancy is not perfect throughout, as in both subjects the ratio for the 2 sec. interval is somewhat larger, and in the case of subject Ww, the ratio for both the 2 sec. and 4 sec. intervals is larger than for other intervals. In the case of subject Vs the variations from the tendency for the ratios to remain constant are slight and irregular, and in view of the fact that the M.V. in the case of the reaction times to even the brightest intensity is about 10 per cent and with the weaker intensities much higher, the deviations from constancy in the ratios is not very reliable. In the case of subject Ww, however, the ratio B/W is decidedly higher for the 2 sec. and 4 sec. intervals than for the others.

If we should, in spite of this deviation in the case of subject

Ww, think of the true tendency as being for the ratios to remain constant throughout, these deviations would indicate that subject Ww had tried harder to react quickly with the short intervals than with the longer ones, in the case of the weaker intensities. The subject, the writer, made no such introspection at the time of the experiment, but the supposition seems plausible. I do not wish to stretch my generalizations, however, and therefore shall not conclude that the true tendency of the ratios B/W is to remain constant throughout. But it is an actual fact that they remain practically constant throughout for subject Vs and from 8-20 secs. inclusive for subject Ww. The general effect of variation in the duration of the preparatory interval, then, on the relative effect of a fixed decrease in intensity may be stated as follows: The relative effect tends to remain constant for intervals varying from 8 to 20 secs., while for shorter intervals the data show a variation. I wish to emphasize the cautiousness of this generalization, and that even though the ratios do not remain constant throughout the whole range of preparatory intervals used, they do remain practically constant throughout a wide range of intervals, a range sufficient to give markedly different reaction times with the same intensity of stimulus. I shall later make considerable use of this fact.

So far the data contained in Table XI have been discussed merely as data upon reaction time. But they have a quite obvious bearing upon the subject of attention, for as has already been pointed out at length in Chapter II, the prolongation in reaction time which occurs with prolongation in the preparatory interval is due to the lesser degree of attention in the case of the reactions following the longer intervals. The difference in quickness of reaction with the different preparatory intervals, under otherwise constant conditions, is due to the difference in the average degree of attention obtaining at the moment of the reaction in the case of the different intervals. Consequently the experiment may be regarded as a study of the effect of a fixed decrease in intensity upon different degrees of attention. All other factors than attention remain constant when the preparatory interval is the only condition which is varied. The sole effect, that shows in the reaction times, which is produced by the variation in interval, is a variation in the degree of the subject's attention. Now, if intensity is not a condition of attention, that is, does not affect the degree of attention, its absolute effect will not vary under conditions which remain constant except for variation in the degree of attention. This holds no matter what other factors than attention may be affected by intensity; for a fixed factor, namely, a given decrease in intensity, would be working upon other fixed factors and the result should be always the same. It is perfectly evident that, if we should assume that a change in the intensity of the stimulus does not affect the degree of attention, then, as long as no other factor than the degree of attention is changed, we should expect a given change in intensity to continue to have the same absolute effect. But, on the other hand, if we find that the absolute effect of a fixed variation in intensity varies markedly with variation in the degree of attention, when other factors are constant, evidently the variation in intensity is affecting the degree of attention. And if the degree of attention is affected by variations in intensity, intensity is a condition of attention. Now it has already been pointed out that the absolute effect of the fixed decrease in intensity increases in a marked manner with increase in the duration of the preparatory interval, in other words, with decrease in the degree of attention, and in accordance with a definite law. Since, therefore, the effect of a fixed variation in intensity varies inversely with the degree of attention, the degree of attention is affected by the variation in intensity, and consequently intensity is a condition of attention. And as a condition of attention its importance naturally increases as the degree of attention conditioned by other factors decreases. We have here then an experimental demonstration of the common assumption that intensity is a condition of attention. The ordinary statement is based upon the direct introspection that attention to a stimulus varies with its intensity, whereas the above experiment demonstrates this indirectly on the assumption that variation in the preparatory interval produces a variation in the degree of attention at the time of the reaction. Consequently, by reasoning backwards, it will be seen that if it is admitted that intensity is a condition of attention, this admission is strong confirmation of the statement that large variations in the degree of attention at the time of reaction are produced by variations in the duration of the preparatory interval.

From the preceding discussion, the conclusion results that a decrease in intensity brings about a decrease in the degree of attention. We may therefore, interpret the preceding experiment as a study in the effect of a detracting condition, namely, weak intensity of stimulus, acting upon different degrees of attention, these different degrees of attention having been produced by different durations of preparatory interval. Although, as I have already shown, variations in intensity affect other factors than attention, nevertheless, since under the conditions of the experiment these other factors were constant, it follows that the variations in the effect produced by the decreases in intensity may be regarded entirely as variations in their effect as detractors of attention. As has already been pointed out, the absolute effect of the variation in intensity increases with decrease in the degree of attention, the latter decrease being produced in the present instance by long preparatory intervals. We may consequently conclude that under the conditions of the present experiment the absolute effect, that is the absolute decrease in efficiency, produced by a constant detractor of attention varies inversely with the degree of attention detracted from. On the other hand, the relative prolongation in reaction time produced by a fixed decrease in intensity does not always vary with variation in the preparatory interval, but on the contrary remains constant throughout a considerable range of intervals, so that we may conclude with certainty that the relative effect of a given detractor *may* remain the same with variation in the degree of attention. It not only may remain the same but shows a rather general tendency to do so, though my results hardly justify the conclusion that it always does so. Now, since we may have variation in the degree of attention without change in the relative effect of a given detracting condition, and since, on the other hand, the absolute detraction effect of a given detractor varies inversely with the degree of attention, we may draw the practically important conclusion, that in the use of a detractor under conditions such as described above, for the purpose of measuring attention, it is the absolute effect which is significant, and not the relative effect. The degree of attention is measured (ranked) by the reciprocal of the absolute detraction effect.

This result is confirmed by other results I have obtained, where I have used other methods of obtaining different degrees of attention, e.g., the use of alcohol, difference in age and having the subject perform simultaneous tasks. These are discussed more in detail in Chapter V, but show that where we presumably are dealing with widely different degrees of attention we still often get very nearly the same relative detraction effect but quite different absolute detraction effects, from given detracting conditions.

So far the data of Tables VIII and IX have been considered as showing the effect of variations in interval on the effect upon reaction time produced by a fixed decrease in intensity. The data acquire additional meaning by studying them as showing the effect of variation in intensity on the effect of prolongation of the preparatory interval. For this purpose I have constructed Table XIII. The first line of the table, headed to the left Intensity gives the intensities used. Line A gives the reaction time for the 2 sec. interval. Line B gives the average of the reaction times for all the longer intervals used with the subject in question, i.e., intervals from 4 to 24 secs. inclusive in the case of subject Vs and from 4 to 20 secs. inclusive in the case of subject Ww. This average is an expression of the effect of the longer intervals all taken together. The difference between the average reaction time for the longer intervals and the reaction time for the 2 sec. interval, given in the line headed B-A, is the absolute amount of the average prolongation produced by the unfavorable intervals. In the line headed A/B, the ratio of the reaction time with a 2 sec. interval to the average reaction time with the longer intervals is given. These ratios, then, serve to show how the relative prolonging effect of the unfavorable intervals varies with the intensity of the stimulus. All reactions are given in σ.

TABLE XIII

(Derived from Tables VIII and IX)

Showing how the Prolongation in Reaction Time Produced by Unfavorable Preparatory Intervals Varies with Variation in the Intensity of the Stimulus.

Intensity		Bright	Dim	Quite Dim	Very Dim
Subj.	R. T. 2 secs. (A)..	202	290	321	386
Vs	R. T. long (B)....	260	374	436	537
"	B-A.............	58	84	115	151
"	A/B............	.78	.78	.74	.72
Subj.	R. T. 2 secs. (A)..	188	249	319	336
Ww	R. T. long (B)....	233	321	414	538
"	B-A.............	45	72	95	202
"	A/B............	.80	.78	.77	.62

Line B-A shows that the absolute prolonging effect of the unfavorable intervals increases very markedly with decrease in intensity. In Figures 7 and 8 this is shown by the fact that the curves representing the results with the weaker intensities show greater increase in height as they extend to the right than the curves representing the higher intensities. It is the rise in the curve, that is, the prolongation produced in the reaction time by the unfavorable intervals, that is numerically represented in Table XIII, column B-A, for each of the four intensities.

The relative prolongation produced by the longer intervals, or the relation of the reaction time with the longer intervals to that with the 2 sec. interval, expressed by the ratio A/B, does not show nearly such marked variation with variation in intensity as does the absolute prolongation. Indeed, with the exception of the weakest intensity, the ratio A/B shows very little variation. The relative prolonging effect of a given unfavorable variation in the preparatory intervals may and does remain constant for a considerable range of variation in intensity (exactly so in the case of subject V's, for the two highest intensities), but does not do so throughout. The conclusion is uncertain, except when stated to the effect that the relative prolongation in reaction time produced by unfavorable intervals *may* not appreciably vary with considerable variation in intensity.

The arrangement of Table XIII as of Table XI, readily brings out the bearing of the data of Tables VIII and IX upon attention. Since the prolongation in interval acts as a condition unfavorable to attention, and solely for this reason produces a prolongation in reaction time, it may be spoken of as a detracting condition, or a detractor. This detractor, used with four different degrees of intensity of stimulus, produces four different amounts of absolute prolongation in the reaction time. Consequently, it has acted on four different degrees of attention, and these different degrees of attention have been conditioned by different degrees of intensity. The detraction effect produced by the prolongation in interval varies greatly with the variation in the intensity of the stimulus. From this fact we may conclude that the degree of attention varies with variation in the intensity of the stimulus and presumably varies greatly. Consequently intensity is not only a condition of attention, but we may further particularize to the extent of saying that the four intensities used in this experiment produced four different, and quite plausibly, four widely different, degrees of attention.

The absolute effect of variations in attention, then, produced in the above instance by variations in interval, is greater the weaker the intensity of the stimulus attended to. This result, merely from the point of view of experimental technique, is important, as it shows the desirability of using rather weak intensities if one wishes to study the effect of attention upon reaction time, as so many investigators have done. If one wished, for instance, to determine whether an "attention wave" were demonstrable by means of reaction time, one should use a weak intensity of stimulus, as variations in attention will then produce a much more marked absolute effect upon the reaction time. Similarly, one could expect that differences in the degree of attention among the members of a class of school children would be more noticeable after a certain amount of fatiguing labor than early in the morning when they are fresh, as fatigue would act as a detractor something after the fashion of weak intensities in the above experiment. And just as weak intensity magnifies, as it were, the differences in attention due to differences in preparatory interval, so would fatigue be likely to magnify the differences in the attentions of different individuals, no matter to what these differences might be due. The weak attentions would be further weakened a great deal by any given detractor while the good attentions would be weakened only slightly, so that the result of the detractor would be greater absolute difference between the weak and the good attentions.

Since the four different degrees of intensity condition four different degrees of attention, and since the prolongation in reaction time produced by the unfavorable intervals may be regarded as a detraction effect, we arrive again at the conclusion that the absolute effect of a given detractor varies inversely as the degree of attention, while the relative effect may or may not remain constant. The practically important point concerning the relative detraction effect is that it certainly *may* remain constant in spite of variation in the degree of attention; and consequently, as already emphasized, it is the absolute and not the relative prolongation, produced by a given detractor, which is to be taken as an index of the degree of attention.

In conclusion, I wish to argue on theoretical grounds for the plausibility of this result, that it is the absolute detraction effect of a given detractor which is to be taken as a measure of attention, in accordance with the law that the attention varies inversely with the degree of the absolute detraction effect—that the relative effect on the other hand may remain very nearly constant for widely different degrees of attention. A given detractor of attention acts *as such* on attention only, and on no other factor; but the process in which the decrease in efficiency produced by the detractor becomes noticeable, in the present instance a reaction process, is bound to involve other factors than attention, no matter how important the factor of attention may be. Variation in these other factors may produce great variations in the efficiency. The efficiency is determined only in part by attention. And if attention may play at one time a relatively small part and at another time a relatively large part, and yet the absolute degree of attention remain the same, evidently the same amount of interference with attention in the two cases, non-attention factors not being disturbed, could not possibly produce the same effect upon the two efficiencies. Theoretically, it might not produce equal absolute effects, but would do so if attention operated as a factor which was variable independently of other factors. Now attention may be varied independently of other factors, as in the case of variation in interval, where factors involved in the reaction process other than the degree of attention remain constant. Evidently, then, it is the absolute detraction effect and not the relative which should be used in the measurement of attention.

SUMMARY

The effect of prolongation of the preparatory interval beyond the most favorable interval, using the regular procedure[11] is to produce a marked and regular increase in reaction time, and this increase occurs at first at a more rapid rate than later, as the interval is uniformly increased in duration. If we call the reaction time y and the duration of any interval of 2 secs. or over x, we may write the equation $y = A + B.\ log\ x$, in which A and B are determinable constants. This conclusion is identical with a conclusion stated in the summary to Chapter I and based on the results presented in that chapter on reactions to sound stimuli. The effect of variation in the preparatory interval upon the reaction time, therefore, follows the same general law whether we use auditory or visual stimuli. The same law holds for any degree of intensity of stimulus. Of course the constants A and B will vary with different individuals and with different objective conditions.

As regards the effect of the duration of the preparatory interval on the prolongation produced in reaction time by a given decrease in intensity, the data of this chapter lead to the following law:

[11] See Chap. II, p. 40.

The absolute increase in reaction time produced by a given decrease in intensity of stimulus, increases as the duration of the preparatory interval is increased beyond 2 secs., and this increase takes place at first more rapidly than later, as the interval is uniformly increased in length. Stated more definitely, if y represents the increase in reaction time produced by a decrease in the intensity of stimulus, and x the duration of any preparatory interval of 2 secs. or over, then $y = A + B. \log\ x$, in which A and B are determinable constants. This law shows that the increase in reaction time produced by a decrease in intensity may be regarded as made up of two factors, one of which will vary with variation in the duration of the preparatory interval, and hence with variation in the degree of attention, while the other will remain constant.

As regards the absolute prolongation in reaction time produced by increase in the duration of the preparatory interval beyond 2 secs., it may be said that this prolongation increases markedly with decrease in the intensity of the stimulus. Since I did not measure the intensities of the stimuli I have not attempted a mathematical formulation of this law.

The relative increase in reaction time produced by a given decrease in intensity may not vary with prolongation in the preparatory interval beyond 2 secs. Similarly, the relative increase over the reaction time with a 2 sec. interval obtained with a longer preparatory interval, may remain the same for widely different intensities of stimulus.

In Chapter I, the conclusion was reached that the effect of variation in the preparatory interval upon reaction time, is due solely to the effect of variation in the interval upon the degree of adaptation of attention; so that the different reaction times obtained with the different intervals correspond to different degrees of attention. Now since the data show that the absolute effect of a given decrease in intensity varies with the duration of the interval, it follows, in accordance with the laws already stated, that the effect of variations in intensity varies with the degree of attention. And any factor which has a greater or less effect on efficiency as the degree of attention involved is greater or less, is a condition of attention. Consequently, intensity of stimulus is a condition of attention. Similarly, since the unfavorable intervals may be regarded as detractors solely of attention, and since their effect was found to vary with intensity of stimulus, we may conclude that intensity of stimulus is a condition determining the effect that a given detractor of attention will produce, in other words, that intensity of stimulus is a condition of attention. The data of this chapter, therefore, assuming the conclusions of the preceding chapter, constitute an experimental proof that intensity is a condition of attention, and that different degrees of intensity condition different degrees of attention. What correspondence between intensity and degree of attention exists, is of course positive, not inverse. Data which corroborate this conclusion are given in Chapter IV.

Now, since the absolute increase in reaction time produced by the use of unfavorable preparatory intervals increases with decrease in the intensity of the stimulus, and since variation in the intensity of the stimulus results, as just pointed out, in corresponding variation in the degree of attention, we may conclude that the absolute increase in reaction time produced by the use of unfavorable preparatory intervals varies inversely with the degree of attention. Or, *the degree of attention varies inversely with the absolute prolongation produced by unfavorable intervals.* In other words, attentions may be measured or ranked, by equating them with the reciprocal of the absolute (but not the relative) prolongation in reaction time produced by the use of unfavorable preparatory intervals. We may use any two given conditions of intervals, one more favorable than the other, as a 4 sec. interval and a 20 sec. interval, both regularly repeated, or a 2 sec. interval regularly repeated and a given set of irregularly mixed intervals. The difference in the reaction times obtained under the two chosen conditions will vary inversely with the degree of attention.

By regarding the effect of unfavorable intervals and of weak intensities upon attention as typical of the effect of detractors in general, we may state the following ***general law of detraction: The absolute detraction effect of a given detractor of attention varies inversely with the degree of attention upon which the detractor acts.*** This law not only furnishes the basis for the measurement of attention but gives a description resting upon experimental data of one of the most important functions of attention, namely, the increase in efficiency which results from the resistance to distracting or detracting conditions. It points out that attention varies inversely as the ability to resist conditions that are unfavorable to attention and that this ability is measurable in its effect upon efficiency. Indirectly, then, increase in efficiency is a function of attention. Were it practically important to have an absolute measure of attention instead of a relative one, I believe that we could very well substitute increase in efficiency for the function usually regarded as the most essential, namely, clearness, and instead of equating the absolute degree of attention with clearness equate it with the absolute increase in the reciprocal of efficiency produced under specified conditions by a specified detractor.

The expression "absolute detraction effect," in the law of detractors that I have just stated, is necessary, for I have shown that the relative effect cannot be used for the purpose of measurement of attention. The relative effect may remain constant while attention varies, as in the case of the relative prolongation of reaction time caused by the use of unfavorable intervals as detractors, where the relative prolongation remains constant while the degree of attention is varied by varying the intensity of the stimulus.

The phrase "a given detractor" conceals many difficulties, but the conditions determining a satisfactory detractor as well as an analysis of the conditions which must be complied with if the detraction effect is to be adequately measured has already been given in the introductory chapter.

CHAPTER IV

The Measurement of Attention by Reactions to a Change in Intensity

The general subject of this chapter is the value of reactions to a change in intensity for the measurement of attention. More specifically, the object of the experiments reported in this chapter is twofold. The first set of experiments was made with the purpose of determining whether it is possible to find a form of reaction the time of which is unaffected by variations in retinal sensitivity, and so to get a method of measuring attention apart from its dependence upon retinal sensitivity. The second set of experiments here reported had for its principal object the verification of the law of detraction, as stated in the last chapter, namely, that the absolute effect of a given detractor varies inversely as the degree of attention detracted from; but in the present instance the different degrees of attention were not produced by change in the absolute intensity of the stimulus, as in the preceding chapter, but by changes in the size of the change in intensity, the reaction being to the change in intensity.

The sensitivity of the sense-organ, whether the eye or ear, would quite certainly affect the result of the measurement of attention by the method so far suggested. Decreasing the sensitivity of the sense-organ is the equivalent of decreasing the intensity of the stimulus, and since intensity is a condition of attention this would certainly affect the result. Consequently, by the method used in the last chapter, a person with a low retinal sensitivity as regards intensity would be very likely to have very bad attention, and a person with normal vision, comparatively good attention. For certain purposes such a result would be unsatisfactory. It seems desirable for the purpose of comparing the attention of different individuals to be able to measure an individual's attention, as it occurs in the reaction process, independently of the variations which might be produced in that attention as the result of variation in the condition of the sense organ involved.

Individuals' attentions under the conditions of the reaction experiment, vary in part because of variation in the sensitivity of their sense organs, but there is nothing indefinite in the concept of measuring these attentions in so far as they differ only because of other factors than the factor of sensory sensitivity. Retinal sensitivity, or any other sensory sensitivity, is capable of separate measurement, possibly, and a correction for it might perhaps be worked out, but this would be too difficult and uncertain. I accordingly sought a method of ranking attentions considering them as different only to the degree they would be different as the result of all conditions other than sensory sensitivity.

Simple reaction times, such as I used in the experiments so far reported, are evidently not suited to my purpose. Since the result of any detracting influence, e.g., the unfavorable intervals, varies with the intensity of the stimulus, it presumably varies also with the sensitivity of the retina. We know that increasing the sensitivity of the retina, as for instance by adaptation to darkness, has the same effect as increasing the intensity of the stimulus, that is, results in an increase in apparent brightness; and while I have not experimented in the way reported in the last chapter with different retinal sensitivities substituted for different intensities of stimulus, there is every reason to believe that the effect produced by unfavorable intervals would vary with variations in retinal sensitivity in a way corresponding to that in which it varies with variation in intensity of stimulus.

A single visual stimulus, then, undoubtedly has the effect of its intensity reduced by a decrease in the sensitivity of the retina. But what is the effect of a decrease in sensitivity on the apparent difference in intensity of two light stimuli? The variation in sensitivity of the retina in different people may be due to various causes, but the result here considered is simply variation in the effect of the intensity of the stimulus. In so far as these variations in the eyes of different people do not affect the intensity effect of the stimulus, they need not here be considered. As regards the effect of intensity, it seems to me that there can be little doubt that the result of a decrease in eye sensitivity would be the same as that produced by placing some sort of a translucent screen before the eye, such as a smoked glass or uniform gray film. If the effect of a decrease in the sensitivity of the eye may be thus likened to that produced by holding a piece of smoked glass before the eye, what effect would a decrease in sensitivity produce upon the apparent difference in intensity of two stimuli? A piece of uniform gray glass (produced by photographic methods) will decrease the absolute intensity of both light stimuli but will not change their relative intensity. And by Fechner's law, as long as the two stimuli have the same relative intensity, the difference in intensity of sensation, that is, the apparent difference in intensity, remains constant. Were Fechner's law true, the noticeability of the difference in intensity of the two stimuli would be unaltered by a change such as produced by the interposition of gray glass, or consequently, I think we may assume, by a decrease in the sensitivity of the sense-organ.

It is pretty well established that neither Weber's law nor Fechner's law hold for very weak intensities, as the relative difference limen becomes larger with such. Consequently, if an individual were nearly blind, a given difference in intensity would be harder for him to discriminate than for a normal person. If, however, apart from extreme cases, the difficulty of discrimination is not affected by variation in sensitivity, a discrimination reaction would be quite satisfactory for the purpose now under consideration, as the number of cases of retinal insensitivity so great as to cause a reduction in the effect exerted upon the optic tract by a moderately bright light down to that exerted by a light so faint as to fall below the range of intensities covered, in the case of a normal retina, by Weber's law, is probably, relatively speaking, not great. For such extreme cases of retinal insensitivity a different method of measuring attention must needs be used, perhaps an auditory method.

While the general consensus of psychological opinion appears to be that Weber's law undoubtedly holds good for moderate intensities, there seems much diversity of opinion as to whether a similar law holds for supraliminal differences. It is not my intention to take up here the criticism of the vast literature bearing upon Fechner's law. The experiments so far made are undoubtedly somewhat inconclusive. The explanation for this is that the law for supraliminal differences can not be directly tested except by the use of the method of mean gradation, and this method is a very treacherous one, as Mueller has pointed out.[1] The law governing the noticeability of supraliminal differences is involved in the present discussion, however, only in so far as it determines whether or not the noticeability of the difference between two intensities bearing a fixed ratio to each other is changed sufficiently as the result of change in absolute intensity to produce a different degree of attention to this difference. This needs some explanation. In the case of attention to a single visual stimulus, the intensity of the stimulus, as was shown in the last chapter, is a condition of attention. In such a case it is perhaps in accordance with prevailing psychology, to think of sensory clearness as the criterion of attention and one can readily understand that this clearness will increase with increase in intensity of the stimulus. Different degrees of intensity, therefore, would condition different degrees of clearness of the single sensation. But the case is different if we are attending to a difference, or to a change, in intensity. It is very doubtful that the degree of attention to a difference in sensations is conditioned by the absolute intensities of the two stimuli. If Fechner's law were true, it would seem rather that the degree of attention to the difference would be conditioned by the ratio of intensities. As long as the ratio of intensities remained the same, the difference in intensity would, other things equal, remain equally clear. Now, while absolute intensity is a condition of attention to a single stimulus, it seems that within a certain narrow range of moderate intensities, the intensity may vary without variation in reaction time and so, in all probability, without variation in the degree of

[1] G. E. Mueller. *Die Gesichtspunkte und die Tatsachen der Psychopyhsischen Methodik*, 1904, 234-244.

attention. So, similarly, it is possible that the degree of relative difference in intensity, even though a condition of attention to the difference, may vary within moderate limits without this variation producing a variation in the degree of attention given to the difference. Variation in the degree of difference is probably a condition of attention to difference, just as variation in absolute intensity of a single stimulus is a condition of attention to the stimulus. I have already shown that the variation in intensity is a condition of attention to the single stimulus and I shall later present figures to prove in a similar way that variation in the degree of difference is a condition of attention to the difference. But in both cases, it is possible, and even indicated, that within quite moderate limits variation does not appreciably affect attention. In the case of a single intensity these limits are indicated as those including what we call moderate or moderately strong intensities. In the case of a difference in intensity, they are perhaps those including what we would call easily noticeable differences, that is, roughly speaking, moderately large differences. Consequently, if we are experimenting with rather large differences, it is quite possible that even though as the result of the interposition of a gray plate between the eyes and the stimuli, the degree of apparent difference were slightly altered, that this variation might not be large enough to condition an appreciably different degree of attention to the difference in question. If Fechner's law held exactly, the apparent difference in intensity would remain exactly the same. For our purpose, however, it is perhaps not necessary that the difference remain exactly the same. It is only necessary that it shall not change sufficiently to condition an appreciably different degree of attention. I have, therefore, not attempted to demonstrate Fechner's law, but merely to determine whether the degree of attention to a given change in intensity is varied by placing a gray glass between the eyes and the stimulus. Since I have assumed this effect of a gray glass screen to be similar to that of a decrease in the sensitivity of the eye to intensity, I shall interpret my data as bearing upon the question whether or not a change in the retina's sensitivity to intensity will bring about a change in the degree of attention to a given large difference in intensities.

While, as I have said, no attempt was made to determine the law of supraliminal differences, the results obtained tend to confirm the statement that equal relative differences are equally noticeable, and I believe the same general technique that I used is better adapted to settling this point than is the method of mean gradation. It was assumed that as the difficulty of discrimination varies, there is a variation in the corresponding discrimination reaction times.[2] The data presented in the second set of experiments reported in this chapter show this to be true. The variation in reaction time with variation in the apparent difference is especially marked when the apparent difference is small. It seems likely therefore, that by taking discrimination reaction times with a small difference in the intensities of the stimuli, and by observing whether or not the reaction times vary as the absolute intensities of the stimuli are varied while their relative intensity is kept constant, that a more reliable test of Fechner's law can be made than by the method of mean gradation. The comparison of two differences in intensity, which is necessary by the method of mean gradation, and which is often so uncertain and apt to be based on misleading criteria, is by the method I have described entirely eliminated.

In the experiment next to be reported, however, a small difference in intensity was not used, but one that was noticeable without the least hesitation. The stimulus consisted of two oblongs or bars of light of equal size and brightness projected from a Mazda tungsten lamp upon a ground-glass screen, the general arrangement being similar to that used in the experiments reported in Chapter III. Either the right or left bar of light was suddenly decreased in intensity, and the subject's reaction consisted in calling as quickly as possible into a Cattell voice-

[2] "The more difficult the discrimination, i.e., the more nearly alike the stimuli, which must be held apart in reaction, the slower is the reaction." Ladd and Woodworth, *Elements of Physiological Psychology*, 1911, 490. The conclusion quoted is based chiefly upon the results of Henmon, in *The Time of Perception as a Measure of Difference in Sensation*, 1906.

key the word "right" or "left." The subject's task, then, a little more specifically, was first to fix definitely in mind which bar of light was the right and which was the left. Both bars being visible before the warning signal (a damped electric bell), no fixation point was necessary. Upon hearing the warning signal the subject, with his mouth already at the voice-key, fixated the two bars and perfected his adjustment to the voice-key at the same time. When the change in intensity occurred, there was no comparison made of the brightness of the two bars. This is certain both from introspection and also from some objective data included in the second set of results reported in this chapter. The decrease in intensity was noticed as a sort of flicker. It would probably be misleading even to say that there had been any real comparison in the case of the bar of light which was decreased in intensity, between its original intensity and the intensity it had after it was decreased. The sudden change in intensity was merely noticed, the reaction word "right" or "left" following as quickly as possible. The reaction therefore was rather a recognition reaction than a discrimination reaction, consisting in recognizing the spacial position, as right or left, of a sort of "flicker sensation" produced by the decrease in brightness of one of the bars. After the reaction, the subject might occasionally make a careful comparison of the brightness of the two bars. From this description of the reaction, it seems that the use of two bars of light in place of one was unnecessary for my purpose, but this in no way invalidates the experiment. That no real comparison was made, is of no particular concern, as the principal object was to find a form of reaction which does not vary with the sensitivity of the eye to brightness.

The apparatus was the same as that described in the preceding chapter, except that the lantern slide, instead of having one aperture, had two oblong ones, standing alongside of each other. These oblong apertures produced oblong images or bars of light having a size upon the glass projection screen of 1 cm. by 0.25 cm., with a distance of 0.5 cm. between. The tachistoscope instead of being allowed to cut off the light entirely, was arranged to decrease the intensity of one of the bars without affecting the other. This was accomplished by removing the lower shutter entirely and attaching to the upper one a short strip of glass of uniformly developed gray. The height of the tachistoscope was adjusted so that when the upper shutter was drawn down by the magnet, not the shutter but only the glass strip came in front of the light. The tachistoscope was supported so that it could be easily adjusted to have the glass strip come over either one of the two bars of light. The order in which the right and left bars were covered by the strip was a pure chance order, different for every series of reactions, and unknown to the subject. In order to have the tachistoscope and the chronoscope circuits separate, a double key was used, as in the apparatus described in the preceding chapter, one-half making the tachistoscope circuit and the other half simultaneously making the chronoscope circuit. Thus the decrease in the intensity of the light occurred simultaneously with the close of the chronoscope circuit. A subtraction was made for the constant error due to the latent period of the tachistoscope shutter. The subjects were the writer and two advanced students, all three well practiced in reaction experiments. The subject sat in the dark-room four feet in front of the light stimuli. The dark-room was dimly illuminated from behind the subject.

One of the most essential points in the arrangement of the experiment was to vary widely the absolute brightness of the bars of light without varying the relative decrease in brightness produced by the photographically prepared glass strip. Four different degrees of brightness were obtained by the use of either a 250-watt or a 40-watt lamp, each of which was used both in a position directly behind the stereopticon and at a distance of four and a half feet behind this position. This gave four widely different intensities, which, however, I did not measure. In Table XIV the intensities are referred to simply as medium, weak, weaker, and very weak. They were not identical with the intensities used in the experiments of the preceding chapter. The glass strip attached to the tachistoscope shutter would evidently cut off the same percentage of light in all cases. Twenty-five reactions were taken with each intensity before passing to the next. The intensities were taken in order from brightest to weakest and from weakest to brightest, back and forth three or four times. A preparatory interval of 2 secs. was used throughout.

TABLE XIV

The Effect of Variation in Absolute Intensity upon the Time of Reaction to a Constant Degree of Change in Relative Intensity.

N, for each series with each intensity = 25. R.T. = average reaction time in σ.
Total no. of reactions = 1,825. M.V. = mean variation.

Intensity		Medium		Weak		Weaker		Very Weak	
Subject		R. T.	*M. V.*	R. T.	*M. V.*	R. T.	*M. V.*	R. T.	*M. V.*
Vs	Series I......	424	*53*	494	*56*	474	*46*	499	*36*
"	" II.....	436	*44*	420	*48*	410	*33*	410	*49*
"	" III....	429	*37*	426	*38*	406	*51*	409	*45*
"	" IV....	436	*47*	436	*46*	447	*53*	439	*60*
"	" V.....	480	*59*	482	*81*	459	*50*	468	*54*
"	**Average**.....	**441**	**48**	**452**	**54**	**439**	**47**	**453**	**49**
Subject Ww	Series I......	410	*35*	407	*44*	417	*32*	416	*35*
"	" II.....	391	*37*	395	*33*	416	*35*	401	*29*
"	" III....	356	*37*	362	*42*	361	*34*	372	*22*
"	" IV....	364	*25*	364	*32*	381	*24*	360	*38*
"	**Average**.....	**380**	**34**	**382**	**38**	**394**	**31**	**387**	**31**
Subject Sz	Series I......	552	*50*	543	*43*	550	*44*	548	*65*
"	" II.....	522	*58*	543	*63*	487	*45*	561	*62*
"	" III....	497	*39*	505	*43*	496	*55*	514	*41*
"	" IV....	430	*52*	424	*50*	470	*49*	471	*34*
"	" V.....	455	*53*	450	*43*	454	*59*	494	*45*
"	" VI....	569	*64*	606	*54*	531	*58*	585	*60*
"	" VII....	534	*52*	532	*47*	533	*54*	539	*42*
"	**Average**.....	**508**	**53**	**515**	**49**	**503**	**52**	**530**	**50**
				Summary					
Vs	Average.....	441	*48*	452	*54*	439	*47*	453	*49*
Ww	"	380	*34*	382	*38*	394	*31*	387	*31*
Sz	"	508	*53*	515	*49*	503	*52*	530	*50*

The results are given in Table XIV. Inspection of the summary of the table shows that the reaction time does not vary much with the absolute intensity. Both the average reaction times and the average mean variation remain strikingly near constant, in spite of the very great variation in absolute intensity. There is, indeed, some slight variation, but in this sort of measurements such very slight variation, when it is irregular in direction, is sufficiently taken account of by being designated as due to "accidental variation." Some significance, perhaps, attaches to the increase in reaction time with the weakest intensity which occurs in the case of subject Sz, though the difference between this reaction time and that obtained with the strongest intensity is less than one-half the average mean variation for either. And even with this subject the next to the weakest intensity gives a shorter reaction time than the strongest. We may conclude, therefore, that as long as the ratio of intensities remains the same the absolute intensity of the stimuli may vary widely without changing the reaction time. A variation in absolute intensity as great as that here used would produce a very marked variation in simple reaction time, nearly have doubled it, as I know from experiments with the same subjects reported in Chapter III. A variation in the absolute intensity of the stimuli, therefore, great enough to produce a very great variation in simple reaction time does not affect the time of a reaction such as described above. This conclusion does not eliminate the possibility of an increase in the reaction time with extremely weak intensities, intensities that are close to the limen, nor with somewhat greater intensities in the case of a very much smaller relative difference in intensity than the one used in obtaining the above results.

Now, if a decrease in the eye's sensitivity to intensity of light may be likened to a gray glass screen placed between the eye and the stimulus, as I have already argued, then the conclusions just drawn will hold also for variations in sensitivity. A gray glass held before two stimuli of different absolute intensity decreases the intensity of each by the same proportion. Such equal proportional decreases in intensity, however, have just been shown to have no effect on the time of reactions, such as the above, to a decrease in intensity,—at least within very wide limits of absolute intensity. We may consequently conclude that the time of reaction to a given change in intensity does not vary with variation, within wide limits, of the sensitivity of the eye to intensity. This conclusion could be foretold if we were sure Fechner's law or some similar law were valid. But while it is in keeping with Fechner's law, it does not demonstrate the same, for the reason, already pointed out, that it is quite possible that the time of a reaction such as I have used might not vary even though the apparent difference in the intensities of the stimuli, or the apparent change in intensity, underwent a slight variation.

With the idea of measuring attention in mind, I should draw the further conclusion that variations in the eye's sensitivity to intensity, within wide limits, would not produce any difference in the degree of attention present in a reaction based upon the recognition of a change from one intensity to another. Any method of measuring attention which makes use of such reactions, therefore, is not affected by even quite large variations in the sensitivity of the eye. It is true that I have not tried again the method used in Chapter III of applying a detraction test for each different absolute intensity; but since these different intensities all gave about the same reaction time this seemed quite unnecessary. In a case like this, *where all conditions but absolute intensity may be regarded as constant,* any change in the degree of attention, produced by change in the absolute intensity, would certainly show in the reaction time with the regularly repeated 2 sec. preparatory interval. This was shown to be true in the last chapter even in the case of simple reaction times, and the more complex form of reaction described in the present chapter is certainly as sensitive to changes in attention as the simple reaction. The preceding experiments, therefore, show how attention may be measured independently of the retina's sensitivity. The procedure need not differ from that used in Chapter III except that a given change in intensity would be used as the stimulus instead of a given absolute intensity, and a set of irregularly mixed intervals would be substituted for the long regularly repeated intervals, as the detractor of attention, so as to make the result independent of the subject's ability to estimate intervals.

Some experiments were next made with the same sort of reaction as described above, but the size of relative change in intensity was varied while the absolute intensity of one of the stimuli remained the same throughout. In these experiments a set of irregularly mixed preparatory intervals was used in each case as well as a regularly repeated 2 sec. interval. My object was primarily to test out again the method of using unfavorable intervals as a detracting condition, and the law already arrived at, that the absolute effect of such detracting conditions varies inversely with the degree of attention. It seemed probable that, since in the present instance it is a question of attention to a change in intensity, different degrees of attention would be brought about by varying the size of the change in intensity of the stimulus. This presumption was confirmed by the fact that such variation was found to produce variation both in the reaction time obtained with the regularly repeated 2 sec. interval and also in the absolute detraction effect produced by the use of irregularly mixed intervals. In the present instance three bars of light were used instead of two. The change in intensity might affect any of the three, and the subject had to call out "right," "left" or "middle," according to which of the three was observed to change in intensity. The object of using three bars instead of two was that it was thought that thereby an order could be used which would make it harder for the subject to anticipate in which bar the change was to occur. The order used was a chance order, determined by drawing gun wads with *r*, *l* or *m* marked on them, was different in every series and included the right, left and middle bars equally often. The use of three bars instead of two may account for the fact that incorrect answers were occasionally given by the subject, as none occurred in the previous experiments reported in this chapter, where only two bars were used. This difference in result in the two cases is, however, apparently due more to the fact that in the case where two bars of light were used, the change in intensity used was large, whereas in the case where three bars were used small changes in intensity, as well as large, were used. The incorrect answers occurred chiefly, though not exclusively, with the smaller changes in intensity.

The apparatus was the same as in the experiment already described in this chapter, except that the stereopticon slide had three oblong apertures instead of two, thus producing a stimulus consisting of three oblongs or bars of light. The change in intensity was produced, as before, by the dropping of a photographically developed glass strip, attached to the upper shutter of the tachistoscope. To obtain different amounts of change, slides developed to different shades of gray were used. I had a large array of such, and cut out strips which appeared to differ in shade about equally from each other. No measurements were made of the proportion of light cut off by the different strips, but there can be no doubt of the correctness of the order of the size of the changes in intensity produced by them. Five different changes were used, which are numbered from 1 to 5 in Table XV, 1 being the smallest change used and 5 the largest. With each size of change in intensity, first, 30 reactions were taken with a regularly repeated preparatory interval of 2 secs., and then 30 with a set of irregularly mixed preparatory intervals. This finished the work done at any one sitting. Two sittings were devoted to the same change in intensity before going on to the next size of change. The different sizes of change in intensity were used in the following order: Beginning with 1 and proceeding in regular order to 5, and then with 5 again and going back to 1. The total number of reactions for each subject with each size of change in intensity was, therefore, (2 × 30) × 2 × 2, or 240. The same set of irregular intervals was used as in the experiments reported in Chapter II, in connection with Table V, with the addition to that set of 25 of the following 5 : 12, 20, 8, 4 and 16 secs. The source of illumination throughout was a 250-watt Mazda tungsten lamp. The light stimuli were visible before the warning signal, a short ring of a muffled electric bell, and in fact were visible all the time except while the tachistoscope was being adjusted to bring the gray glass strip over a different bar of light.

I have already presented data on the effect of an irregular series of preparatory intervals and argued that the prolonging effect of such a series, upon reaction time, is due to the fact that the reactions occur with a lesser degree of attention. Additional evidence of a very decisive character that the reactions with irregular intervals occur with less adaptation of attention than the reactions with the regularly repeated 2 sec. interval was obtained in the course of the present experiment. This evidence consists in the fact, that when a very slight change in intensity was used, yet not so slightly but that it was promptly noticed if it occurred at the end of regularly repeated intervals of 2 secs. it was often *not noticed at all* with the totally irregular intervals. It has already been pointed out that the sudden decrease in the intensity which occurred in one of the stimuli was simply observed as a sort of a flicker, and that the observation of this flicker did not necessitate any comparison between the separate bars of light. With a very large decrease in intensity, this flicker is very easily noticeable, but with an extremely small change in intensity it is exceedingly difficult to notice. Yet, when the regularly repeated 2 sec. interval was used, even the smallest decrease used was practically always noticed,—in every case with one subject and in all but two cases wth the other subject. But with irregular intervals, when a very small change was used, the flicker effect produced by the change was very frequently unnoticed. Even with some of the larger changes it was occasionally unnoticed. This was determined, directly, by the subject's reports, and, indirectly, by observation of the reaction times. The subject noted on paper after each reaction, whether he had called "right," "left" or "middle," so that his responses could afterwards be checked up as right or wrong. He also noted any disturbance or anything unusual of any sort, and further made note each time that he did not observe the flicker effect. I found that when the flicker effect was not observed the reaction word was usually correct but the reaction time at least several hundred sigma longer, sometimes a whole second or two longer, and sometimes no reaction occurred at all. Both subjects gave the introspection that in case no flicker was observed and yet a reaction occurred, it was after a comparison of the brightness of the two lights. This comparison occurred either merely accidentally because the subject had not much else to do than to fixate the two lights, or else because he had a doubt as to whether one of them had flickered, and made a deliberate comparison of the brightness of the three bars in order to settle his doubt.

This frequent failure of the subject to notice a flicker with irregular preparatory intervals, when one was noticed every time with a regularly repeated 2 sec. interval, can only be explained on the ground that in the case of the irregularly mixed intervals there existed at the time of the flicker a lower degree of attention to the light stimuli. The failure to notice the flicker, notwithstanding the very short duration of the same, was certainly not due to winking. The subjects were both able to refrain from winking for periods much longer than 20 secs., without difficulty, as was determined by an actual test, and both felt sure they did not wink during the preparatory intervals. It is, therefore, highly improbable, even though some unobserved winks may have occurred, that these would have coincided with the change in intensity, in as many cases as 10 or 14 out of 30. Nor can the failure to observe the flicker be explained as due to inaccuracy in the fixation of the stimuli by the eye, in the case of the irregular intervals. It would be very hard to show that a slight inaccuracy in fixation of a fairly bright light would change the size of the differential limen. And, moreover, if the eyes did wander more with irregular intervals than with regular, in view of the results presented in Tables XVII and XVIII, Chapter V, it could hardly be because they were more fatigued, but merely because the attention wavered. We have here then a striking proof that the use of an irregularly mixed series of widely different preparatory intervals decreases the degree of adaptation of attention to the reaction process. Further, since the proportion of times the flicker was unnoticed decreases as the size of the change in intensity increases, we may conclude that the degree of attention to a change in intensity is conditioned by the amount of the change in intensity, just as the degree of attention to a simple stimulus is conditioned by its absolute intensity. This conclusion is identical with the assumption upon which the experiments of this chapter are founded.

The frequent occurrences of these cases in which with irregularly mixed intervals the flicker was not observed constitutes a certain defectiveness in the technique when the primary object of the experiment is borne in mind. This was to determine the effect of the irregular set of intervals, and to determine how this effect varied with the size of the change in intensity used. Since when a small change in intensity was used it was sometimes noticed, but frequently not, or at least not noticed directly, it becomes impossible to average the reaction times obtained in these cases, and thus the calculation of the effect of the irregular set of intervals in these cases is difficult and in an accurate quantitative way impossible. Another difficulty which arose consisted in the fact that often the subject reacted incorrectly, e.g., calling out "right" in place of "left."

Neither the times of incorrect reactions nor those in which the flicker effect was not observed are averaged with the others. The number of such reactions is noted in Table XV for each change in intensity. The average given is for all the remaining reaction times, the number thus averaged in the case of each degree of change in intensity being 30 (30 with regularly repeated, and 30 with irregularly mixed, intervals), minus the number of incorrect reactions and the reactions where no flicker was observed.

In column A of Table XV are given the times obtained with a regularly repeated 2 sec. interval and in column B are given the times with the set of totally irregular intervals. The numbers 1 to 5 occurring in the column headed Degree of Change in Int. refer to the amount of decrease in the intensity of the bar of light over which the gray glass slide dropped. The number 1 represents the smallest change in intensity and 5, the largest. It is evident that the averages given for the smaller changes in intensity are quite misleading, as many were thrown out. It seems certain that in those cases in which no flicker was observed

Table XV

The Effect, upon the Time of Reaction to a Change in Intensity of Stimulus, of Variation in the Degree of Change, both with a Regularly Repeated Preparatory Interval of 2 Secs. and with Irregularly Mixed Preparatory Intervals.

N, for each average, with each degree of change in intensity = 120. Total No. of reactions = 2,400.

	Degree of Change in Int.	A (R. T. 2 secs.)		B (R. T. Irreg.)		B−A	Flicker Unobserved		Incorrect Reaction Word	
		Av.	M. V.	Av.	M. V.		2 secs.	Irreg.	2 secs.	Irreg.
Subject Vs	No. 1	551	*83*	763	*103*	212	..	7	1	..
"	"	559	*85*	746	*97*	187	1	12	..	..
"	"	528	*60*	728	*113*	200	..	8	3	..
"	"	531	*75*	805	*108*	274	..	6	1	..
"	No. 2	464	*62*	662	*89*	198	..	6	2	..
"	"	483	*46*	667	*65*	184	..	4	..	1
"	"	494	*49*	703	*77*	209	1	4	..	..
"	"	436	*31*	621	*56*	185	..	8	1	2
"	No. 3	439	*36*	636	*65*	197	..	1	..	1
"	"	460	*48*	619	*77*	159	..	..	..	1
"	"	440	*36*	600	*67*	160	..	2	3	..
"	"	468	*30*	672	*76*	204	..	5	3	1
"	No. 4	465	*40*	558	*52*	93	..	1	2	3
"	"	468	*38*	619	*62*	151	..	..	1	4
"	"	455	*35*	663	*67*	208	..	..	..	3
"	"	424	*34*	612	*71*	188	..	..	..	1
"	No. 5	444	*50*	598	*87*	155	..	1	..	..
"	"	453	*60*	628	*54*	175	..	..	4	3
"	"	474	*36*	600	*54*	126	..	1	..	..
"	"	445	*50*	579	*49*	134	..	..	2	2
Subject Ww	No. 1	564	*70*	791	*81*	227	..	4	..	1
"	"	492	*57*	676	*58*	184	..	4	..	..
"	"	477	*46*	652	*50*	175	..	6	..	..
"	"	514	*55*	721	*108*	207	..	9	..	1
"	No. 2	500	*69*	656	*133*	156	..	1	..	..
"	"	489	*70*	633	*80*	144	..	1	..	..
"	"	451	*48*	565	*64*	114	..	2	..	1
"	"	455	*33*	606	*44*	151	..	1	..	..
"	No. 3	439	*44*	564	*65*	125	..	..	..	..
"	"	431	*43*	579	*72*	148	1	..	..	..
"	"	460	*35*	574	*46*	114	..	1	..	1
"	"	486	*34*	588	*40*	102	..	..	..	..
"	No. 4	442	*42*	576	*55*	134	..	..	..	..
"	"	431	*49*	587	*62*	156	..	..	..	..
"	"	418	*25*	511	*57*	93	..	..	..	..
"	"	429	*42*	532	*42*	103	..	..	..	..
"	No. 5	415	*41*	497	*92*	82	..	..	1	..
"	"	421	*41*	530	*33*	109	..	..	..	..
"	"	430	*36*	540	*54*	110	..	..	..	..
"	"	431	*50*	534	*48*	103	..	..	..	..

Summary

Subject Vs	No. 1	542	...	760	...	**218**	1	33	..	..
"	No. 2	469	...	663	...	**194**	1	23	..	..
"	No. 3	452	...	632	...	**180**	..	8	..	..
"	No. 4	453	...	613	...	**160**	..	1	..	..
"	No. 5	454	...	601	...	**147**	..	2	..	..
Subject Ww	No. 1	512	...	710	...	**198**	..	23	..	..
"	No. 2	474	...	615	...	**141**	..	5	..	..
"	No. 3	454	...	576	...	**122**	1	1	..	..
"	No. 4	430	...	552	...	**122**	..	..	..	..
"	No. 5	424	...	525	...	**101**	..	..	..	..

the attention was the poorest, and therefore that the reaction times in these cases which were thrown out, were extremely long. The greatest number of "flicker unobserved" cases occurs with the two smallest changes in intensity, with irregular intervals. Consequently in interpreting the results, it must be remembered that the averages given for changes 1 and 2 in intensity with irregular intervals are misleadingly short. In the column headed B-A, is given in σ the absolute prolongation in reaction time produced by the use of the irregular set of intervals. As has been pointed out, the absolute prolongation so produced varies inversely with the degree of attention.

A study of the summary of the table shows that the reaction *time with the regularly repeated 2 sec. interval manifests a tendency* to increase with decrease in the size of the change in intensity. This tendency is not shown very uniformly, but is marked, especially in the case of the smaller changes in intensity. The reaction time with irregular intervals also increases with decrease in the size of the change in intensity, but in a much more marked manner, so that the difference between the time with regular and irregular intervals increases greatly as we pass from the largest change in intensity to the smallest. In other words, the absolute prolongation in reaction time produced by the irregular intervals increases as the size of the change in intensity decreases. This occurs in spite of the fact, pointed out in the preceding paragraph, that the reaction times with irregular intervals and the smaller changes in intensity are misleadingly small. When allowance is made for this latter fact, it is evident how enormously greater the prolonging effect of the irregular intervals is in the case of the smaller changes in intensity.

The fact of the increase in cases of "flicker unobserved" with decrease in the size of change in intensity, does of itself constitute a proof that the size of change is a condition of attention in this experiment. Consequently, the results obtained with each of the five sizes of change in intensity were obtained with different degrees of attention on the part of the subject, the best attention occuring in the case of size of change No. 5, and the worst, in the case of No. 1. Since the magnitude, B-A, varies inversely with the size of the change in intensity, the results evidently confirm the law already arrived at, that a given set of unfavorable preparatory intervals results in an absolute prolongation of reaction time varying inversely with the degree of attention involved in the reaction, or, more generally, the absolute effect of a given detractor of attention varies inversely with the degree of attention on which the detractor acts. As a matter of fact, however, it is so plausible from general considerations that the size of a change in intensity determines its noticeability and its clearness and is thus a condition of attention, that apart from the increase in cases of "flicker unobserved" it would be safe to assume that different degrees of attention prevailed as the size of the change in intensity was varied. And both the increase in the number of "flicker unobserved" cases and the lengthening of reaction time, produced in each case by the irregular intervals, are detraction effects resulting from the use of the set of irregular intervals as a detractor. Consequently, in both of these kinds of detraction effect, taken together or singly, we have confirmation of the law that the absolute detraction effect of a given detractor varies inversely with the degree of attention.

In the preceding discussion of the data presented in Tables XIV and XV the feature that has been most emphasized is that the reactions involved a recognition of change in intensity. A fact of considerable practical importance in the measurement of attention, however, is brought out when we remember that the reactions reported in the present chapter are "choice" reactions. The form of the reaction depends upon a certain feature of the stimulus by which the subject must be affected before he can react properly, so that, in spite of the fact that the subjects were instructed to react as quickly as possible, there was no danger of premature reactions. In my own work I have not felt that premature reactions were a source of difficulty. I have frequently met with them, but those so premature that the reaction had actually occurred before the stimulus would never affect the chronoscope at all, and only very seldom have I gotten reaction times so short that I could be sure that the reactions had been prematurely initiated. On the whole I believe that the reaction times that I obtained were distributed fairly symmetrically, as in the sample distribution presented in Table II, Chapter II. I have not actually plotted the distribution of all the reaction times I have taken, but the very short reactions that I have obtained I believe to be fully counterbalanced by the very long ones. Yet it may very well be that with some subjects premature reactions would prove troublesome. Indeed it may be that the results here reported, especially those in Chapter V on practice, have been influenced to some extent, without my detecting it, either by a slight tendency to premature reactions or by carefulness on the part of the subject to avoid premature reactions. Should it be found that a tendency to premature reactions is sometimes troublesome in the case of the simple reactions with a regularly repeated 2 sec. interval, the results of the present chapter show that this difficulty may be met by using choice reactions, as in the experiment reported in Table XIV.

The reaction time of choice reactions in influenced fully as much by irregularity in the preparatory intervals as is simple reaction time. The same law of detraction holds for both sorts of reactions, and the procedure for measuring degree of attention would be the same for both forms of reaction. Further, it seems exceedingly probable that a true discrimination reaction could also be satisfactorily employed. A reaction to either an increase or a decrease in brightness, the reaction word being "more" in one case and "less" in the other, would not only be safe from premature reactions but would preserve the advantage inherent in the use of a change in brightness as a stimulus, namely, independence, within wide limits, of variation in retinal sensitivity.

SUMMARY

The time of a reaction to a change in intensity varies with the size of the change in intensity. This is shown in Table XV by the increase in reaction time, with either regular or irregular intervals, with decrease in the size of the change in intensity.

The time of a reaction to a change in intensity remains very nearly constant for a very wide range of absolute intensities of stimulus, providing the relative change in intensity is kept constant. From this, it seems probable, by analogy, that the reaction time to a given change in intensity would remain very nearly constant throughout a wide range of change in retinal sensitivity to intensity, other factors than retinal sensitivity remaining constant. Such a constancy in the reaction time would indicate a constancy in the degree of attention, conditioned by the given change in intensity, in spite of variations in retinal sensitivity to intensity. It follows, therefore, that by the use of a reaction time to a change in intensity, *attention can be measured independently of wide variations in retinal sensitivity*. This is of considerable importance in the comparison of different individuals. The method, using such a reaction, would be to determine the reaction time with a regularly repeated preparatory interval of 2 secs., and then to determine the absolute prolongation in this time produced by the use of a given set of totally irregular preparatory intervals, keeping the other conditions constant, and to rank the attention as the reciprocal of the prolongation obtained.

A smaller degree of adaptation of attention to the reaction exists in the case of reactions following irregularly mixed preparatory intervals than those following regularly repeated preparatory intervals of 2 secs. This conclusion was arrived at in Chapter II as a result of a study of the literature on the effect of the preparatory interval on reaction time, and is a basic proposition of the present monograph. Table XV contains an experimental confirmation of this proposition in the fact that it shows that slight changes in intensity were very frequently not noticed with irregular preparatory intervals while they were always, or practically always, noticed with regularly repeated intervals.

The attention involved in a reaction to a change in intensity decreases with decrease in the degree of change in intensity.

Table XV shows that both absolute prolongation in reaction time and increased frequency of the cases in which the change in intensity was unnoticed resulted from the use of irregular preparatory intervals in the case of each degree of change in intensity; and that both these detraction effects of the irregular intervals increased markedly as the degree of the change in intensity decreased, or, consequently, as the degree of attention decreased. So, finally, we may conclude again, as in Chapter III, but from different experimental data, that the absolute detraction effect of a given detractor varies inversely with the degree of attention against which the detractor acts.

Irregularly mixed preparatory intervals constitute fully as effective a detractor of attention in the case of choice reactions as in the case of simple reactions. Consequently, if it should be found that premature reactions were a source of error in the measurement of attention by the procedure here proposed, a choice reaction or a true discrimination reaction could be used and thus the difficulty avoided. A change in brightness as reaction stimulus, which might be sometimes an increase and sometimes a decrease, would not only be safe against premature reactions but would also preserve the advantage that is inherent in the use of a change in intensity as a reaction stimulus, namely, independence, within wide limits, of variation in retinal sensitivity to intensity.

CHAPTER V

ILLUSTRATIVE APPLICATIONS

(A) PRACTICE

A serious drawback to almost all, if not all, of the mental tests now in use is that the result obtained varies with the degree of practice which the subject has had in the activities or functions measured by the test. The result of one or a few applications of the test, therefore, serves as a measure of the trait only at a particular stage of practice,—it measures neither the original ability nor the final ability. Even in adults, all of whom have already had a great deal of practice in the trait or complex of traits tested, marked improvement may occur with even moderate practice, and this improvement varies in amount with different individuals and with different traits. Practice effects are not only invariably found in the case of simple mental tests, but also in the case of our most elaborate and scientific mental measurements. And reaction time itself usually shows a marked shortening as the result of practice. The problem of practice is very evidently, therefore, one of great importance throughout the whole field of mental tests and measurements, and in general constitutes a serious obstacle. Many of the conclusions that have been arrived at from the use of mental tests and measurement are valid, but many of them would be seriously modified by correction for the practice error. Without this correction it is hard to see how a satisfactory comparison can be made between different individuals, between different traits in the same individual, or of the effect of various conditions acting at different times on the same mental trait in a given individual. There are three simple ways, theoretically, of obviating the difficulty. One is to make the measurement before practice has begun, one to make the measurement always at the same stage of practice, and one to make it at the terminal stage, that is, after such long continued practice that no further improvement is noticeable. But all three of these methods are usually more or less impracticable and it is seldom that any one of them has been rigorously applied.

Our knowledge of what "practice" means is in its infancy. While we may define it as the improvement in a function resulting from the exercise of that function, it must be admitted that very frequently indeed we assume altogether without warrant that we are measuring the same functions at the beginning and end of our practice series, whereas it is quite likely that the quality or type of function changes with practice, in which case the measured increase in efficiency does not so much represent an improvement in the given psychophysical processes as the adoption of different ones. To understand practice, we must not be content to note merely the improvement in the results of the psychophysical function. We must determine the factors that work together to produce the results, and then determine whether there has been improvement in these factors, and in which of them, or whether on the other hand merely a similar but better result is being produced by different factors. For example, because attention is involved in a certain psychophysical function. and the results show practice effects, we cannot complacently explain the practice effect as due to improvement in the attention as the result of the practice. We could as correctly speak of the practice effect in electro-motive force if we observed that the output of some electrical plant improved with the time it had been in operation, even though we were not sure but that the manager had been constantly introducing different machinery and altering his method. At present the effects of practice have not been studied sufficiently analytically to enable one to say, in most cases at any rate, to what practice is due. We can easily determine the change in the output, but we know very little about the accompanying changes that occur in the "plant." We do not at present know what psychophysical functions improve with practice, not to raise the question in what the improvement consists.

Attention cannot be measured, of course, without its being exercised, so that each time the subject's attention is measured the subject has practice in attention. I consequently undertook the investigation of the effect of practice on the degree of attention. My problem was merely whether I should get the same result time after time throughout a long series of measurements. It is true that simple reaction time under any given set of conditions usually shows a very decided practice effect. But, as usual, we do not know to what the practice effect is due. If reaction time decreases with practice, because of increase in the degree of attention, I should get a practice effect in my measurements of the degree of attention. If, on the other hand, it is true that a high degree of attention is present only in the initial stages of learning a habit, and that as the reaction is repeated it tends to become reflex and consequently to involve a lower degree of attention, my measurement of attention, if valid, should show the opposite of a practice effect. The actual data obtained tend to show that neither a practice effect nor the opposite is the result. The degree of attention was not found to show any general tendency either to increase or decrease with repetition of the measurements.

The methods used in the present experiments on practice are similar to the method described in the last chapter, though considerable simplification of technique was introduced. The reactions were motor or abbreviated reactions to a change in intensity. The conclusion was reached in the last chapter that the use of a change in intensity as the reaction stimulus renders possible a fairer comparison of individuals. A comparison of different individuals is not particularly important in the present instance, but the fact that a reaction to a large supraliminal change in intensity is independent within wide limits of the absolute intensity or of the sensitivity of the sense-organ, renders it unnecessary to use a dark-room, or to allow any particular time for adaptation of the retina to the prevailing illumination, or to work at all times under the same illumination. Consequently in the present work all these factors were allowed to vary somewhat and no particular attention paid to them. In place of two or three lights or bars of light, only one was used. I found in the work with several bars of light, that when one changed in brightness, the change was noticed directly, and that either no comparison at all occurred between the brightness of the bar which changed and the other bars, or else such a comparison was incidental. Moreover, in the present experiment the change in brightness was produced in a different manner. Instead of the elaborate tachistoscopic apparatus for the exposure of the light used in the experiments described in Chapters III and IV, the single light used was arranged so as to be visible at all times, and its increase in intensity was produced merely by increasing the current in the electrical circuit which caused the illumination. This was accomplished by throwing into the circuit a parallel shunt, using a double key, so that the shunt was thrown in synchronously with the make of the chronoscope circuit. Another simplification was the return to an ordinary reaction key, Scripture's so-called "noisless key," in place of the Cattell voice-key, and the use of an ordinary break (upward) reaction movement. The click of an electric sound hammer was used in place of the ring of an electric bell for the warning signal. To estimate the intervals the experimenter made use of a noiseless pendulum in place of a metronome. This last change was due to the fact that the adjoining subject's room used in this part of the work was by no means sound proof, being separated from the experimenter's room by an ordinary tile wall and wooden door. The subject could even hear the starting of the chronoscope. The chronoscope was not stopped between successive reactions, but allowed each time to run until the driving weight reached the bottom, or nearly so.

The light stimulus was an all-frosted 25-watt Mazda lamp placed behind an aperture 4 cms. square in a dark box. The aperture was covered by ground glass. The intensity of this light was not measured, though the conditions could be fairly accurately reproduced from the description below. Before the increase in brightness constituting the reaction stimulus, the light was bright enough to be visible easily, what might be called a moderately dim light. The change in intensity, likewise not measured, was very great, so that the light looked nearly twice as bright after the change as before. The current used was a direct current of 110 volts, supplied by the University power plant. With the arrangement used a slight or even considerable variation in intensity of the circuit supplied would not appreciably affect the noticeability of the relative change in intensity, which is the only thing it was necessary to keep constant. The 25-watt lamp was placed in this 110-volt circuit in series with a 40-watt Mazda 110-volt lamp, with no other resistance except a number of feet of copper wire necessary for the connections. The increase in brightness was produced by throwing into the circuit a shunt containing a second 40-watt Mazda, in parallel with the other 40-watt Mazda. This produced an extremely sudden increase in brightness.

Of course, this increase in brightness, while apparently instantaneous, required really a few thousandths of a second. The method would be unpermissible if it were a matter of obtaining absolute reaction times. But my only object was to measure the absolute prolongation in reaction time resulting from the use of irregular intervals. The time required for the change in brightness to occur is a constant when sufficient interval is always allowed the light each time to return to its original brightness before each increase. This interval, which to the eye appeared to be almost nothing, was certainly many times less than the smallest interval between any two reactions with either the regularly repeated intervals of 2 secs. or the irregular intervals, and thus in both cases the time required for the change in intensity constituted a constant error which would not affect the absolute difference in reaction time. No attempt, consequently, was necessary to correct for this error.

From the description of the method of producing the change in intensity which constituted the reaction stimulus, it will be seen that the entire apparatus was very simple. A standard chronoscope and fall-hammer circuit, three lamps and a dark box is all that was required. The manipulation on the part of the experimenter was equally simple. At the same time the apparatus seems entirely satisfactory for its purpose.

Unfortunately for the sake of uniformity, the results I have obtained on the effect of practice were not all taken with the same apparatus. In addition to the apparatus just described, two sets of practice series, those with subjects Vs and Sz, presented in Table XVIII, were taken with the apparatus described in Chapter I in connection with Table I, where a sound stimulus was used.

Both methods are equally good, for the study of practice effects, but the one described in this chapter is better for purposes in general, since it permits a comparison of individuals apart from sensory sensitivity. The present study extended over several years and each part indicated some improvement in method, which was usually adopted in the following parts. And some study of practice as well as some preliminary applications were made at various stages of the work, thus accounting for the use of more than one method in the experiments described in this chapter.

In all cases the procedure was essentially the same. The subjects served only one hour a day, for a number of successive days, Sundays omitted. Each day, reactions were first taken with a series of regularly repeated 2 sec. preparatory intervals, and then with a series of irregularly mixed preparatory intervals varying fom 4 to 20 secs. In the case of the two practiced subjects whose results are given in Table XVI, 30 reactions were taken with the regularly repeated 2 sec. intervals, and then 30 with the irregularly mixed intervals; and this constituted the entire procedure for one day. In the case of the two subjects included in Table XIX, the procedure was the same as that just mentioned, except that 50 reactions instead of 30 were taken with each of the two kinds of preparatory intervals, i.e., the regularly repeated 2 sec. intervals and the irregularly mixed intervals.[1] In the case of the subjects included in Tables XVII and XVIII, the procedure was as follows: first, 30 reactions were taken with

[1] The set of 30 irregularly mixed intervals used in obtaining the results presented in Tables XVI, XVII and XVIII was the same as used in connection with Table XV of the last chapter, namely: 4, 16, 20, 4, 8, 20, 12, 16, 8, 4, 12, 4, 20, 8, 12, 4, 16, 20, 8, 16, 12, 12, 8, 16, 20, 12, 20, 8, 4, and 16 secs. The set of 50 irregularly mixed intervals used in connection with Table XIX was the same as the preceding set plus the first twenty of that set.

the regularly repeated 2 sec. intervals, and then 30 with the irregularly mixed intervals; then, after a few minutes intermission, during which the subject rested and the experimenter tested the accuracy of the chronoscope by means of the Wundt's fall-hammer, 30 more reactions were taken with the regularly repeated 2 sec. intervals and then, lastly, 30 more with the irregularly mixed intervals. In these cases the average reaction time for the 2 sets of regularly repeated 2 sec. intervals is subtracted from the average reaction for the 2 sets of irregularly mixed intervals, and the difference considered as constituting a single measurement of attention. In all four tables the average (Av.) and the mean variation (M.V.) of each set of intervals used on each day is given in σ. In Tables XVII and XVIII, there are given, in addition, the average for all of the regularly repeated 2 sec. intervals (2 secs. Av.) and for all of the irregularly mixed intervals (Irreg. Av.) used during one day's sitting. In the last column at the right, in all the tables, headed 1/A, is given the absolute difference between the average reaction time for all the 2 sec. intervals and the average for all the irregular intervals, used at one sitting. Since the time with the irregular intervals is always greater, this column gives the absolute prolongation produced by the irregular intervals, or, in other words, the detraction effect of the irregular intervals. This is the quantity which it has been shown in the preceding pages varies inversely as the degree of attention, or directly with 1/A, in which A represents the degree of attention. In the Tables XVI-XIX the results of the measurements are presented in the order in which the measurements were made, the order being indicated by the column headed No.

In all, eight subjects were used. Six of these, subjects Lm, Sh, Vs, Sz, Ll and St, were absolutely unpracticed subjects. Since practice effects are invariably found to be more marked at first than later,[2] it would seem that 10 or 12 hours of work distributed

[2] "Finally, if irregularity is discarded and all curves smoothed out, only those facts conforming to the 'law of the practice curve' are represented, namely, that a person improves in any work most rapidly at first and makes little and slow improvement after reaching a certain degree of ability."

over as many days should be sufficient to determine whether or not such an effect were present. Two subjects, Mn and Ww, were both highly practiced in nearly all kinds of reaction time work. The results with these subjects are given to determine what degree of constancy can be expected in the results of the measurement of attention in the case of trained laboratory subjects. This is important, for even though a considerable degree of practice effect might invalidate the method for widespread use in the measurement of different individuals, it would by no means invalidate it for research work and other purposes in the case of practiced reagents. The results with these subjects are also interesting in comparison with the results on unpracticed subjects.

TABLE XVI

The Variation in a Series of Measurements of Attention. Practiced Subjects. Visual Reaction Time Method.

N, for each average = 30. Total No. of reactions = 840.

		2 secs.		Irreg.		
Subj.	No.	Av.	*M.V.*	Av.	*M.V.*	1/A
Mn	1	159	*40*	235	*16*	66
"	2	172	*17*	235	*15*	63
"	3	178	*17*	260	*21*	82
"	4	171	*24*	227	*19*	56
"	5	165	*17*	233	*20*	68
"	6	173	*33*	233	*18*	60
"	7	163	*24*	241	*26*	78
"	8	158	*20*	224	*20*	66
"	9	170	*21*	237	*9*	67
Ww	1	166	*10*	248	*13*	82
"	2	175	*19*	256	*19*	81
"	3	167	*20*	255	*25*	88
"	4	166	*15*	251	*10*	85
"	5	165	*10*	245	*9*	80

The point of main interest in Tables XVI-XIX is whether the quantity 1/A, that is, the absolute prolongation produced by the irregular intervals, varies with repetition of its measurement.

Whitley, *An Empirical Study of Certain Tests for Individual Differences, Archives of Psychology,* 19, 1911, 136.

To determine this point, it is necessary to study somewhat in detail the results obtained with each subject. To take up first the two subjects Mn and Ww, who had had a great deal of previous practice in reaction time work of various kinds, it may be said that there is no sign of either a general practice effect

TABLE XVII

The Variation in a Series of Measurements of Atttention. Unpracticed Subjects. Visual Reaction Time Method.

N, for each average of each series = 30. Total No. of reactions = 4320.

Subj.	No.	1st Series 2 Secs. Av.	1st Series 2 Secs. *M.V.*	1st Series Irreg. Av.	1st Series Irreg. *M.V.*	2d Series 2 Secs. Av.	2d Series 2 Secs. *M.V.*	2d Series Irreg. Av.	2d Series Irreg. *M.V.*	2 Secs. Av.	Irreg. Av.	1/A
Lm	1	230	*35*	309	*23*	248	*22*	348	*39*	239	329	**90**
"	2	206	*13*	321	*39*	251	*39*	360	*52*	229	341	**112**
"	3	203	*35*	302	*27*	256	*28*	329	*25*	230	316	**86**
"	4	213	*22*	302	*39*	236	*11*	335	*49*	225	319	**94**
"	5	220	*16*	312	*30*	234	*34*	358	*77*	227	335	**108**
"	6	222	*18*	316	*27*	251	*18*	338	*37*	237	327	**90**
"	7	202	*19*	301	*35*	245	*20*	327	*33*	224	314	**90**
"	8	216	*11*	319	*30*	231	*20*	329	*41*	224	324	**100**
"	9	194	*32*	331	*43*	256	*21*	329	*37*	225	330	**105**
"	10	230	*18*	335	*37*	227	*13*	335	*35*	229	335	**106**
"	11	191	*17*	277	*40*	211	*28*	316	*38*	201	297	**96**
"	12	211	*18*	306	*29*	232	*9*	326	*43*	222	316	**94**
"	13	214	*14*	313	*37*	218	*11*	316	*29*	216	315	**99**
"	14	197	*14*	306	*29*	228	*15*	321	*29*	213	314	**101**
"	15	209	*19*	310	*32*	216	*24*	311	*27*	213	311	**98**
"	16	216	*20*	305	*23*	205	*27*	311	*35*	215	312	**97**
"	17	183	*17*	306	*26*	210	*22*	319	*32*	201	317	**116**
"	18	196	*10*	318	*30*	198	*17*	314	*25*	201	320	**119**
"	19	183	*22*	315	*37*	200	*37*	300	*34*	196	312	**116**
"	20	193	*9*	312	*20*	215	*18*	314	*24*	208	317	**109**
"	21	192	*14*	312	*35*	221	*14*	305	*39*	211	313	**102**
"	22	190	*23*	295	*29*	207	*19*	300	*32*	203	302	**99**
"	23	208	*15*	301	*21*	232	*16*	341	*40*	224	325	**101**
"	Av.	205	*19*	309	*31*	227	*21*	325	*37*	216	317	**101**
Sh	1	213	*45*	326	*39*	252	*33*	335	*37*	233	331	**98**
"	2	201	*18*	296	*27*	217	*17*	304	*37*	209	300	**91**
"	3	203	*16*	304	*39*	205	*23*	303	*35*	204	304	**100**
"	4	185	*12*	270	*28*	195	*21*	290	*33*	190	280	**90**
"	5	180	*15*	279	*29*	189	*29*	286	*28*	185	283	**98**
"	6	177	*25*	283	*33*	210	*25*	273	*23*	194	278	**84**
"	7	169	*29*	275	*26*	191	*27*	288	*22*	180	282	**102**
"	8	200	*11*	262	*21*	218	*30*	251	*36*	209	257	**48**
"	9	195	*21*	257	*18*	184	*24*	264	*34*	190	261	**71**
"	10	194	*11*	280	*32*	187	*18*	276	*16*	191	278	**87**
"	11	173	*22*	275	*13*	192	*10*	288	*29*	183	282	**99**
"	12	220	*23*	274	*29*	209	*12*	281	*26*	215	278	**63**
"	13	210	*10*	268	*16*	218	*19*	280	*30*	209	274	**65**
"	Av.	193	*20*	281	*27*	205	*22*	286	*30*	199	284	**85**

or the reverse. The results are presented in Table XVI. Improvement in attention would be indicated by decrease in the size of 1/A in successive measurements, whereas a lessening of the degree of attention would be represented by an increase in the size of 1/A. As a matter of fact no general tendency to increase or decrease is observable. The variations are altogether irregular in direction, and most of them of little reliability in view of the size of the mean variations. With subjects like these, evidently there would be no difficulty in using the method for accurate quantitative study of the laws and conditions of attention. With subject Mn, the absolute mean variation for nine consecutive measurements of 1/A is 5σ, and relative 7 per cent, and with subject Ww, for five consecutive measurements, the absolute mean variation is 3σ, the relative, 4 per cent.

The results with subjects who were complete novices at the

TABLE XVIII

The Variation in a Series of Measurements of Attention.
Unpracticed Subjects. Auditory Reaction Time Method.

N, for each average of each series = 30. Total No. of reactions = 2400.

Subj.	No.	1st Series 2 Secs. Av.	*M.V.*	1st Series Irreg. Av.	*M.V.*	2d Series 2 Secs. Av.	*M.V.*	2d Series Irreg. Av.	*M.V.*	2 Secs. Av.	Irreg. Av.	1/A
Vs	1	142	*17*	199	*32*	117	*15*	211	*44*	130	205	75
"	2	122	*14*	203	*24*	128	*12*	213	*31*	125	208	83
"	3	125	*13*	193	*27*	129	*17*	199	*19*	127	196	69
"	4	139	*13*	209	*33*	130	*17*	191	*27*	135	200	65
"	5	115	*12*	184	*31*	106	*13*	195	*38*	111	190	79
"	6	117	*13*	210	*39*	115	*23*	209	*29*	116	210	94
"	7	110	*17*	200	*43*	115	*11*	202	*31*	113	201	88
"	8	124	*12*	196	*25*	135	*12*	204	*26*	130	200	70
"	9	131	*17*	195	*24*	129	*18*	209	*25*	130	202	72
"	10	134	*12*	210	*22*	138	*16*	207	*27*	136	209	73
"	Av.	126	*14*	200	*30*	125	*15*	204	*30*	126	202	76
Sz	1	153	*20*	256	*38*	138	*31*	229	*38*	146	243	97
"	2	137	*23*	219	*37*	124	*21*	204	*32*	131	212	81
"	3	140	*14*	224	*34*	129	*17*	220	*34*	135	222	87
"	4	156	*22*	236	*26*	164	*15*	243	*22*	160	240	82
"	5	136	*18*	211	*26*	152	*23*	224	*27*	144	218	74
"	6	143	*15*	213	*23*	141	*16*	223	*37*	142	218	76
"	7	137	*12*	207	*24*	142	*15*	214	*30*	140	211	71
"	8	162	*13*	202	*27*	163	*14*	213	*26*	163	208	45
"	9	155	*14*	214	*17*	155	*18*	228	*28*	155	221	66
"	10	157	*13*	205	*23*	158	*17*	214	*29*	158	210	62
"	Av.	148	*16*	219	*28*	147	*19*	221	*30*	148	220	72

beginning of the work, presented in Tables XVII-XIX, show certain interesting peculiarities, but in no case, I think, a true practice effect. Subject Lm (Table XVII) who was given 23 tests, the greatest amount of practice given any of the subjects, certainly shows no practice effect, but if anything, the opposite of a practice effect. That is to say, no tendency is evident on the part of the magnitude 1/A to decrease as the number of times it has been measured increases. The general tendency is quite definitely for 1/A to remain the same throughout the series of measurements, or else to very slightly increase. As in the case of all this work on practice, every effort was made to impress it upon the subject that all reactions, both those with the regularly repeated 2 sec. intervals and those with the irregularly mixed

TABLE XIX

The Variation in a Series of Measurements of Attention. Unpracticed Subjects. Visual Reaction Time Method.

N, for each average = 50. Total No. of reactions = 2600.

Subj.	No.	2 Secs. Av.	2 Secs. *M.V.*	Irreg. Av.	Irreg. *M.V.*	1/A
Ll	1	247	38	305	38	58
"	2	189	23	277	33	88
"	3	193	25	255	31	62
"	4	194	26	252	27	58
"	5	188	14	250	25	62
"	6	189	21	250	23	61
"	7	203	24	269	28	66
"	8	181	10	243	30	62
"	9	176	13	247	19	71
"	10	197	19	251	21	54
"	11	181	23	240	20	59
"	12	225	23	291	19	66
"	13	216	14	288	15	72
"	14	204	38	279	22	75
"	15	195	16	261	18	66
"	16	217	21	295	25	78
St	1	191	22	253	42	62
"	2	187	12	232	25	45
"	3	179	24	245	28	66
"	4	190	24	241	28	51
"	5	229	23	287	24	58
"	6	202	36	281	22	79
"	7	220	20	280	22	60
"	8	211	27	273	28	62
"	9	207	28	276	25	69
"	10	203	30	275	18	72

intervals, were to be made as quick as possible. The most prominent feature of the results with subject Lm is the variation in the magnitude of 1/A from day to day, rather than any general tendency on the part of this magnitude to regularly increase or decrease. Yet there is nothing astonishing in these variations from day to day, and it is not at all improbable that they were entirely paralleled by variations from day to day in the degree of the subject's attention. I was unable to obtain any information from the subject, who was a young woman of 28, which seemed to account for the variations from day to day, though there was considerable variation in the amount of sleep per night during this period, and in the amount of work she did before she came into the laboratory at 5.00 P. M. for the test. The mean variation in 1/A, however, for the entire 23 measurements was only 7 per cent, with an average of 101 σ. The simple reaction times, whether for the 2 sec. intervals or the irregular intervals, show a definite practice effect, though this effect is neither very great nor regular. The average, for the first 5 days, of all the reactions with the regularly repeated 2 sec. intervals is 230 σ, for the last 5, 208 σ; while the average reaction time with totally irregular intervals, for the first 5 days is 328 σ and for the last 5, 314 σ. The average of 1/A for the 1st 5 measurements is 98 σ and for the last 5, 105 σ.

The results with subject Sh (Table XVII) are less clear cut. Subject Sh certainly shows no practice effect, as regards the degree of attention, during the first 7 days; that is, there is certainly no general tendency on the part of the magnitude 1/A to decrease during this period. Since practice effects are most marked at the very earliest stages of practice, we should expect them to become noticeable, if present at all, before the end of the seventh day, with practice an hour per day. Indeed, in the case of the simple reaction times, both with the regularly repeated 2 sec. intervals and the irregularly mixed intervals, a very marked practice effect is noticeable. In spite of this practice effect in the simple reaction times during the first 7 days, there is no sign of a decrease in the magnitude 1/A. And yet on the eighth day, 1/A decreases very suddenly. From this point on, no further decrease in 1/A occurs, but on the other hand, a regular and marked increase, until the twelfth day, when a second drop in the size of 1/A occurs. It seems to me improbable that these two sudden decreases in the size of 1/A correspond to real increases in the degree of attention. Consequently, whatever the explanation of these sudden decreases in 1/A may be, I must recognize that there is here involved some serious source of error in my method. I shall attempt to show, however, that this error is not the result of any practice effect in the degree of attention, but due to the detrimental effect upon the favorableness of the 2 sec. intervals exerted by the long irregularly mixed intervals when the use of the latter is frequently alternated with the use of the regularly repeated 2 sec. intervals. I believe this error can be entirely avoided or at least rendered of negligible importance by a slight modification of the method, which I shall speak of in connection with Table XIX.

A study of the results for subject Sh will show that the two sudden drops in the value of 1/A correspond to two sudden increases in the reaction time with the 2 sec. preparatory intervals. The reaction time for the 2 sec. intervals, as the result of the first 7 days practice, decreases in a fairly regular manner from 233 σ to 180 σ. The reaction time for the irregular intervals shows a similar decrease. But on the eighth day, while the reaction time with the irregular intervals continues to decrease, a sudden slump occurs in the reaction time with the 2 sec. intervals, the latter jumping from 180 σ to 209 σ. The reaction time with the 2 sec. intervals then again improves, reaching 183 σ on the eleventh day, only to jump on the following day up to 215 σ, a time longer than any obtained after the very first day. This peculiar behavior on the part of the reaction time with the 2 sec. intervals fully accounts for the irregularity in the value of 1/A. If the cause of the decrease in the value of 1/A were an increase in degree of attention resulting from practice, it would be incredible that just at the points where the decrease in 1/A was strikingly apparent, a marked increase would be found in the simple reaction time with the 2 sec. preparatory intervals.

Before taking up the explanation of the results obtained with subject Sh, I wish to mention the results obtained with subject Sz (Table XVIII), as the results with the latter subject closely resemble those with subject Sh. In the case of Sz there are two marked increases in the reaction time with the 2 sec. intervals. One of these increases occurs on the fourth day and the other on the eighth day. On the fourth day the reaction time with the 2 sec. intervals rose to 160 σ, which is 14 σ longer than the reaction time for the first day and 25 σ longer than the reaction time for the preceding day. On the eighth day the reaction time for the 2 sec. intervals was 163 σ, which is 19 σ longer than that for the first day and 23 σ longer than that for the preceding day. No marked change occurs in the reaction time with the irregular preparatory intervals. The decrease in the size of 1/A, therefore, is clearly due to the fact that the reaction time with the 2 sec. intervals increased with practice instead of showing the normal decrease. In neither subject Sh nor subject Sz, therefore, can a practice effect in the degree of attention be noted. It is true that 1/A decreases and that I have claimed that 1/A measures the degree of attention. But an analysis of the results shows that the values of 1/A have been influenced by some factor which constitutes a source of error. The effect of this source of error has been just the opposite of a practice effect in that it consists in a prolongation of the 2 sec. reaction time.

In view of the results I have presented in Chapter II on the effect of the order in which preparatory intervals of different length are used, I think there can be little doubt that the lengthening in the reaction time with the 2 sec. intervals, noted in the case of subjects Sh and Sz, is due to the result of adaptation to the longer irregularly mixed intervals. As I have already explained, in the case of the two subjects in question, each day's procedure was, first to take 30 reactions with a preparatory interval of 2 secs., and then, 30 reactions with a series of irregularly mixed intervals varying from 4 to 20 secs. in length; and then, after a few minutes pause, to take 30 more reactions with a 2 sec. interval and lastly, 30 with the series of irregularly mixed intervals. Thus it will be seen that, while the 2 sec. interval was repeated 30 times in succession, this whole series of repetitions was alternated with the use of much longer irregularly mixed intervals. I have shown in Chapter II, Tables V-VII, that the natural favorableness of the short preparatory intervals is largely destroyed when short intervals are preceded by longer ones. A certain adaptation to the long intervals occurs, and this adaptation to the long intervals has the result that the subject is unprepared for a stimulus which comes at the end of a short interval; so that in a series of irregularly mixed intervals of various length, it is extremely likely that the shortest interval which occurs in the series will give the longest reaction time, in spite of the fact that this shortest interval when used by itself would give shorter reaction times than the longer intervals.

I have pointed out, further, in Chapter II, that adaptation to short intervals has a much less detrimental effect upon reaction time with long intervals than does adaptation to long intervals upon the reaction time to short intervals. Now it seems to me that the peculiar trend of the reaction times with the 2 sec. intervals, which I have already noted in the case of subjects Sh and Sz, is fully explained by this phenomenon of temporal adaptation. Adaptation to the series of irregularly mixed intervals carried over to the regularly repeated 2 sec. intervals and rendered the latter less favorable than they were at the beginning of the experiment. It might be thought that using the 2 sec. interval 30 times in succession would obviate the effect of adaptation to the longer irregularly mixed intervals. But it is quite possible that daily experience with the two sorts of intervals had the effect of producing a more or less fixed attitude which prevented the best possible adaptation to the regularly repeated 2 sec. intervals. In working with irregularly mixed intervals such as here used, there is little adaptation of attention to any particular interval, as was shown in Chapter II; and I think it quite probable that the subjects Sh and Sz formed a habit as the result of working with these intervals which they could not throw off when they returned to the 2 sec. intervals.

As regards the remaining three subjects, subject Vs, Table

XVIII, and Subjects Ll and St, Table XIX, it may be said that there is absolutely no trace of a practice effect in the values of 1/A. With subject Vs, Table XVIII, the average value of 1/A for the first 3 of the series of 10 measurements is 74 σ and for the last 3, 75 σ. The average value of 1/A for the entire series of 10 measurements is 76 σ with a mean variation of 7 σ, or slightly less than 10 per cent. In the case of subject Ll, Table XIX, who was given a series of 16 measurements, the average of the first 3 values of 1/A is 69 σ and of the last 3, 73 σ, while the average of the entire series of 16 measurements is 66 σ with a mean variation of 7σ, or 11 per cent. In view of the irregularity in the size of 1/A from day to day, it can hardly be said that there is any reliable general tendency for 1/A either to increase or decrease. In the case of subject St, Table XIX, there is a slight tendency for 1/A to increase with repetition of its measurement, that is, for the opposite of a practice effect. This increase in the size of 1/A is not so marked, however, but that it may reasonably be explained as due to a wearing off of interest, or a decline in zeal, with the progress of the work. The average of 1/A for the first half of the series of 10 measurements is 56 σ and for the second half is 68 σ, while the average for the entire series is 62 σ with a mean variation of 7 σ, or 11 per cent.

It will be observed that the sudden decreases in the value of 1/A which occurred after a certain number of repetitions of its measurement in the case of subjects Sh and Sz did not occur in the case of any of the four subjects whose results are presented in Tables XVI and XIX. It will be observed, also, that the procedure used in obtaining the results presented in these last mentioned tables did not involve the use of the 2 sec. intervals directly after the use of the irregularly mixed long intervals as did the procedure used with subjects Sh and Sz. I am inclined to believe, therefore, that the error of temporal adaptation already alluded to can be avoided merely by always avoiding the use of 2 sec. intervals soon after the use of the irregular intervals. The 2 sec. intervals ought to be used first, and then the irregularly mixed intervals, and then the test should end, not to be repeated for at least one day. I am inclined to believe further that the error of temporal adaptation will be still more surely avoided by taking not more than 30 reactions with each of the two sorts of preparatory intervals, i.e., the 2 sec. and the irregularly mixed. This latter method has the further advantage of consuming less than 20 minutes of the subject's time.

On the whole, I think the results presented in this chapter demonstrate that the method of measuring attention proposed in these pages is a practicable one. The data of Tables XVI-XIX show conclusively that the detraction effect exerted by the unfavorable preparatory intervals, that is, by the irregularly mixed intervals, does not tend to wear off with a few hours practice. On the whole, the detraction effect is fairly constant from day to day. It is especially constant in subjects who are highly practiced in general reaction technique and yet in such subjects there is no evidence that the absolute size of the detraction is smaller than in unpracticed subjects. But even in unpracticed subjects there is no evidence that the detraction effect exerted by the unfavorable intervals wears off with practice. The six unpracticed subjects give results unequivocally against the conclusion that the absolute detraction effect decreases with practice. With subject St, Table XIX, it increases, and perhaps also with subject Lm, Table XVII. With a fifth subject, Sh, Table XVII, the results for the first 7 days are equally decisive against a decrease in the detraction effect of the unfavorable intervals as the result of practice. The results with the last part of the series of measurements made with this subject, however, as also the results with subject Sz, Table XVII, show certain peculiarities, due, as pointed out above, to marked lengthening as the result of practice, instead of shortening, in the reaction times with the 2 sec. intervals. These peculiarities require interpretation and the results may, therefore, be called inconclusive. The explanation that I have given of these peculiarities is that they are due to an error resulting from temporal adaptation. I can see no more evidence in the last mentioned results than in the others of a wearing off in the detraction effect exerted by the unfavorable preparatory intervals. The error of temporal adaptation is a serious one, but I have indicated how it may probably be avoided. Subjects Ll and Lm, given respectively 16 and 23 hours' practice, show no practice effect whatever in degree of attention.

In general, then, it may be said that the data of Tables XVI to XIX indicate clearly that the detractor I have used for measuring attention is one whose efficiency as a detractor is fairly constant and does not wear off with practice. The very fact of the general constancy in the effect of the detractor indicates that the degree of attention under the prevailing conditions did not improve. For the detractor itself remained the same throughout. This means, of course, that the attention which is involved in a simple reaction such as here used does not improve with practice.

If the degree of attention does not vary with practice, the question arises, how shall we account for the improvement in simple reaction time with practice. The answer is simply that the attention factor is only one factor in the reaction process, and that the improvement occurs in other factors. The equation[3] $y = A + B.\ log\ x$ shows how this is possible. Whenever the degree of attention varies, the magnitude $B.\ log\ x$ varies, and consequently it follows that as long as this magnitude remains constant the degree of attention remains constant. But y, the reaction time, may vary, as the equation shows, without variation in the magnitude $B\ log\ x$, and therefore without variation in attention. Indeed, nothing is more certain than that reaction time may vary without corresponding variation in attention. Therefore, no new problem is raised when we find that reaction time improves with practice without any accompanying improvement in the degree of attention.

A much more important matter than the explanation of improvement in reaction time is the question of the rôle of attention in mental development in general—a most fundamental problem of the psychology of learning. It is not uncommon to explain improvement in any mental process as due to improvement in the degree of attention. And indeed, a large part of the appar-

[3] See Summary, Chapter 1.

ent transfer of training from one process to another is often ascribed to improvement in attention. A few statements from the symposium on the doctrine of formal discipline by Angell, Pillsbury and Judd[4] will suffice to illustrate this widespread custom. Angell writes: "But, in any event, nothing is more certain than that a boy's auditory attention must itself receive separate training if it is ever to be of much value."[5] And in reply to the general question whether the serious pursuit of any study whatever may be expected to result in benefit for the subsequent pursuit of any other study, he answers that ". . . it seems probable that a certain gain in the power to use and sustain attention will accrue from any purposeful and persistent application." These results, he says, "may be expected to come in part from the suppressing or disregarding of disagreeable and distracting sensations, and in part from the discipline afforded to the common element in all acts of attention, whether this common element be found in some conditions of the cerebral cortex, or in some motor conditions which are essential concomitants of all attentive attitudes."[6] Thus, according to Angell, one of the fundamental causes of the transference of training lies in the improvement in attention which he assumes occurs with practice. Pillsbury, in explaining the effects of training on memory, writes that "In both rote and logical learning there are definite habits and capacities of attending to be acquired, and these may apparently be acquired in one field and used in another."[7]

The above explanations are evidently invalid if it is true that attention does not improve with practice, a conclusion arrived at earlier in the chapter, so far as the attention involved in reaction is concerned. Since I admit that a more elaborate investigation of the effect of practice in attention may cause me to modify this conclusion, I shall not insist too strongly that the

[4] *The Doctrine of Formal Discipline in the Light of Contemporary Psychology, Educational Review,* June, 1908.
[5] *Loc. cit.,* 11.
[6] *Loc. cit.,* 13.
[7] *Loc. cit.,* 27.

common view that attention improves with practice is erroneous. The experimental results I have already presented, however, seem to me clearly to indicate that the degree of attention involved in a given psychophysical process does not improve with practice, and that consequently *transference* of practice effects in attention is out of the question. As pointed out earlier in the chapter, the undoubted improvement in efficiency in a particular process is not a valid objection. What practice *may* do, is to change the conditions and the direction of attention. Better attention to something which we are more familiar with, more interested in, with more serious purpose, is not what I understand by improvement in attention. An improvement in the "capacity" of attention means that a greater degree of attention exists under certain given conditions than would have existed without that improvement. That the degree of attention changes when any of the conditions of attention are varied is not proof of improvement in the "capacity" of attention, unless the only condition varied is the number of times the attention has been exercised. Again, the "disregarding of disagreeable and distracting sensations" is no proof of improvement in the "capacity" of attention. On the other hand, the latter would be shown only by a heightened degree of attention to the main business in hand *without* lessened attention to the distracting sensations, or else increased attention to the latter without less attention to the former. Results presented in the latter part of this chapter on the distracting effect produced by an electric current show that this effect wears off with repetition, but this, I think, is due to a change in other factors than the degree of attention. While all such distractors are less attended to with practice, it is probably largely because of sensory and affective adaptation, so that these distractors can not be regarded as constant.[8]

[8] Pyle analyzes a case of learning to neglect distractions, and concludes as follows: "But a training with such results is really a training in habits of work, is a training in a certain response to a certain kind of situation, and in no proper sense a training of attention." *The Outlines of Educational Psychology*, 3rd ed., 1911.

While arguing against a true practice effect in the degree of attention, I wish at the same time to express the conviction that, contrary to general opinion, the question of whether or not a single faculty or capacity of attention exists, is still an open one. If it were possible to devise several widely different but definitely prescribed methods of measuring attention, making use of widely different types of mental processes, and if all individuals were found to have the same ranking by all of these methods, we should have proof of a general or single faculty of attention. This possibility can by no means be said to have as yet been disproved, if for no other reason than that the degree of attention of a number of individuals has not hitherto been measured by even one method in such a way that a ranking of their attentions is possible. The results of a study such as suggested in this paragraph will be presented in the near future. It is true that I have in the previous pages described two methods or submethods of measuring attention; namely, a method which uses sound as a stimulus and a method which uses light or a change in intensity of light as a stimulus. The data at hand do not permit me, however, to say whether the absolute effect of unfavorable intervals is the same in these two cases, or what degree of correlation, if any, exists between the results of the two methods.

Again, the conclusion that the degree of attention does not improve with practice should not be understood as denying a marked effect as the result of maturity. I have found such an effect, as is shown in the results of the latter part of this chapter. As long as a person is awake, attention is being practiced, and so the very existence of attention means its practice. But while attention must exist, in order that it may grow or mature, its existence, together with the practice inherent in its existence, is only a negative condition of its growth, not the cause of the growth.

(B) MISCELLANEOUS DETRACTORS

The following preliminary applications are given more for the purpose of illustrating the use of the method described in the preceding pages and leading to a better understanding of it than for the purpose of working out fully the problems to which the method is here applied. A general statement of the applicability of the method to the study of a wide range of conditions of attention has already been made in Chapter III.[9] It is evident that if we once have a satisfactory method of measuring attention we can measure the effect on attention of variation in any condition which can be varied, determining not only whether the condition varied is a condition of attention, but how the degree of attention varies with variation in the given condition. I have already presented several such studies in the preceding pages. In Chapter II, I have presented results on the effect of varying the objective condition of intensity, which show that intensity is a condition of attention, and in the earlier part of the present chapter, results on the effect of practice, which show that practice in a particular act of attention is not a condition of the degree of attention involved in that act. And in Chapter III, I have shown that variation in absolute intensity, within very wide limits, does not change the degree of attention to a constant relative change in intensity.

It would seem natural to expect that the degree of attention would increase with age. Careful observation indicates in many ways that an adult is capable of attending to a given task much better than a child. This seems so obvious that it may even be regarded as a test of the validity of any method of measuring attention that its application result in higher values of attention in the case of adults than in the case of children. I am unable at present to present elaborate data on the growth of attention. To do this it is necessary to measure the attention of a large number of children of each age, or else to measure the same children year after year from an early age up to maturity. The data here presented, however, are sufficient to show clearly that a great difference in attention exists between adults and children from 9 to 14 years of age. I have experimented on only three children, and a number of adults. Subject H. C. was a girl, 9 years, 0 months old, who had finished the A 3rd grade, and intended to enter the B 4th the following September. (The

[9] p. 71.

measurement here recorded was made in August.) Subject R. W. was a bright appearing boy of 14 years, 4 months, height, 5 ft. 3½ in., weight, 108 lbs. He had entered the first year of high school three months previous to the time of serving as subject in these experiments. Subject H. F. was a boy 10 years, 3 months old, weight, 63 lbs., height, 4 ft., 2 in., who had entered the B 4th grade three months previously. The attention of one of the children, H. C., was measured by the auditory method referred to in the preceding section of this chapter, results with which are presented in Table XVIII. With the other two children, R. W. and H. F., the visual method as described in connection with Table XVII was used. The results are presented in Table XX. For the sake of comparison I have given the range of final values obtained with all the adults measured by the same method as used with the children. By the final value is meant the average result of all the measurements made on a given individual, that is, the average of the differences obtained at each sitting between the reaction times with a regularly repeated 2 sec. interval and the reaction times with a set of totally irregular intervals. In the case of the adults this result alone is given, in the column headed 1/A. The headings of the columns have the same significance as in Tables XVI-XIX.

TABLE XX

Variation in Degree of Attention with Chronological Age.

			1st Series 2 Secs.		1st Series Irreg.		2d Series 2 Secs.		2d Series Irreg.		2 Secs.	Ir-reg.	1/A
Method	Subj.	Age	Av.	*M. V.*	Av.	*M. V.*	Av.	*M. V.*	Av.	*M. V.*	Av.	Av.	
Auditory	Adults	29	...	..	...	..	...	..	...	..	...	...	77
"	"	24	...	..	...	..	...	..	...	..	...	...	76
"	"	24	...	..	...	..	...	..	...	..	...	...	72
"	H. C.	9	271	*87*	495	*83*	227	*43*	510	*98*	249	503	254
Visual	Adults	29	...	..	...	..	...	..	...	..	...	...	83
"	"	28	...	..	...	..	...	..	...	..	...	...	101
"	"	27	...	..	...	..	...	..	...	..	...	...	67
"	"	26	...	..	...	..	...	..	...	..	...	...	66
"	"	25	...	..	...	..	...	..	...	..	...	...	85
"	"	25	...	..	...	..	...	..	...	..	...	...	62
"	R. W.	14	249	*17*	406	*62*	277	*41*	415	*76*	263	411	148
"	"	..	218	*18*	384	*57*	243	*31*	398	*46*	231	391	160
"	"	..	217	*23*	380	*55*	233	*29*	401	*70*	225	391	166
"	H. F.	10	378	*84*	536	*110*	326	*34*	654	*71*	352	595	243
"	"	..	282	*43*	508	*93*	364	*85*	653	*108*	323	581	258

In spite of the meager nature of the above results, the important conclusion may be drawn that a marked increase in degree of attention occurs with increase in maturity. While only three children have been used, the difference between the children and the adults is so immense that it leaves no room for doubt that the method used is plenty fine enough to bring out the effect of age upon attention in a striking manner. The results show that children are more affected by irregular intervals than are adults. The absolute increase in reaction time with the children is much greater in the case of reactions with irregular intervals than in the case of reactions with a regularly repeated 2 sec. interval. Of course, as should be understood by this time, the interpretation offered is that the irregular intervals constitute an unfavorable or detracting condition of attention, and that children are less able to resist the influence of detracting conditions than are adults; in other words, the children have a poorer attention.

As already stated there can be little doubt that there exists a great difference in the degree of attention of adults and that of children. One way to get different degrees of attention is to use subjects of different age. Now in Chapter III results were presented on the variation in the detraction effect produced by unfavorable preparatory intervals in the case of four different degrees of attention, the different degrees of attention being produced by the use of four different degrees of intensity of stimulus. In Table XX, also, we have results on the variation in the detraction effect of unfavorable preparatory intervals with variation in the degree of attention, the different degrees of attention being produced by the use of different degrees of maturity. The results in the present chapter lead to the same conclusion as those of Chapter III, namely, that the absolute detraction effect varies inversely with the degree of attention detracted from. The relative detraction effect, on the other hand, shows no great variation. The detraction effect exerted by the unfavorable preparatory intervals, then, is affected in the same manner by a decrease in the intensity of the reaction stimulus as by a decrease in the maturity of the subject. In both cases, the results show that it is the absolute detraction effect, and not the relative, which should be used in the measurement of attention.

In addition to the study of the effect of immaturity a study was made of the effect of a few other detractors, three of which (Nos. 1-3 below), were also distractors, resembling those commonly employed. The detractors used were the following:

1. An electric current, intermittent at the rate of 4 times a second, passed through the left hand.

2. Playing rather difficult music upon a German zither.

3. Putting blocks into a formboard with aid of vision.

4. One quart of Burgundy drunk about one-half hour previous to the reactions.

Only two subjects were used, one with detractor No. 1, and the other, with detractors Nos. 2-4. In the latter case, since the detractors required the use of the hands, at least Nos. 2 and 3, a Cattell voice-key was used for the reaction and the arrangement of apparatus was that described in connection with Table XV of Chapter IV, the size of the change in intensity being No. 4 of that table. With the electric detractor, however, the auditory method already referred to in connection with Table XVIII was used. In both cases the procedure was the same as used in the measurements of attention already described in connection with Tables XVII and XVIII,—first, 30 reactions with a 2 sec. interval, then 30 with a series of totally irregular intervals, a few minutes rest, and then 30 more with a 2 sec. interval and lastly 30 more with the set of irregular intervals.

The results are given in the following table, Table XXI, in which the column headings have the usual significance, except that in the column headed Conditions is given the detractor used, or else the fact that no detractor was used is indicated by the word Normal.

The results presented in Table XXI show that a number of ordinary detractors have a detraction effect upon the attention and they give the amount of this detraction effect. At the same time they show in a number of ways how unreliable such de-

TABLE XXI

The Effect of Various Detractors upon the Degree of Attention in Reaction.

Simple sound reactions used with subject Vs; visual recognition reactions with subject Ww.

		1st Series 2 Secs.		1st Series Irreg.		2d Series 2 Secs.		2d Series Irreg.		2 Secs.	Irreg.	
Subj.	Conditions	Av.	M. V.	Av.	M. V.	Av.	M. V.	Av.	M. V.	Av.	Av.	I/A
Vs	Normal....	142	*17*	199	*32*	117	*15*	211	*44*	130	205	**75**
"	Normal....	110	*17*	200	*43*	115	*11*	202	*31*	113	201	**88**
"	Current....	244	*96*	355	*105*	230	*73*	376	*74*	237	366	**129**
"	Current ...	166	*42*	343	*88*	235	*77*	308	*69*	201	326	**125**
"	Normal....	124	*12*	196	*25*	135	*12*	204	*26*	130	200	**70**
"	Current ...	168	*35*	285	*60*	185	*54*	294	*73*	177	290	**113**
"	Normal....	131	*17*	195	*24*	129	*18*	209	*25*	130	202	**72**
"	Current ...	184	*16*	275	*33*	183	*14*	264	*18*	184	270	**86**
"	Normal....	134	*12*	210	*22*	138	*16*	207	*27*	136	209	**73**
"	Current ...	177	*25*	258	*34*	173	*16*	281	*26*	175	270	**95**
"	Normal....	(Av	erag	e 5 se	ries)	...	..	...	..	128	203	**75**
"	Current ...	(	"	"	")	...	..	...	..	195	304	**109**
Ww	Normal....	431	*50*	534	*48*	430	*36*	540	*54*	431	537	**106**
"	Normal....	421	*41*	530	33	415	*41*	497	*92*	418	514	**96**
"	Music.....	563	*50*	678	*64*	536	*49*	683	*71*	550	681	**131**
"	Form Board...	586	*55*	723	*70*	586	*61*	744	*83*	586	734	**148**
"	Burgundy .	453	*61*	621	*95*	500	*72*	684	*65*	477	653	**176**

tractors are for use in the measurement of attention. Of course, an electric current is not satisfactory, for however easy it may be to regulate physically, its effect upon the body cannot be accurately regulated, largely because of the great influence exerted by sensory adaptation. Adaptation is perhaps nowhere more marked than in the tactile sense, though clearly the difficulty applies in the case of many other detractors which one or another investigator has recommended, especially in the case of smell. In using the electric current as a detractor, I adjusted its strength at the beginning of each sitting so that it was approximately just not painful. An accurate comparison of the distraction effect produced on different days can not be made just because the effect of the current on the body could not be regulated, yet I believe it is a characteristic result I have obtained when I find that the detraction effect is 120 σ the first time the measurement is made but only 86 σ the fourth time. This is in keeping with the well-known tendency of the attention to be less and less diverted by such detractors. It is this fact, probably, more than any other, which has led to the conclusion that the degree of attention improves with practice, a conclusion which, as already pointed out, is of very doubtful validity.

Table XXI shows, moreover, that one can not predict whether such detractors as there used exert their effect wholly as detractors of attention, or whether they likewise affect the other factors than attention which are bound to be involved in any psychophysical act. For we find that the relation between the absolute prolongation beyond the 2 sec. reaction time produced by the detractor and the additional prolongation produced by the irregular intervals varies markedly in the case of different detractors. For instance, the alcoholic liquor produced only a slight increase in the 2 sec. reaction time but a very great decrease in attention, the latter point being shown by the great additional prolongation produced by the irregular intervals. The performance of music and the manipulation of the form-board blocks, on the other hand, produced a great prolongation in the 2 sec. reaction time, much greater than that produced by alcoholic liquor, but affected attention less than the liquor, since the irregular intervals did not produce such a great additional prolongation. Evidently, then, the performance upon the zither and the form-board were lengthening the 2 sec. reaction time by affecting in a detrimental way other factors than attention, or else the alcoholic beverage was affecting other factors than attention in a favorable way. The result shows clearly that we cannot be sure that any such detractors as these are purely detractors of attention, and accordingly that, apart from the difficulty and often impossibility of objective control, they are unfit for use as the detractor in the measurement of attention by the detraction method. The above results also demonstrate conclusively that simple reaction time does not in all cases vary directly inversely with the degree of attention. That it does so under constant conditions is the basis of the present work, but equally basic is the fact that it does not do so under varying conditions and consequently, therefore, could not be used as a measure of attention under varying conditions. This means that simple reaction time is practically worthless as a measure of attention. It varies with attention, but with many other factors as well. By means of simple reaction time, or indeed by means of the simple measurement of efficiency of any sort, we could compare neither different individuals nor the same individual on different days, or even at different times of the same day under otherwise apparently constant conditions, for the physiological condition varies from day to day, and at different times of the day, and without a measure such as described in the present treatise, we should have no way of being sure whether the variation in reaction time were due to variation in degree of attention or to variation in other factors. To investigate by means of simple reaction time or any other simple efficiency the effect upon attention of any conditions which affect anything else than attention, would be out of the question, and in all such cases we should have to remain ignorant of whether the condition did affect other factors than attention. On the other hand, by the use of a detraction method such as I have described in the preceding pages, which employs a detractor which detracts solely by acting upon attention, the influence upon attention of any variable condition can be readily ascertained; and further, the effect of variation in this condition upon the efficiency of the act in which the effect of the variation becomes noticeable can be analyzed into an effect upon attention and an effect upon other factors than attention, and the magnitude of each of these two kinds of effects may be determined separately.

SUMMARY

The method, described in the present chapter, for the measurement of the degree of attention is capable of being applied over and over again without any general tendency for the values obtained for the degree of attention to either increase or decrease. In highly practiced subjects, the irregular intervals continue to constitute a marked and very constant detractor. In four out of six subjects who were altogether unpracticed in reaction time

experiments at the beginning of the work reported in this chapter there was no evidence of the slightest tendency for the magnitude of the detraction effect produced by the irregular intervals to decrease with practice. In one of these four, the detraction effect increased slightly towards the end of a series of ten measurements. In the case of the other two of the six unpracticed subjects a peculiar increase with practice was noted in the reaction time with the regularly repeated 2 sec. intervals, and this increase produced an apparent decrease in the magnitude of the detraction effect. This peculiar increase with practice in the reaction time with the 2 sec. intervals may be explained as due to the phenomenon of temporal adaptation. This phenomenon consists in an adaptation on the part of the subject to the irregularly mixed series of preparatory intervals of 4 to 20 secs., an adaptation which normally occurs in working with such a series of intervals and which I have described in Chapter II, but which in the present instance carried over to the work with the regularly repeated 2 sec. intervals and there exerted a detrimental influence by checking the natural tendency of the subject to adapt his attention as quickly as possible and so attain a maximum adaptation at the end of 2 secs. This phenomenon of temporal adaptation may, therefore, be regarded as a source of error in the measurement of the detraction effect exerted by the unfavorable intervals, but I have described a procedure whereby this error may probably be avoided, and was avoided in the case of the subjects with which it was used (the subjects in Tables XVI and XIX). It should be noted that this phenomenon of temporal adaptation never comes in as a source of error except in a *series* of measurements. If this phenomenon of temporal adaptation is regarded as the explanation of the decrease found in the case of two of the subjects in the detraction effect produced by the irregular intervals, it may be said that the data of this chapter afford very nearly conclusive evidence that the degree of attention involved in the reactions shows no general tendency either to decrease of to increase with practice. The data show that in the method here described we have a method of measurement that can be applied a number of times without much variation in the result. The degree of practice the subject has had does not need to be taken into consideration.

Since the degree of attention as involved in the reaction experiment does not improve with practice, in spite of the fact that reaction time itself may shorten considerably with practice, I am inclined to believe that it is generally true that the degree of attention involved in any specific psychophysical process will show no improvement with repetition of that process. Improvement is here understood to mean an increase in the degree of attention while all the conditions of attention remain constant,—aside from the number of times the specific psychophysical process in which attention is involved has occurred. In other words, the mere repetition of an act, even with the purpose in mind at each occurrence of the act to be as efficient as possible, does not bring about any result which increases the degree of attention involved in the act. It may seem to, but only because other factors, which can be kept constant under proper experimental conditions, have not been kept constant. If the degree of attention in a particular psychophysical process does not improve with practice, it follows, of course, that "transference of training" cannot be explained even in part as due to improvement in degree of attention. At the same time, it seems to me that the existence of a single faculty or single general capacity of attention must be admitted to be still an open question awaiting an experimental decision.

Application of the method described in the preceding pages to the study of miscellaneous detracting conditions gives results which corroborate the validity of the method. Such detracting conditions as rapid electric shocks, the performance on a musical instrument, or fitting blocks into a form-board, simultaneously with reacting, and the presence of alcoholic liquor inside the body resulted in a marked lowering in the value obtained for degree of attention. Analysis of the results shows at the same time that simple reaction time is entirely unsatisfactory as a measure of attention, and also that such detractors as the above would be altogether inaccurate as detractors to be used in the measurement of attention by means of the detraction procedure; that is, they could not be used in the way I have used irregular preparatory intervals.

The results of Table XX show that the degree of attention of adults is very much superior to that of children. Further, by assuming *à priori* that attention increases with maturity, the results of Table XX lead to the same conclusion as those of Chapter III, namely, that the absolute detraction effect exerted by unfavorable preparatory intervals varies inversely with the degree of attention detracted from. This same conclusion was also reached in Chapter IV from the results of Table XV. The results of Chapter III and those of Table XX, taken together, show that the detraction effect produced by the unfavorable preparatory intervals is affected in the same manner by a decrease in the intensity of the reaction stimulus as by a decrease in the maturity of the subject. The results in both cases make it clear that only the absolute detraction effect of the unfavorable preparatory intervals, and not the relative, can be used as a measure of attention.

CHAPTER VI

General Summary

It is not my intention to restate here all the conclusions that may be drawn from the experimental work reported in the preceding pages. The most important of these conclusions have already been summarized at the end of each chapter. In conclusion, however, I shall give a general account of the method for measuring attention that has been worked out in the preceding pages. This account may, perhaps, best be made by basing it upon an outline of the distraction method, inasmuch as the distraction method is one with which every psychologist is familiar, and one that has been generally regarded as one of the most hopeful of the methods by which the measurement of attention has hitherto been attempted.

There are a number of ways in which the distraction method may be formulated, but the following schematic statement will, I think, be found fairly just. First, the efficiency of the subject in some work is to be determined under maximally favorable conditions. This work may be any kind of work which requires attention, as, for instance, the cancellation of certain letters of a printed page or the discrimination of a small difference in brightness. Second, the efficiency of the subject in this work is to be determined while he is working under definitely specified distracting conditions, or distractors, all other conditions remaining the same. A distractor is some condition which takes away a part of the subject's attention from the main task in hand. For instance, if a subject were to cancel the *A*'s in a page of printing and at the same time to count the beats of a metronome, the counting of the metronome beats would constitute the distractor. Or, in case the subject were not required to count the metronome beats, then merely the sound produced by these beats might be called the distractor. After the decrease in efficiency resulting from a given distractor has been determined, this decrease is somehow to be utilized as a measure of attention, presumably on the assumption that the decrease in efficiency produced by a given distractor varies inversely as the degree of attention against which the distractor acts. In short, attention is to be measured by measuring the ability of the subject to resist distraction.

I believe the general principles of the distraction method are sound. Practically, however, this method has been a failure. One of the chief reasons for this failure is that it has been found impossible to obtain a satisfactory distractor. A satisfactory distractor is one that, among other things, is constant or uniform in its effect. It must not greatly decrease the subject's efficiency at one time, and then hardly affect it at all at another time. No distractor which is constant in its effect has yet been discovered. Those so far used are not only irregular in their action but, for the most part, soon lose their efficiency.

One of the chief reasons for the failure of distractors is that they require divided attention, though this division may, perhaps, be thought of rather as an oscillation of attention. When the subject's attention is divided, it is impossible for the experimenter to control the proportion between the two parts. I have, therefore, undertaken to work out a method which would preserve the fundamental principle of the distraction method, but would not involve divided attention upon the part of the subject. The fundamental principle of the distraction method is not to distract, that is, to rend attention asunder, but merely to increase the difficulty of attention, to introduce a definite resistance. Now it is possible to increase the difficulty of attention without asking the subject to divide his attention. An important paragraph in any textbook of psychology is entitled the *Conditions of Attention*. Under this heading we have given a number of conditions which bring about a high degree of attention. Many, and probably all, of these conditions may be varied, that is, they are subject to quantitative gradation. Take for instance the so-called objective condition, intensity of stimulus. The intensity of the stimulus may be increased or decreased. And when we speak of intensity of stimulus as a condition of attention, what we mean is that the more intense the stimulus, the more attention it attracts. Other things equal, a bright light attracts more attention than a dim one, and a loud sound attracts more attention than a soft one. Evidently, then, by weakening the intensity of a stimulus, we make a change which is unfavorable to a maximal degree of attention.

There are many other conditions of attention than intensity. An unfavorable state of any of these conditions is unfavorable to the highest degree of attention, but does not necessarily result in division of attention, and, therefore, cannot be spoken of as a distractor. It is proposed to use the term *detractor* to designate an unfavorable state of any of the conditions of attention. A distractor tears attention apart, a detractor merely reduces the degree of attention—no matter how. A detraction method of measuring attention, then, is the same as a distraction method, except that the distractor of the distraction mehod is replaced by a detractor, i.e., an unfavorable state of one of the conditions of attention, and replaced by a detractor which does not require division of attention.

In the detraction method described in the preceding pages the act the efficiency of which is measured is the act of reaction. When the subject is instructed to react as quickly as possible, the subject's efficiency is measured by the reaction time. In reaction time work it has always been customary to have a warning signal precede the stimulus by an interval of about 2 secs. This warning signal is given in order to allow the subject time to get ready to react as quickly as possible, so that the interval between the signal and the stimulus is called the preparatory interval. With a preparatory interval of 2 secs., especially after it has been repeated a few times, the subject knows exactly when to expect the stimulus, and so reacts with maximal adaptation of attention. Now when the procedure is varied so that the subject does not know just when to expect the stimulus the reaction time is much longer. For instance, if the reaction time to a visual stimulus with a regularly repeated 2 sec. preparatory interval is 200 σ, with a set of intervals varying from 4 to 20 secs. in length, given in entirely irregular order, it may be, perhaps, 300σ. In the case of the reaction experiment, therefore, one of the conditions of maximal attention is a preparatory interval of 2 secs. Longer and irregularly mixed intervals on the other hand bring about a lower degree of attention. They decrease the degree of attention under which the reaction occurs, so that as regards the attention involved in a reaction, they constitute a detractor. The method, then, stated briefly, consists in determining first an individual's reaction time with a regularly repeated 2 sec. preparatory interval, and second, the prolongation produced in this time by substituting for the regularly repeated 2 sec. interval a set of irregularly mixed intervals of widely different length. This prolongation remains, on the average, constant in the case of a given individual, and does not decrease with moderate practice. This fact not only demonstrates the constancy of the action of the unfavorable preparatory intervals as detractors of attention, but means that the measurement of attention by this method does not vary with practice. This latter fact differentiates this measurement from most, if indeed not all, mental measurements so far in use.

A question of fundamental importance which remains to be answered is, just how is the prolongation produced by unfavorable preparatory intervals to be used as a measure of attention? Shall we, for instance, use the reciprocal of the absolute prolongation or the reciprocal of the relative prolongation? This problem was solved by artificially producing different degrees of attention, and applying the detractor to these different degrees of attention. In order to obtain the different degrees of attention, among other methods, use was made of one of the conditions of attention already referred to, namely, intensity of stimulus. Four different intensities of stimulus were used, on the assumption that the weaker the intensity the lower would be the degree of attention. It is true that weakening the intensity of stimulus brings about a lengthening of reaction time as the result of its effect upon other factors involved in the reaction than attention. It is not a pure detractor of attention. This fact would clearly prevent the use of weak intensity as a detractor for the purpose of measuring attention by a detraction method. It is largely this necessity of having a pure detractor that led to the selection of unfavorable preparatory intervals. Unfavorable preparatory intervals exert their detrimental effect upon reaction time solely by bringing about a lesser degree of adaptation of attention at the instant of the reaction, whereas weak intensity of stimulus slows reaction time not only by lessening the degree of attention, but in other ways as well, e.g., lengthening the latent period of retinal stimulation. Nevertheless, intensity is a condition of attention, so that the use of four different degrees of intensity of stimulus brings about four different degrees of attention. Having thus secured four different degrees of attention, I then applied my detractor, namely, the unfavorable preparatory intervals, to each of these degrees of attention, and found that the absolute prolongation in reaction time was different in each case, being greatest in the case of the lowest degree of attention (with the weakest degree of intensity) and least in the case of the highest degree of attention (with the strongest degree of intensity). The relative prolongation, on the other hand, tended to a certain extent to remain constant. It follows that in the measurement of attention we should use the absolute decrease in efficiency produced by the detractor and not the relative; that is, we should make our measurement on the basis of the following law of detraction, namely, that *the absolute detraction effect produced by a given detractor varies inversely as the degree of attention detracted from.* Three independent demonstrations of this law are given, one in each of Chapters III, IV andV. The degree of attention is measured by the reciprocal of the absolute detraction effect.

It is often desirable to measure the degree of attention apart from the condition of sensory sensitivity. I believe, on the basis of the results presented in Chapter IV, that this can be accomplished, at least with the exception of extreme cases of sensory insensitivity, by using as the reaction stimulus a supraliminal change in intensity. This can be done most easily, probably, by using light as the stimulus.

To sum up, the degree of attention involved in reacting may be measured, in the sense of ranked, as follows: by obtaining, first, the average reaction time of 30 reactions, using a regularly repeated preparatory interval of 2 secs.; second, the average reaction time of 30 reactions with a set of irregularly mixed preparatory intervals of widely different length; and third, equating the degree of attention with the reciprocal of the absolute difference between the two aforementioned average reaction times. It is highly advisable, in case a long series of measurements is intended, not to make more than one measurement a day, as otherwise, after a few measurements, the phenomenon of temporal adaptation may come in as a disturbing factor. Further, it is of course essential that no condition other than the preparatory interval should be changed at any time during the course of a single measurement. The "motor" or "abbreviated" form of reaction should be used, that is, the subject should always be instructed to react as quickly as possible. As the reaction stimulus, I regard a large and sudden increase in brightness as the best, and as the reaction movement, I prefer the removal of two fingers of the right hand from a reaction key, but both the reaction stimulus and the reaction movement may be varied to suit the purpose of the experimentation. A choice or discrimination reaction may be used whenever there is any danger that the results may be influenced by a tendency to premature reactions.