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ON THE VALIDITY OF THE GRIESBACH METHOD OF DETERMINING FATIGUE.¹

BY DR. JAMES H. LEUBA,

Bryn Mawr College.

In the opinion of many psychologists the results published by Griesbach and his imitators, Dr. Ludwig Wagner and Dr. Vannod, were highly surprising. Experience with the æsthesiometer leads easily to the opinion that, although the ability to discriminate simultaneous touch sensations might very well be altered by fatigue, it would be impossible to measure its influence without taking into account many other factors. That, without regarding these other factors, the dependency of the discrimination sensibility on fatigue could be ascertained safely and easily enough to make of 'the method of Griesbach a practical means of determining and of comparing the degree of fatigue'²—a method applicable to the school problem, for instance—went against what many thought to be a legitimate interpretation of their experience.

Griesbach's paper, coming at the timely moment when the fatigue question was the topic of the day in many a teacher's circle, attracted a great deal of attention, and speedily found imitators among teachers apparently delighted to have at last in

¹ The larger part of the experiments here recorded were performed at Heidelberg, Germany, in part in the Laboratory of Professor Kraepelin, and with the improved Griesbach æsthesiometer belonging to the said laboratory. Our thanks are due to Professor Kraepelin for his assistance, and to Dr. and Mrs. Lindley, who acted as subjects during the experiments carried out in Germany, and generally coöperated with the writer.

² Wagner's 'Unterricht u. Ermüdung,' p. 112.

hand an easy means of settling the bitter discussion of school fatigue. The results of Drs. Wagner and Vannod confirmed the claim of the initiator, and to-day the method is widely accepted as filling the need of the teacher and of the physician for a comparative determination of fatigue-states.

The writer undertook last winter a series of experiments which were to be the beginning of an exhaustive investigation into the various factors influencing the discrimination of simultaneous touch sensations: the temperature of the surrounding atmosphere and of the parts affected; the blood circulation; the emotional state, etc. As the preliminary measurements clearly contradicted the claims of the authors cited, it was, for several reasons, thought wise to publish them without waiting longer for the completion of a work already several times postponed.

The point at issue in what follows is not so much the correlation of fatigue with discrimination sensibility, as the validity of the *æsthesiometric* method for the determination of fatigue.

The measurements on which we base our conclusions extended over 14 days and include some 6,000 separate judgments. They were taken at Heidelberg on three persons whom we shall designate by the numerals I, II, III. The writer was one of the subjects; his measurements were taken by Dr. Lindley. To these data, about 180 threshold-determinations were added at Bryn Mawr, involving about 2,000 separate judgments, obtained from six young women students at Bryn Mawr College, by three post-graduate students who had been prepared by a good deal of practice.¹ Dr. Lindley and myself had both worked before with the *æsthesiometer*; nevertheless, to insure from the start dexterous use of the instrument, tests were taken during two days before record was made of them.

At Heidelberg we used the instrument carefully, guarding as far as possible against the known sources of errors, such as cold spots, momentary hyperæsthesia easily induced, in some persons at least, by focusing the attention on one bit of the skin; the interference of after-images and the partial anæsthesia caused

¹ Miss M. Hussey, Miss G. Locke and Miss N. Wood, to whom I desire to express my thanks.

by too frequent and too rapid touches. We found it necessary to allow about 6 minutes for the determination of the thresholds of one person taken at two places; this included frequent intervals for the skin to return to its normal state. We proceeded as Griesbach had done: the threshold for one and that for two points were successively found for the forehead—along a line running horizontally across the middle of the forehead—and for the ball of the thumb. The place was marked, but we took care to avoid putting the points always on the same spots. The threshold for one point was sought by a gradual decrease; that for two by a gradual increase of the distance between the points of the instrument. Each threshold determination involved usually about eight judgments, sometimes more, especially when after having said ‘one,’ the subject fell back to two, although the distance had been further reduced. In a case of this kind the figure put on record was the one indicating the longest distance at which the two points were *definitely* felt as one.

In order to draw a parallel between the discrimination sensibility and fatigue, it is evidently not sufficient to have a measure of the former; we should also have a measure of the latter. To establish the discrimination curve and then to interpret its ups and downs in fatigue terms with one's own feeling, or the probable fatigue effect of a lesson in geometry or in singing as the only guide, is evidently a ‘*pis aller*.’ If, in this respect, we did not do much better than the investigators in question, we had at any rate the production of fatigue under better control than was the case with the school boys and apprentices tested by them; we could so choose the objects of our attention and so direct it that a relatively constant increase of fatigue took place. Moreover, we were enabled to measure the amount of work done for two half hours daily during six days. This was afforded us by the experiments carried on at the time by Dr. Lindley, experiments in which all three of us participated.¹ They were so conditioned and controlled that the number of

¹ An account of these experiments tending to determine the influence of periods of rest of various lengths on the amount of work performed in a given time, is to be published in Kraepelin's *Psychologische Arbeiten*.

additions performed in the half hour, or in the hour, could be taken as the measure of the mental work done. Unfortunately for us, the limitation of the adding to two daily half hours reduces seriously the value of this control. To submit oneself to the conditions required by such experiments, if they were to last for several hours during three or four days, would be an ordeal beyond the endurance of most men.

In the measurements taken at Bryn Mawr the method pursued was the one used by Wagner: the threshold was gradually approached from two extreme distances, one evidently too great and the other clearly too small; the former distances alternating with the latter. This procedure has the advantage of keeping clearly before the subject's mind the qualitative differences between what he is to call 'two' and what he is to call 'one,' while the other practice delays the recognition of 'twoness' and of 'oneness.'

We begin with the experiments performed at Heidelberg. The three subjects noticed early in the investigation, as other observers had done before them, that the passage from 'oneness' to 'twoness' is through a sensation of length: the touch loses its pointed quality and acquires that of a line gradually stretching until it breaks in the middle, thus producing two spatially disconnected sensations. A similar transformation takes place, but in the reverse order, when the threshold for one is sought. It was therefore agreed to keep answering 'one' however extended the sensation, as long as the break had not occurred.

In the following accounts of our experiments we shall, for the sake of directness and concision, refrain from entering into details which, interesting though they might be to the psychologist, do not bear directly upon our immediate object. For the same reason we shall give only as many of the curves we have obtained as appears to us necessary to establish our opinion.

Fig. I will enable the reader to compare the oscillations of the discrimination sensibility during the three days of severe mental work with those having taken place during three days of rest. Each curve is the resultant of three daily curves. The full lines are the rest curves, the dotted ones the fatigue curves. The time at which the measurements were taken is indicated by

the figures along the axis of ordinates. The thresholds are given in millimeters.

We kept at work from 9 or 9:15 A. M. until 1 P. M. without other interruption than the one occasioned by the taking of the tests at 10:45 or 11 o'clock. During the afternoon we had

Fig I.

Forehead

I

Ball of Thumb

II

III.

Threshold for one.

Threshold for two.

from two to three hours of work before 5 P. M., and we set to work again immediately after an early supper—*i. e.*, from about 7:15 or 7:30 until 9:15 P. M. The subjects kept on working until their time came to be tested. I. spent most of her time reading German literature (Goethe); III. perused books on psychology and philosophy (chiefly Wundt's *Grundriss der Psychologie*), while II. computed the returns from the experiments before referred to, a task by no means easy. The German language introduced in our reading an additional element of fatigue; Goethe required on the part of I. close attention and induced very soon real fatigue. We did our best all through the day not to allow our mind to wander, even though it cost us frequent painful efforts.

We worked all three in the same room to eliminate the fluctuations of temperature and of blood circulation which would have been produced by the passage from the open winter air into the warm atmosphere of a room. Our life was well regulated; we retired early and nearly at the same hour each day and our coffee and tea drinking was kept as much as possible the same during the six days of experimentation.

The fatigue produced was well marked. The words used to describe it were, for the first day: 'Quite tired; a little

nervous' (III); 'very tired, understand no more' (I); 'worked with energy all day, but could not go on much longer' (II). For the second day: 'Tired' (III); I., who felt very tired before supper, was somewhat excited and disposed to go on when 9: 15 P. M. came; 'very, very tired, tired out' (II). At the end of the third day we were all three quite tired and extremely glad at the prospect of the coming days of rest. The last hour of the morning was usually quite burdensome, not that our work was lacking in interest, but that we were no more able to attend spontaneously; it was already fatigue and not simply nervousness. The reader might wish that we should give the curves for each one of the six days, together with a designation of our fatigue feelings at the moment of the measurements and not only the resultants. If anything more than what can be inferred from the resultant curves could be derived from the separate curves, they would be reproduced here; but it is not the case: the daily curves do not follow the fatigue feelings any better than the resultants.

As each one of us engaged for the whole morning in mental work engrossing his attention and requiring a considerable degree of mental tension and drove himself continuously at full speed, the reader acquainted with Griesbach, Wagner's or Vannod's papers will expect our fatigue-curves to ascend more or less regularly from 9 A. M. to 1 P. M. The ups and downs of the curves of these investigators due, according to them, to the different degree of difficulty presented by the lessons, some of them being hours of relaxation, could not be expected in our case. At 5 P. M. the curves should not be found much, if any lower than at 1, the after-dinner rest being offset by from two to three hours of work; and we should expect them to reach the highest point at 9: 15.

Concerning Fig. I the following points are to be noted:

1. The vertical extremes between which the fatigue-curves wander remain very near together. For II. the distance between these limits goes once beyond 3^{mm} and reaches that figure three times only; for I. it never reaches 3^{mm} and four times only does it go beyond 2^{mm} , while for III. it exceeds 2^{mm} only once and then just by a fraction of a millimeter.

2. A striking and not to be expected lack of agreement between the curves for the two-threshold and those for the one-threshold. Concerning the four pairs of curves of I., only the thumb fatigue-curves agree tolerably well with each other, as the reader will see. With III. the fatigue and also the rest-curves for the thumb agree fairly well, but those for the head show more frequently opposite directions. The tracings of II. may be called satisfactory in this respect.

3. The corresponding forehead- and thumb-curves agree still less; neither in the tracings of I. nor in those of II. is there any general agreement to be found; on the contrary, the curves are on the whole the opposite of each other. III. distinguishes himself in that he shows two pairs of curves in agreement: the fatigue-curves of the one-threshold and the rest-curves of the two-threshold.

4. A comparison of the fatigue- with the rest-curves does not bring to light any general, decided tendency. The oscillations of the rest-curves are about as great as those of the fatigue-curves, although Griesbach states that "the sensibility under normal conditions [he means no fatigue] changes not at all or only very little." Sometimes the rest-curve ends higher above its beginning than in the case for the corresponding fatigue-curves; sometimes they follow each other almost parallelly. If we draw total average curves summarizing for each subject the four rest- and the four fatigue-curves, we get the tracings of Fig. II, in which the oscillations are so much reduced that we had to increase four times the scale of the drawing. The distances between the vertical extremes of each curve, expressed in millimeters, are as follows: for rest, 1 (I), 1 (II), $\frac{1}{6}$ (III); for fatigue: $1\frac{1}{4}$ (I), $1\frac{3}{8}$ (II), $1\frac{3}{4}$ (III). If we compare in each line the starting with the ending point, we find two of the rest-curves (I and III) ending exactly where they began and one (II) ending 1 mm. below; while of the fatigue-curves two end higher and one lower: + 1 mm. (I), + $1\frac{1}{8}$ (II), - $\frac{7}{8}$ (III). If we consider only the morning part of the tracings, we find that concerning I. two of the rest-curves end higher than they start, one ends at the same level and the other lower; while of the fatigue-curves two end lower, one at the same level and one higher. Concern-

Fig II.
Resultant curves computed from Fig I.

The scale in Fig. II. is four times larger than in Fig. I.—i. e., four squares, instead of one, stand for one millimeter.

The starting points of the curves of Fig. II. have been arbitrarily determined.

ing II., two of the rest-curves end higher than they began and the two others lower, while the four fatigue-curves end higher. Concerning III., the rest-curves end lower in three cases and at the same level in the fourth one, while the four fatigue-curves end *lower* than their starting point.

It is clear that from Figs. I. and II. no general deduction regarding the effect of fatigue could be drawn with any confidence, and yet the curves put in regard the discrimination sensibility during three days of severe mental work and three days of rest. If the æsthesiometric method does not yield here unambiguous results, how could it be used in the class-room?

Let us pass to the curves of Fig. III. Each curve, with the exception of those in the middle, represents the changes in the discrimination sensibility as they occurred during one hour

of adding performed on five successive days. The distances from one point to the next, measured vertically, indicate the modification of the sensibility during one hour of adding. The hour was divided in two halves separated as follows: 1st day, no rest; 2d day, 5 minutes rest; 3d day, 15 minutes; 4th day, 30 minutes; 5th day, 60 minutes. The continuous lines represent the one-threshold; the broken line, the two-threshold. The curves in the middle are each the resultant of the four others belonging to the same subject. No value is to be given

to the position of the starting-point of the segments as, in order to get a curve, the end-point of one day was used as the beginning of the next.

Concerning Fig. III, we notice that: 1. As in Fig. I, the one-threshold curves agree only occasionally with the two-threshold curves. Compare, for instance, the thumb-curves of III. Those agreeing best are the forehead curves of II., and even then one of them indicates a decrease of sensibility during the adding of the third day, while the other shows an increase.

2. The agreement of the head- with the thumb-curves is no better than previously. In the case of II. and of III. the divergences generally reach opposition. In I. the one-threshold curves exhibit a noteworthy concordance.

3. Regarding the relation between fatigue and the sensibility, we have in the addition returns a means of measuring fatigue, and consequently of controlling the results yielded by the æsthesiometric method, which, if not absolutely reliable, is at any rate of some value. We should not take it for granted, even though we could assume that the initial psycho-physiological state of the subject was each day the same, that the degree of fatigue varies in inverse proportion to the length of the rest-period separating the two half-hours of work. The amount of work actually performed will be a much safer index of the fatigue increase. But can we accept the statement that the greater the amount of work, the greater the fatigue; and that, as far as the adding periods are concerned, all the work done is represented by the number of additions; and can we consequently assume that the fatigue increase bears, in the same person, a constant relation to the number of additions performed? Man is a too complex and not well enough unified machine for such an assumption to be true. Coexistently with the physiological activity involved in adding, many other processes take place equally efficient as modifying factors of the body metabolism, but not constant enough to constitute a fixed quantity. The muscular tensions which vary so much from one time to the other will, for one, contribute their share towards the fatigue increase and at the same time tend to bring about a reduction in the amount of the mental work performed. The

number of additions will not even represent the whole product of the physiological activity having a conscious correlate; the adding process is at times accompanied, at other times interrupted, by trains of thoughts and feelings varying greatly, from day to day, in duration and vividness. This supplementary mental work, the adding does not record; or if its effect is perceivable in the number of additions, it is as a *decrease* that it reveals itself. Stated in general terms, the objection here formulated is that the number of additions performed during a given time is not the whole of the psycho-physiological activity, and consequently cannot be an exact correspondent of the fatigue increase. Nevertheless it may serve as an approximate means, and therefore we give in the following Table the returns of the adding for comparison with the curves of Fig. III. It is evident that it would be sheer waste of time to compare these figures with the separate curves of Fig. III., as, if they agreed with one of them, they must necessarily disagree with another, since between head and thumb, as also between the one- and the two-threshold there reigns an apparently hopeless discrepancy. The only possible thing would be to make use of the resultants of the four curves of each subject, however slight the confidence deserved by a curve having such progenitors.

A. FOR THE WHOLE HOUR.

I.	II	III.
2d day -84	- 10.8	- 72.8
3d " +78	+ 17	+145.2
4th " +89	+374.2	-424.8
5th " +64	+ 38.8	+285.2

B. FOR THE SECOND HALF HOUR.

2d day + 12	- 21.4	-101.9
3d " + 94	+ 10.6	+ 83.1
4th " + 59	+234.	-231
5th " +110	+ 49.6	+176.1

C. DIFFERENCES BETWEEN THE FIRST AND SECOND HALF HOUR OF THE SAME DAY.

1st day -103	-148	+122	No Rest
2d " +5	-180	- 9	5 ^m "
3d " +95	-163	+ 12	15 ^m "
4th " +124	- 72	- 26	30 ^m "
5th " +180	+ 66	+ 41	60 ^m "

A gives the differences in the number of additions performed between the day named opposite the figure and the preceding one. For instance, *2d day - 84*, means that during the second day there was a decrease of 84 in the number of additions of the first day.

B takes into account only the second half of the hour and *C*, instead of comparing two successive days, gives the differences between the first and the second half hour of the same day. The influence of practice has been eliminated by the deduction of the practice gain. How the practice gain was determined may be ascertained from Professor Lindley's paper, already referred to. The figures of *C* represent, in our opinion, the nearest approach to a successful expression of the changes in the fatigue state, provided they are interpreted as follows: a falling off in the additions in the second half hour as compared with the first is a sign of fatigue; consequently we shall expect the curve to move upward whenever the second half hour yielded less work than the first, and vice versa. How far this interpretation is to be relied upon is not at all clear; but it seems to us the best use we can make of these figures. When construed in this way the resultant curve of subject II. follows remarkably well the figures; and, barring the segment of the first day, that of I. is also satisfactory. But inasmuch as the curve of III. does not at all reflect the oscillations shown by the figures, no general inference can be drawn.

Against *A* and *B*, looked upon as fatigue indicators, it may be urged that the initial work-power of the subject is not taken into account, as it should in order that the figures be really indicative of proportional fatigue changes. For instance, the number - 84 is to be interpreted as indicating a smaller loss of work-power (less fatigue increase) during the second than during the first day. But if the initial fatigue was greater the second than the first day, a loss of 84 in the number of additions during the second day may very well mean greater loss of working power during the hour than was experienced the preceding day, although more work was done; we should then, if that supposition was true, expect the curve of the second day to show a greater rise than the one of the first, despite the fact that less work was accomplished.

The measurements taken upon the Bryn Mawr students need not delay us long; they confirm the negative results of the others. Out of the thirty-six separate curves obtained, we pick out twelve (Fig. VI) possessing as fairly as possible the characteristics of the whole batch. The æsthesiometer was used at Bryn Mawr as Wagner used it—*i. e.*, instead of determining the one- and the two-threshold, the instrument was applied alternatively with the points too far apart to be felt as one and too near together to give the impression of twoness; from these two extreme distances the threshold was gradually approached. To keep the attention of the subject and prevent the influence which regularly in the succession of the sensations expressed as 'two,' 'one'; 'two,' 'one' might have, the subjects were frequently touched with one point only. The measurements were taken without haste and with due regard for the circumstances on which exactness of result depends: absence of disturbing external stimuli; ignorance on the part of the subject of the method pursued; interruption of about one minute and a half after every four or five touches, etc. Moreover, to prevent the bewildering effect which too many touch sensations produce when crowded in a short space of time, we endeavored to reach safe results with as few touches as possible. Eight applications of the instrument were found the lowest practical number for each threshold. Under these conditions about five minutes were required for the determination of the two thresholds—forehead and cheekbone—taken at each sitting. No attempt was made in this series to find out and avoid the temperature spots, our intention being primarily to imitate Dr. Wagner's method, and to use it on persons younger than the Heidelberg subjects. Nevertheless we proceeded, even in these experiments, with more care than the German investigators. The students who served as subjects were requested to keep faithfully at work from 8:15 A. M. to 1:15 P. M.; they understood that we wanted them to get as tired as possible, and they willingly entered into our purpose. During the morning they attended either three or four lectures or recitations; the rest of the time they filled with private work. The two post-graduate students who took the measurements here recorded knew that the discrimination sensibility is

Fig VI.

B. M. L. Age 19½
March 8.

B. M. L. Age 19½
March 8.

E. D. E., Age 20¼

M. J. age 21.

H. H. Age 18

S. Age 21.

thought to decrease with fatigue, and expected their returns to agree with this belief; instead of this, they show an almost constant increase in the sensibility. The figures increase only 15 times out of 108 possibilities as we pass from one measurement to the next, and only 5 of the 36 curves end higher than they begin; yet the last measurement was taken at 1:15 P. M., after five hours of mental work, interrupted only by the time necessary for the tests, the first of which was taken 15 minutes after breakfast. As to the correspondence of the forehead with the cheekbone curve, the reader will see that on the whole it is closer than in the previous curves, but how far yet from the admirable harmony reigning between Griesbach's tracings!¹

The preceding facts warrant, it seems, the following general conclusion: If the ability to discriminate simultaneous tactile sensations is in some way under the influence of fatigue, it depends also and to such an extent upon other factors that it cannot serve as an index of the fatigue-state. These other factors are the temperature spots, the irregularities in the sensitiveness of adjacent bits of the skin surface, the temperature of the surface tested, the state of the blood circulation, the highly complex inner determinants of the intensity, duration, and kind of attention paid to the sensation, in so far as they are independent of fatigue, etc.

It is not our present purpose to enter into a discussion of the relative importance of these several factors; to do this profitably would require long series of skillfully planned and carefully carried out experiments. But we may, before closing, support our general conclusion by the results obtained and the opinion expressed by Tawney in a recent and painstaking work,² and also by a criticism of the method used and of the results obtained by Griesbach and Wagner.

According to Tawney—and this we have ourselves often noticed—it is of the greatest importance that the points of the æsthesiometer produce a sensation of equal subjective intensity. This cannot be secured by equal pressure of the points, since

¹ The full-line is the forehead curve; the broken line, the cheekbone curve.

² Guy A. Tawney, *Ueber die Wahrnehmung zweier Punkte mittelst des Tastsinnes*, Philosophische Studien, 1898, Vol. 13, p. 163.

Fig VII

Fig VIII

Fig IX

Fig X

Fig XI

Figs VII., VIII., IX., X. and XI. are taken from Guy A. Tawney's paper before mentioned.

neighboring bits of the skin differ considerably in the thickness of the insensitive superficial layer, and probably also in the sensitiveness of the deeper layer. He found, for instance, in one part of the shoulder blade that the point touching the skin lightly was felt more distinctly than the other, although heavily applied. Concerning the relative importance of fatigue and of the mood (*Gemüthslage*), he writes "Es Würde nämlich bemerkt dass die Gemüthslage der Versuchsperson eine sehr bedeutende Rolle spielt, während z. b. der Umstand dass sie bis 12 Uhr in der vorigen Nacht gearbeitet hatte, fast gar keine Rolle spielte." He found also that widely different results were obtained when the attention was transferred from the object touching the skin to the subjective sensation, or when its intensity was altered by means of suggestions in the form of information imparted to the subject on the purpose of the experiments. But the point of greatest interest to us in Tawney's paper is the great variations shown by the threshold of the same person, measured at the same spot and at the same time on different days. Fig. VII and Fig. VIII, pp. 16-19, give the thresholds of two subjects measured at 7:30 A. M., on the same part of the body (the dorsal side of the forearm in the case of Fig. VII; the dorsal side of the upper arm in the case of Fig. VIII) on successive days.

The thresholds recorded for these curves are, for each day, averages of four threshold-determinations. This, according to Tawney, accounts for the regularity of the decrease of curve VII, a decrease due to practice; but it does not prevent Fig. VIII from showing daily oscillations reaching almost 20 mm. We are not told how the preceding nights were spent, but the remark quoted above indicates clearly enough that, in the opinion of the author, irregularities of the curve cannot be explained by fatigue due to late work and insufficient sleep. Fig. IX shows similar oscillations; but as the time of the measurements was not always the same, we cannot make use of them. The time at which the tests recorded in Figs. X and XI were taken is not mentioned; we may suppose that the rule was followed, namely, to measure always at the same time of day. The following figures, representing the thresholds for the volar side of

the forearm, measured daily during 19 days, indicate again very great variations: 60, 52, 60, 64, 54, 52, 55, 50, 42, 40, 45, 40, 45, 40, 38, 41, 42. The table numbered XV in Tawney's paper exhibits a similar irregularity; the thresholds for ten days separated by intervals of one to six days' duration are: 15, 25, 30, 40, 45, 45, 25, 16, 35, 45. The preceding curves and figures are not picked out of a larger number; they represent the whole of the results obtained by Tawney bearing upon our investigation. He had himself no intention of studying the relation of fatigue to the discrimination sensibility.

When these results and those obtained by ourselves are put together, it becomes difficult to look upon the work of Griesbach, Wagner and Vannod with any other feeling than one of wonder. When the resultant curves of three persons for three comparable days of hard, persistent work and for three days of rest—to speak only of the part of our work which we offer here—move up and down apparently without any reference to a fatigue clearly felt and legitimately inferred from the work performed; when an hour of adding by three persons, during six days, yields no better result; when five morning hours of intellectual activity on the part of six college students interrupted by only short pauses, bring with them remarkably uniform increase in the discrimination sensibility; when, moreover, it is known that the same spot may yield on successive days and under apparently the same conditions, results varying up to 20 mm., the admirable consistency and uniformity of the results published by the said investigators become a problem whose solution is not easily found. To this should be added that these remarkable results have been obtained under circumstances far from favorable to exactness of return. Wagner, for instance, measured in 10 minutes—the length of the interval between the class sittings—from six to ten persons at one point, and Griesbach, in apparently the same time, two or three subjects in six different places. This appears to us verging on the impossible.

If we now turn to the consideration of the method used by the German investigators, we find that Griesbach is not very explicit in his description of the manner in which he proceeded. His method was the one we followed at Heidelberg:

only, judging from the rather vague utterances of his monograph and from a private communication, he allowed himself a good deal of freedom. How far one could, with the help of a little looseness in the use of the *æsthesiometer*—a looseness unavoidable, it seems, when the measurements are to be taken as rapidly as they were in this case—unconsciously influence one's returns when possessed by an idea which, if confirmed by experiments, would prove of great scientific and of much practical value, is an open question. We may be excused for formulating it on this occasion.

Wagner's method was similar to the one used in Bryn Mawr by our students and ourselves: too great and too small distances alternating until the threshold is reached. This procedure is decidedly to be preferred to the former under the circumstances in point, the alternation of distances giving clearly two, with distances yielding but one sensation, gives to the subject, from the very beginning, a clear knowledge of the difference with which his judgment is to deal. Otherwise, if, for instance, the experimenter begins with a very small distance and increases it until the threshold is reached, the subject who has not had the opportunity of comparing twoness with oneness will often show by his answers that he does not know what he is to call 'one' and what 'two.' We tested many persons with regard to this, and found in almost every case that the usual verbal instructions are not sufficient: before the subject is made acquainted with the sensations he is to call 'two' and 'one,' he may call 'two,' two points clearly below the threshold and give the same answer when touched by one point; this source of error will be greatly increased if the subject gets into his head that it is to his credit to feel two points as often as possible. This objection applies with all its force to the method used by Griesbach, since his subjects changed generally each day and were expected from the very first trial to give recordable judgments.

Wagner declares his results to be in perfect agreement with those of Griesbach, and concludes that "the *æsthesiometric* method of Griesbach is a practical means of determining the degree of fatigue and of comparing it quantitatively" (p. 12). There is shown, he holds, 'a clear relation,' between the dis-

crimination sensibility and six specified circumstances, among which we find not only the sort of instruction received, but also the teaching ability of the instructor. For the interpretation of separate turns of his curves he shows a boldness of which Griesbach was not guilty. No doubt his results are in close agreement with those of Griesbach, yet there is one particular in which the concordance appears defective; in looking over his tracings it occurred to us that their upward gain was made chiefly, if not entirely, between the first and the second measurement, and that they frequently ended below the point reached at the second test—*i. e.*, after the first hour of study. In order to reach a definite opinion on this interesting point the sum was made (1) of the measurements taken before the beginning of the lessons; (2) of those taken after the first hour; (3) of those taken after the last morning hour, with the results given below. Each table in Wagner's paper includes the measurements taken on from five to ten students of the same class, before the beginning of the morning's work and after each recitation of one day. There were usually five recitations, separated from each other by an interval of ten minutes. Each one of the figures composing the first vertical row of our tables is the sum of the figures representing the measurements taken before work in one of the tables of Wagner; the figures of the second row give each the sum of the measurements after the first class hour, and those of the third row the sums of the last measurements of the same table. We have added before the figures the names of the studies after which the tests were taken. We omitted the measurements taken after 'Religion' when given during the last hour, because the lesson was attended by only about half the students used as subjects. We acted similarly with gymnastics that intellectual work only be taken into account. Furthermore, when the last figure was missing we left out, for that day, the measurements of the person concerned.

TABLE A.
MEASUREMENTS IN QUARTA.

55	French exercise,	79	Phædrus, 80	Thresholds of 6 subjects
42	Arith. (Rechnen),	67	Latin, 91	" " 8 "
86	French,	108	German, 120	" " 8 "
78	German,	110	Geom., 135	" " 8 "
70	Geometry,	118	Latin, 106	" " 6 "
45	Arithmetic,	73	Latin, 97	" " 6 "
73	Arithmetic,	106	Latin, 136	" " 7 "
83	French exercise,	171	Latin, 173	" " 9 "
104	German compos.,		German, 175	" " 10 "
127	Latin exercise,	178	Latin, 180	" " 10 "
114	Geometry,	188	History, 167	" " 10 "
	Arithmetic,	160		
Totals: 877		1358	1460	88

The average increase of the threshold between the initial and the final test is, accordingly, in millimeters,..... 6.6
Between the first and the second measurement,..... 5.5
Between the second and the final measurement,..... 1.2

TABLE B.
MEASUREMENTS IN UNTERTERTIA.

27	Latin,	35	Geogr.,	44	Thresholds of 4 subjects
47	History,	51	Latin,	43	" " 4 "
55	Greek Ex.,	77	Geom.,	65	" " 6 "
93	German,	114	History,	99	" " 8 "
57	Greek,	65	Geom.,	73	" " 5 "
83	Greek Ex.,	114	Natural Sci.,	107	" " 8 "
81	Latin Ex.,	107	Geogr.,	98	" " 8 "
97	Greek,	107	Geom.,	106	" " 8 "
87	Greek Ex.,	108	Natural Sci.,	118	" " 8 "
90	Latin Ex.,	119	Geogr.,	114	" " 8 "
Totals 717		897	867	67	

The average increase of the threshold between the initial and the final test is, accordingly, in millimeters,..... 2.2
Between the first and the second measurement,..... 2.7
Between the second and the last measurement,..... —0.4

Remarks on Table B.—Wagner explains as follows the surprising fall of the figures at the end of the morning in the second series (47, 51, 43): " * * * alles Erstaunen verschwindet und die Theorie erhält gerade hier eine interessante Bestätigung, sobald man erfährt, dass alle 4 Stunden dieses Tages von angehenden Accessisten gehalten wurden," p. 63. Unfortunately, the fourth series exhibits a similar drop (93, 114, 99) without 'Accessisten.'

Notice, also, that the 6th (83, 114, 107) and the 9th series (87, 108, 118) exhibit inverse changes of the sensibility, although the subjects of study were for both days the same: Ovid, Latin, Religion, Natural Science.

TABLE C.

MEASUREMENTS IN OBERTERTIA AND UNTERSECUNDA.

35	Caesar,	71	History,	68	Thresholds for 6 subjects.		
75	German compos.,	126	Latin Gram.,	117	"	"	8
32	Latin Grammar,	39	History,	49	"	"	4
37	Greek,	36	Latin,	54	"	"	5
72	Greek,	99	Latin,	96	"	"	7
44	Algebra,	58	Xenophon,	67	"	"	5
Totals: 295		429	451		35		

The average increase of the threshold between the initial and the final test is, accordingly, in millimeters,..... 4.5
 Between the first and the second measurement,..... 3.8
 Between the second and the last measurement,..... 0.6

What do these figures mean? Can they be reconciled with the claims made in favor of the æsthesiometric method? Are they to be interpreted as meaning that fatigue takes place almost entirely during the first hour, and remains nearly the same through four additional hours of work, one or two of which require as much exertion as the first? Before proceeding with this problem let us notice that, in this respect, Wagner's results agree neither with those of Griesbach nor with ours. During the first hour of work the sensibility of the three Heidelberg subjects increased (see Resultants, Fig. II). The same is true of the Bryn Mawr students, while the Griesbach curves continue to ascend more or less regularly after the first hour and generally end at the close of the morning (12 o'clock), higher than after the first hour—we refer chiefly to the cheek bone and forehead curves. It might be that this lack of agreement between the German investigators is due to the unequal difficulty of the subjects with which the morning's work opened in the respective classes to which their subjects belonged. As a matter of fact, in the classes with which Griesbach dealt, natural history and modern languages are frequently at the beginning of the schedule. But whether this be the ground of their disagree-

ment or not, the problem before us remains. It will not do to have recourse at this juncture to the different degree of attention required by the several branches of study, for, if we consider only the subjects of the last hour, leaving out of count the three middle ones, we see that they cannot be said to be clearly inferior to the first in respect of their fatigue-producing power: and even though they were of a somewhat less exhaustive kind, the curves would not thereby be explained unless it could be shown that between the first and the last hour the sensibility, in consequence of the recuperative quality of the three intermediary subjects, had nearly returned to the norm.¹ But to accept this would be equivalent, it seems to us, to giving up the claims of the believers in the method. It cannot be said either, by way of explanation, that the 10 minutes rest between each hour was enough to produce return to the normal; and that, consequently, the figures show the fatigue increase to have been, on the whole, about the same for each hour. It is evidently not true that two, three, four or five hours filled with the Gymnasium studies just mentioned leave the student just as fresh 10 minutes after.² We should rather be disposed to affirm that 10 minutes after the first hour of work a student might be quite fresh, while 10 minutes after the fifth hour he would be quite tired and often exhausted. Another explanation, plausible this time, but destructive of the claims under consideration presents itself to us: although nothing is said as to the place where the first tests were taken, we may assume that it was in the school building, the first measurement being taken as the students arrived from their homes. Now the usual condition of a young man after an early morning

¹ The intermediary subjects for the days on which the measurements were taken, were: History, Geometry and Phædrus; Phædrus, Grammar, and Geography; French, Gymnastic and History; Geometry and History; Drawing, Religion and Geography (this group is found only once); Drawing, Algebra, Ovid; Geometry, French, Greek and other similar groups. Considering Gymnastic, Wagner says (p. 126) summarizing: "The hour of Gymnastic has * * * in $\frac{1}{3}$ of all the students (according to the most favorable construction of the figures) produced a relative recuperation; in the two other thirds it induced a clearly marked [ganz ausgesprochene] fatigue."

² Or shall we assume that it is only during the first hours that the Gymnasium student really works and that during the rest of the morning, either because of exhaustion or of laziness, he foregoes all tiresome mental effort? Probably no gymnasium director would countenance such a supposition.

walk and the exhilarating encounter with classmates is one of comparative bodily and mental alertness. An hour later, after a recitation in Latin, Greek or Geometry, the blood circulation, the respiration and the general feeling may be assumed to have changed considerably. Under such dissimilar circumstances we should hardly expect to get comparable æsthesiometric results. We have taken some measurements with the hope of determining the influence of these physiological changes, but we have been unable to have our subjects fulfill sufficiently well the conditions necessary for exact experimentations to warrant any positive conclusion. The temperature of the part of the body tested and of the room in which the measurements are taken should also be taken into consideration in an attempt to interpret the curve-peculiarity under discussion. Wagner experimented during February and the first part of March; consequently both the temperature of the skin of the face and that of the room would change materially during the first hour. Loewenton found that the threshold was elevated by an increase of temperature of the room. We need not insist on the possible influence of these two factors; the reader will see how they might have combined to bring about the relatively low figures of the first measurements. If accepted, this explanation would invalidate the conclusions drawn by the German investigators: the chief rise of the curves would not be due to fatigue, but to other causes. Unfortunately, we do not know whether Griesbach's different figures must be interpreted as discrediting this solution, for we are not informed as to the circumstances on which the comparableness of the figures of the two investigators depends. As to our own curves, all that can be said on this point is that they do not show a corresponding rise during the first hour; and that the cause we have suggested for this rise as it occurs in Wagner's curves existed neither in the case of subjects I., II. and III., nor in that of the Bryn Mawr students, since the latter and I. and II. were tested in their own rooms, while the measurements of III. were taken 15^m after his entrance into the rooms occupied by I. and II.

Returning to the general problem of the discrepancy existing between our results and those of the German investigators,

we may, in closing, advert to such thought as the following: the Heidelberg and the Bryn Mawr subjects might be, one and all, abnormal persons; or, we may have failed to get correct thresholds because of lack of skill in handling the instrument; or, our subjects were older than those of Griesbach and Wagner;¹ or, the discrimination sensibility of German youth is not comparable in its behavior to that of American men and women—thoughts which appear to us either inadmissible, or insufficient to silence the suspicion that the conclusions of the papers here considered are not well founded.

In this state of indecision we must let the matter rest for the present and until a thorough and systematic investigation of all the factors affecting the discrimination of simultaneous touches enables us to assign to fatigue its particular rôle. Two groups of factors will have to be taken into consideration: (1) those affecting the peripheral organs—temperature, thickness of epidermis, the peripheral blood supply, etc.; (2) those affecting the general psycho-physiological condition of the subject, and more especially his ability to attend. An *à priori* consideration of the influence possessed by these factors leaves but little ground for the hope that the discrimination sensibility to simultaneous touches may serve as a practical test of fatigue, for many of them (temperature, blood circulation) vary under unchanged fatigue conditions. As to attention—considered independently of its relation to fatigue—it lacks the constancy and steadiness which are absolutely required if the experimenter is to draw his inferences from a very small number of measurements. It is a rhythmic function, and, moreover, is readily and rapidly modified by the will to attend—a quantity that cannot be maintained constant.

¹ No age limit is set by them to the applicability of the pretended relation existing between the discrimination sensibility and fatigue. When testing persons of the age of our Bryn Mawr subjects, Griesbach found the same results as when dealing with younger persons.