The time of perception as a measure of differences in intensity.

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When a student at Leipzig under Professor Wundt, I made some experiments on the time required to estimate the size of lines of different lengths and in briefly communicating the results said:

»Mit den horizontalen Linien stellte ich eine ziemlich große Zahl von Versuchen an, da ich das Verhältniss zwischen der Länge der Linie und dem mittleren Fehler (psychophysisches Gesetz) einerseits und dem Fehler und der zum Urtheil gebrauchten Zeit anderseits kennen zu lernen wünschte. Ich halte es indessen für wünschenswerth, die Zahl der Versuche noch weiter zu vermehren, bevor ich die Resultate veröffentliche«[1]).

The problem here indicated has always seemed to me important and I have taken it up on several occasions[2]), but the solution requires a larger number of routine experiments than I have found time to carry out. I may, however, take this occasion to present some preliminary results of a research begun at Leipzig and following lines laid down by the eminent founder and director of the Leipzig Laboratory.

Weber's work on the relation between the magnitude of the

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1) Philos. Studien, IV, S. 250. 1888.

2) Proceedings of the American Psychological Association for 1893. Professor Münsterberg has, however, anticipated me in the publication of experiments on the length of lines, cf. A psychometric investigation of the psychophysic law. Psychological Review, vol. I, p. 45—51. 1894.

stimulus and the just noticeable difference and Fechner's deduction of a logarithmic relation between stimulus and sensation have been followed by a large number of experimental researches and an extensive literature. In the experiments and discussion I have shared[1]). I have argued that in most of our experiments we have measured the error of observation, which determines the accuracy of perception, but does not measure the intensity of sensation. This holds for experiments by the methods of average error and of right and wrong cases. The method of just observable difference appears to me to have been used ambiguously. On the one hand, it may be reduced to the method of right and wrong cases, when the wrong cases are but few and the determination is difficult. On the other hand, the observer may seek to make the differences equally noticeable, in which case the results are analogous to those of the method of mean gradation and really estimate differences in sensation. Such estimates are, however, inexact, lacking an objective criterion. Different observers or the same observers at different times vary greatly in their estimates of equally noticeable differences. It seems that these estimates may be based on the known objective relations of the stimuli, and consequently can not be used to determine a relation between the sensation and the stimulus.

It is, however, possible to approach the problem from a new direction. An observer can not decide with any certainty when the difference in one pair of sensations is equal to the difference in another pair, but the time it takes to perceive a difference can be measured. The smaller the difference between two sensations, the greater is the time required to perceive it. When differences require equal times for discrimination, the discrimination is equally difficult, and the differences are equal for consciousness. A gray physically midway between white and black looks more like white than black, but observers differ greatly in the gray that they select as midway between white and black. If, however, we measure the time required to discriminate black from a gray reflecting 50% of the light, we find it to be shorter than the time required to discriminate the gray

1) On the perception of small differences (with Professor G. S. Fullerton), University of Pennsylvania, 1892. On Errors of Observation. Amer. Journ. of Psychol. 1893.

from white. We can in this way find the gray equally difficult to discriminate from white and black, and this is the gray which for consciousness is midway between white and black. By the same method it is possible to make a complete scale of equal increments in sensation between white and black, and for the range of intensity or quality in any sense.

I have made experiments with intensities of light and sound, with differences in color and with lines, but will here record only the first mentioned. I should, however, like to call attention to the fact that apart from the measurement of sensation the method offers an excellent way to test differences in sensibility. For example, a person with normal color-vision takes about as long to discriminate red from green, as to discriminate yellow from blue. A person who belongs to one of the classes of red-green color-blindness takes a much longer time to discriminate red from green than to discriminate yellow from blue. This method of testing color-blindness follows closely the actual requirements of the railway service for stopping trains by color signals, in which case the determination of color-blindness is of practical importance.

In the experiments on the intensity of light, I used various methods. These included a method of securing a given physical difference by altering the angle of incidence of the rays of light, which constitutes, I believe, a new form of photometer, having certain advantages. I found it, however, most convenient to use gray surfaces, reflecting a known percentage of the light. These surfaces were washed with Indian ink. The ink was made as black as possible, and one piece of drawing paper was washed; then a drop of water was added to the ink, another piece was washed, and the process was continued until the wash became imperceptible. In this way 211 shades between black and white were obtained. These grays (in cards 5 cm. sq.) were then tested by various photometric methods. The series proved to have a fairly regular gradation, except that the steps increased toward the white end, the gray 95 steps from white being midway between white and absolute black.

Such a series of grays[1] is suitable for testing the accuracy of

1) A hundred grays forming equal physical steps could be selected that would be preferable to this series of 211 cards.

discrimination and its variation under different circumstances, as with the intensity of the stimulus, in memory, etc. The physical differences are smaller than can be perceived, and if an observer arranges the grays as nearly as possible in the order of brightness, errors occur which measure the accuracy of discrimination. Thus in ten trials — the first two by the present writer and the others by eight different observers — the errors of displacement were as follows: 6,63, 7,97, 6,04, 6,2, 7,44, 7,81, 8,29, 8,77, 9,68, 11,5. The arrangement can be made in about an hour, and, as there are over 200 separate judgments, the average has a probable error of only about 0,5. Observers differ within the extremes of about 1 : 2 which agrees with other determinations. For the more accurate observers the error is 6 cards, or about 1/35th of the range between black and white. The degrees that appeared just noticeable when these were selected were between 13 and 32, but errors occured in the case of the larger number.

When the results of the ten series are combined and the relation of the error of displacement to the intensity is considered, it is found that while the error increases with the stimulus, it does so more slowly than required by Weber's law. The average displacement for each of seven groups of 30 cards (allowance being made for the longer steps between the brighter cards) was, approximately, 13,61, 10,06, 12,14, 10,03, 6,46, 5,09, 2,98.

In the table are given: (I) the approximate percentage of light reflected from the middle gray in each of the seven groups, that is the magnitude of the stimulus; (II) the error of observation in terms of percentages of light between white and an absolute black; (III) the error of observation in terms of the magnitude of the stimulus to the nearest whole fraction; (IV) the error of observation in terms of percentages of the magnitude, and (V) the error of observation in terms of percentages of the square root of the magnitude.

I.	II.	III.	IV.	V.
85	5,44	1/16	6,4	59
68	4,02	1/16	5,9	49
56	4,85	1/14	8,7	65
44	4,01	1/11	9,1	60
32	2,58	1/12	8,1	46
20	2,03	1/10	10,2	45
8	1,19	1/7	14,9	42

It appears, consequently, that as the stimulus increases the error of observation increases, but not so rapidly as the stimulus, being about $^1/_7$ with the weakest and $^1/_{16}$ with the strongest stimulus. It increases much more nearly in direct proportion to the square root of the stimulus, in accordance with the hypothesis I have proposed in place of Weber's law. This hypothesis — »The error of observation tends to increase as the square root of the magnitude, the increase being subject to variation whose amount and cause must be determined for each special case« — has not as yet received the consideration which the experimental evidence and theoretical explanation seem to me to warrant.

The photometric cards were made, as has been stated, for experiments in which differences in intensity were to be measured by the time of perception. Two gray surfaces, each 3×3 cm and of different intensities, were mounted side by side; the card was thus 6×3 cm and, viewed from a distance of 40 cm, was of convenient size for distinct vision. It was exposed by means of a dropping screen on the general plan of the gravity chronometer used by me at Leipzig. The screen was, however, of aluminium, and was drawn down by a long spiral spring, so that the rate of motion when the card was exposed was about 10 m per sec. The exposure appeared to be instantaneous, the card being uncovered in $3\,\sigma$ and the registration being made with exactness. The Hipp chronoscope was used in the usual manner, being carefully regulated, so that its variable and constant errors were smaller than $1\,\sigma$. The observer reacted with right or left hand in accordance with the character of the stimulus — whether, e. g., the brighter card was to the right or left. For white the card was painted with zinc oxyde, and a nearly absolute black was secured by using a hole in a black box.

In the following table are given in σ the times of discrimination and movement of two observers (including the writer, C), when the differences in the lights were as stated. Each entry is the result of 100 measurements. The mean variation was between 10 and $20\,\sigma$ in the different series, and the probable error of each is consequently between 1 and $2\,\sigma$. The first three and the last four differences were used simultaneously.

Lights	Times		Differences	
	C	X	C	X
100 : 0	231	243		
100 : 50	282	283	51	40
50 : 0	240	246	9	3
100 : 75	311	317	80	74
75 : 50	274	293	43	40
50 : 25	268	285	37	41
25 : 0	239	263	8	20

It will be seen by the table that white was discriminated from black and the movement made in 231 and 243 σ. When the differences were made smaller the times became longer, and the probable errors and the agreement between the two observers prove the validity of the method. A gray midway between white and black could be more quickly discriminated from black than from white, and equal objective differences are more quickly discriminated when the magnitudes are smaller.

As has been indicated a large number of experiments would be required to determine by this method degrees of intensity equally easy to discriminate and consequently equal for consciousness. I have also made preliminary experiments with sounds, lines and colors, but, as it is uncertain when I shall complete them, it seems desirable to take advantage of the present occasion to publish the method.