THE OBSOLESCENCE OF WEBER'S LAW

By KERMIT W. OBERLIN

WEBER'S law has been considered as an important part of general quantitative psychology, and especially of psychophysics, since 1860. It was at this time that G. T. Fechner brought the law into prominence by proclaiming it as the fundamental psychological law. He held it to be a statement of the relationship between the amount of change in a stimulus and the corresponding amount of change in experience, awareness or consciousness. His formulation became $S=K \log R$, which means that any sensation is equivalent to a constant times the logarithm of the stimulus.

In the majority of the text-books of psychology, the authors, after stating Weber's law, refer to the fact that it has generally been found to hold rather well for the middle range of strengths of stimuli but that it does not hold for the more extreme strengths. This implies that there is a constant relationship, then, between the strength of the stimulus and the strength of the sensation, within the middle range. Investigators, working with lower animals, have obtained results which cast some doubt upon this supposed constancy. In fact, working with different kinds of animals and employing different techniques for measuring the same thing, they have found that they always get variability. Furthermore, the variability is always of the same kind. In the light of such experimental results the problem of determining the variability of human sensitivity became of interest. Accordingly, some experiments were devised in order to gather data on this problem.

The first experiment was to determine the acuteness of discrimination under three different conditions, and to discover what differences in acuity were present under these circumstances. Two naive subjects were used, a man and a woman. A set of five weights, ranging from 92 to 108 grams, was used. The difference between members of this set amounted to four grams and there was an additional weight of 100 grams used as the standard. The various weights were identical in size and shape.

The other apparatus consisted of a screen between the subject and the weight, so that the weight was not visible to him, and an arm-rest which fitted the angle at the elbow when the arm rested comfortably on the table. The weights were presented at the same place every time so that the arm always remained in the same position while awaiting the presentation. Three different movements were employed for lifting the same weights, a wrist movement, an elbow movement and a shoulder movement. This means only that when the wrist movement was employed, no part of the arm above the wrist was moved; with the elbow movement, no part above the elbow was moved; and with the shoulder movement, the whole arm was moved along with the movement of any of the more distal joints. By means of a metronome, the time-interval between the presentations of each member of a pair was held constant in an effort to avoid any variation of the time-error. The observations were made in periods of one hour each, with intervals of approximately one week between experimental periods.

The subjects were given the following instructions: "You will be presented with weights successively and rhythmically. You are to judge always the second in relation to the first and report your judgment as 'heavier', 'equal' or 'lighter'. In all cases where you are doubtful, report 'equal' unless your doubt is due to some distraction, in which case you will report 'doubtful'. Please make and report your judgments as quickly as possible."

The method of constant stimulus differences was used and 250 comparison judgments, with each kind of movement, were obtained from each of the subjects. About twenty five 'practice' judgments were taken before each experiment period.

The following tables present the data and results of this experiment. The crude data were put through a process of calculation called Urban's Tables. This is a formula for weighting properly the values of each set of observations or judgments depending upon how remote they are from the middle of the range, or the standard weight of the set.

Table I

Presenting the actual number of judgments 'heavier' and 'lighter', with their percentages, for each movement and each subject.

Observer I	grams	heavier	lighter	%H	%L
	108	30	2	60	4
wrist	104	21	3	42	6
	100	16	14	32	28
movement	96	4	20	8	40
	92	2	35	4	70
elbow	108	42	1	84	2
	104	28	7	56	14
movement	100	19	14	38	28
	96	4	29	8	58
	92	3	37	6	74
shoulder	108	45	3	90	6
	104	33	9	66	18
movement	100	23	19	46	38
	96	9	31	18	62
	92	5	36	10	72

Observer II	grams	heavier	lighter	%H	%L
	108	44	3	88	6
	104	36	9	72	18
wrist	100	28	18	56	36
	96	26	21	52	42
movement	92	16	33	32	66
	108	48	2	96	4
elbow	104	43	7	86	14
	100	42	7	84	14
movement	96	31	19	62	38
	92	13	37	26	74
	108	49	1	98	2
shoulder	104	41	9	82	18
	100	27	23	54	46
movement	96	22	28	44	56
	92	11	39	22	78

Table II

The values of h (the measure of precision), P (the probable error of the distribution of judgments) and L as calculated from the above data.[1]

Obs. I.	judgments of heavier			judgments of lighter		
	h	P	Lu	h	P	Ll
wrist	.0886	5.3826	105.4700	—.1042	—4.5768	95.1320
elbow	.1193	3.9975	102.6808	—.1117	—4.2695	96.6052
shoulder	.1137	4.1944	100.8564	—.0950	—5.0200	97.3192
Obs. II.						
wrist	.0656	7.2698	96.8848	—.0791	—6.0290	95.4516
elbow	.1015	4.6985	95.0124	—.1020	—4.6755	94.9432
shoulder	.1038	4.5944	97.6844	—.1038	—4.5944	97.6844

Table III

The values of I. U. (the interval of uncertainty), DL (the difference limen) and P for each movement and each subject.[2]

Obs. I.	I. U.	DL.	P	Obs. II.	I. U.	DL.	P
wrist	10.3380	5.1690	9.9594		1.4332	.7166	13.2988
elbow	6.0756	3.0378	8.2670		.0692	.0346	9.3740
shoulder	3.5372	1.7686	9.2144		.00	.00	9.1888

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[1] In Warren's Dictionary of Psychology, h is defined as being the index of precision. It determines the steepness of the curves of the psychometric functions and hence indicates the homeogeneity or precision of the several judgments.

P is defined by Culler as being the probable error of the distribution of judgments of "heavier" or "lighter". See his article in Psychological Monographs, vol. 35, no. 2, 1926, pp. 115-122. There is a different P-value for each category of judgment, those for the "lighter" judgments having a negative value.

The limen, L, is defined as that value of the stimulus at which the probability of any given report, except an intermediate report, equals the summed probabilities of the other reports. See Volkmann, J., The Method of Single Stimuli, Amer. J. Psychol., 44, 1932, p. 809.

[2] I. U. is the range between the upper and lower limens within which no part of the psychometric functions for the difference judgments will assume a value as great as their value at the limens.

DL, the difference limen for all judgments except "equals", is simply half the I. U. value.

In general, these results show that there is a decrease in the DL and I.U. as the movement in the arm becomes less distal. A decreased limen means increased sensitivity, when the weights remain the same. This progressive increase in sensitivity could not have been due to practice because these data were obtained from the two subjects in reversed temporal order. With the exception of the inversion of the results for one subject at the elbow and shoulder movements, a decrease in P accompanies the decrease in DL, although by no means proportionately.

A possible explanation of these results is that there are more muscle-fibers, and therefore more receptors, brought into function as the fulcrum for the movement of the arm becomes more proximal. If this hypothesis is correct, then any other method of increasing the number of functional receptors should bring about an increase in sensitivity also. In order to test the correctness of this hypothesis, experiments were planned, in which the type of movement was held constant, but the measurements were taken at various places along the scale of intensities.

Experiment I

In this first experiment, beyond the preliminary experiment described above, the data were obtained by the method of constant stimulus differences.[1] Only the wrist movement was employed and judgments were made on seven different sets of weights by each subject. There were five different weights in each set, plus a standard weight. The following table gives the mass of the various weights. The values appearing in the third column represent the value of the standard weight for that particular set, the corresponding row.

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[1] Titchener, E. B., Experimental Psychology, vol. II, part ii, pp. 263-275. Macmillan, 1923.

Table IV

No. of weight in set	I	II	III	IV	V
Set 50	46	48	50	52	54
Set 100	92	96	100	104	108
Set 150	138	144	150	156	162
Set 250	230	240	250	260	270
Set 350	322	336	350	364	378
Set 450	414	432	450	468	486
Set 550	506	528	550	572	594

The weights, as in the preliminary experiment, were all of the same size, shape and material, differing only in mass. They were not visible to the subject and were always presented to him at the same place, thus avoiding the space error, by means of a turn-table, a disc which could be rotated and upon which the weights rested so that they could be turned around to any position. While lifting the weights, the subject always sat in a straight-backed chair and extended his right arm through an aperture in a screen.

These experiments were carried out in a darkened room in order to decrease the distraction for the subjects. There was a light behind the screen only, so that the experimenter could see which weights he was presenting and record the judgments. Each member of a set was presented twenty-five times to each subject. The comparison weights were presented in haphazard order and at the beginning of each sitting each subject was put through a training period in order to establish a rhythm of lifting which kept the time interval between standard and comparison constant. The instructions were the same as those used in the preliminary experiment, except that here no judgments of 'equal' were given.

Four subjects were used in this experiment, three men and one woman. The men were graduate students in the Harvard Psychological Laboratory and the woman a senior, psychology major in Radcliffe College. The men were experienced in making psychological judgments.

Since no 'equal' judgments were taken in this experiment, the h-values for the 'heavier' judgments will equal the h-values for the 'lighter' judgments, except that the former will be positive while the latter are negative. For this reason, the following table presents only the h-values for the 'heavier' judgments.

Table V

Individual values of h, for the judgments of 'heavier', obtained from the data, and their averages for each set of weights.

Obs.	Set I	Set II	Set III	Set IV	Set V	Set VI	Set VII
Hn.	.0857	.0731	.0670	.0507	.0532	.0301	.0218
Ht.	.0771	.0869	.0737	.0444	.0336	.0232	.0247
St.	.0878	.0687	.0558	.0431	.0206	.0147	.0155
Ha.	.0562	.0508	.0504	.0320	.0136	.0195	.0133
Aver.	.0767	.0699	.0617	.0426	.0303	.0219	.0188

Comparison of h-values in Table V shows the variability in precision between the observers and between one set of weights and another. The average h shows more clearly how the factor of precision decreases as one proceeds from Set I to Set VII, from weights of approximately fifty grams to those approximating 550 grams. As the value of h gets smaller progressively from Set I to Set VII, it means that curves representing the distribution of the percentages of 'heavier' and 'lighter' judgments for each set of weights get flatter as the weight of the stimulus increases. One thing that h means, then, is the flatness or steepness of the curves. As the value of h increases, the precision of the judgments also increases. It has been shown that the value of h can change without its affecting a liminal measure in any way.[1]

Since no judgments in the intermediate category were recorded in this experiment, the limen was not used as a measure of sensitivity. Under these conditions and

[1] Boring, E. G., Urban's Tables and The Method of Constant Stimuli, Amer. J. Psychol., 1917, vol. 28, p. 280.

with the use of the method of constant stimulus differences the probable error of the distribution, P, which is a measure of variability, is also a better objective measure of sensitivity than the limen.[1] It was therefore decided to adopt this measure which is derived in much the same way as the limen. To find the liminal value, the lower limen is subtracted from the upper limen to get an interval of uncertainty and this is divided by two. Here, then, the P-value for the 'lighter' judgments, P_l, is subtracted from the P-value for the 'heavier' judgments, P_h. This remainder corresponds to the interval of uncertainty and can be divided by two to get a quotient which corresponds to a limen.[2] In Table VI, below, are presented the P-values, P_h-P_l, derived from the data of this experiment.

Table VI

The P-values for each observer and each set of weights with the averages for each set of weights.

	Hn	Ht	St	Ha	Average
50	11.1296	12.3710	10.8634	16.9716	12.8339
100	13.0478	10.9758	13.8836	18.7756	14.1707
150	14.2358	12.9416	17.0932	18.9246	15.7988
250	18.8126	20.4820	22.1298	29.8062	22.8077
350	17.9284	28.3868	46.3010	70.1324	40.6872
450	31.6876	40.9356	64.8844	48.9128	46.6051
550	43.7522	38.6154	61.5354	71.7142	53.9043

Table VI shows that the P-values increase in size as the sets of weights become heavier. This is not surprising, since one would not expect the same absolute amount of variability with vastly different sets of weights. The P-values, however, vary only about one to four while the sets of weights vary as one to eleven. In order to use the P-values as a comparative measure of sensitivity, they must be put on an equal footing. This can be done by devising a relative P-value, or dividing the P-value for

[1] Culler, E., Studies in Psychometric Theory, Psychol. Monog., vol. 35, No. 2, 1926, pp. 115-122.

[2] Culler, E., ibid.

each set of weights by the value of the standard weight for that set. Table VII presents these relative P-values and their averages and from this table it is evident that the relative variability is not equal for all sets of weights. It is especially high for the lighter sets of weights.

Table VII

The relative P-values and their averages.

	Hn	Ht	St	Ha	Average
50	.2226	.2474	.2173	.3394	.2567
100	.1305	.1097	.1388	.1877	.1417
150	.0949	.0863	.1073	.1262	.1037
250	.0792	.0819	.0885	.1192	.0922
350	.0512	.0811	.1323	.2004	.1163
450	.0704	.0910	.1442	.1087	.1036
550	.0795	.0702	.1119	.1304	.0980

The above relative P-values are analogous to relative I. U. values.

It was planned to carry out more experiments of the same general kind for three reasons: first, to obtain more grounds for a comparison of P with I. U., as a measure of sensitivity; second, to gain more evidence on the question of the variability of sensitivity and its relation to the strength of the stimulus; third, to extend the range of stimuli beyond the limits of the weights already used to discover what happens to the sensitivity at these points.

Experiment II

Methods and procedures:

Here the apparatus differed from that used in the preceding experiment only in that the sets of weights were different. The weights varied from a set around twenty-five grams to a set around 600 grams. The lightest set had a twenty-five gram weight for a standard and five comparison weights, one of which was also twenty-five grams, while two were heavier and two were lighter and differed by the amount of one and five-tenths grams. Thus, this set ranged from twenty-two to twenty-eight grams. A second, similar set ranged around a standard of fifty grams, but with two grams difference between the different comparison weights, thus ranging from forty-six to fifty-four grams. The four other sets of weights had standards of 150, 350, 550 and 600 grams, with differences between members of six, fourteen, twenty-two and twenty-four grams, respectively.

The instructions to the five observers of this experiment were as follows: "You will be presented with pairs of weights upon which you are to make comparison judgments, judging the second weight lifted in reference to the first weight lifted, i. e., as to whether it (the second) is heavier than, lighter than, or equal to the first weight. Report your judgment, 'heavier', 'lighter', or 'equal', as soon as possible after lifting the second weight." There were two sittings during each experimental period and 125 comparison judgments were taken at each sitting.

In this experiment the method of constant stimulus differences was employed. The judgments were recorded as reported, 'heavier', 'lighter' or 'equal'. At the completion of a sufficient number of judgments upon each member of the set of weights, the percentages of the 'heavier' and the 'lighter' judgments were taken separately and put through the Urban process of calculation. By this process one eventually arrives at the values for the upper and lower difference limens, DL's, and their respective h's or measures of precision. By subtracting the lower DL from the upper DL, the interval of uncertainty, I. U., is obtained. Half the interval of uncertainty is equivalent to the DL for the total number of judgments. This can be taken as a measure of discriminability for that particular stimulus. It has also been argued that h can serve as a measure of discriminability. [1, 2]

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[1] Titchener, E. B., Experimental Psychology, N. Y., Macmillan, II, ii, pp. 285-312.

[2] Kelley, T. L. and Shen, E., Foundations of Experimental Psychology, 1929, Clark University Press, chap. 22, pp. 869.

For each of the five observers in this experiment the frequency of judgments of 'heavier' and 'lighter' for each weight was obtained. These frequencies are then changed to percentages which furnish the basis from which the calculation starts. From the calculation of these percentages are derived the h-values for judgments of 'heavier' and of 'lighter', the upper and lower limens, DL, and the interval of uncertainty, I. U. The P-values, or P_h-P_l, are derived by formula from the corresponding h-values. Table VIII, below, presents the averages of these values for all observers.

Table VIII

	Upper DL	Lower DL	I. U.	Upper h	Lower h	P_h-P_l
25	25.83	22.81	3.01	.2378	.1733	6.0983
50	50.26	46.79	3.47	.1331	.1327	7.4018
150	149.08	141.26	7.82	.0583	.0581	16.6457
350	345.72	332.24	13.48	.0295	.0316	33.3316
550	546.07	519.93	26.14	.0196	.0201	49.4465
600	608.43	561.25	47.18	.0209	.0208	45.8512

The absolute limens are not presented in this table, but they are found by dividing the interval of uncertainty by two. It is apparent, then, that the values of any liminal measure increase as the stimulus increases. However, for purposes of comparison, to show how the sensitivity or discriminability varies over the full range of weights employed, it is necessary to have relative difference limens and not absolute ones. Relative difference limens are derived by dividing the absolute difference limens by the value of the stimulus yielding those limens. Relative intervals of uncertainty can be equally well used here; the values are twice as high as for relative difference limens but the same relations are preserved. From the same data there are available the P-values. These are obtained by taking the probable error of the psychometric function for the 'heavier' judgments and subtracting from it the probable error of the psychometric function for the 'lighter' judgments. It is also essential that the relative P-values be dealt with rather than the absolute ones given in Table VIII, above. Table IX, following, gives the relative I. U. values and relative P-values, averaged for all observers.

Table IX

	Average Relative I. U. Values.	Average Relative P-Values.
25	.1206	.2439
50	.0688	.1481
150	.0533	.1110
350	.0389	.0952
550	.0435	.0899
600	.0624	.0764

DISCUSSION

A comparison of the relative P-values in Table IX with those in Table VII shows that there is quite good agreement between the two experiments in which the weights employed were variable. This agreement seems the more remarkable when it is considered that the subjects and their instructions were both different in these two experiments. The agreement between the relative P-values for the two experiments is shown graphically in Figure 1. With such close correspondence of the two curves, it cannot be doubted that the P-values, or the relative P-values, for the two experiments are comparable measures, in spite of the fact that there were no "equal" judgments admitted in one experiment, while there were in the other. Figure 1 also presents the curve for the relative I. U. values. Here, these values are only about half the size of the relative P-values and, for the heaviest set of weights, the relative I. U. values rise while the relative P-values decrease. There is fairly good agreement in the shape of the curves with this exception. It seems perfectly safe to assume that the P-values furnish a measure of discriminability, in addition to their

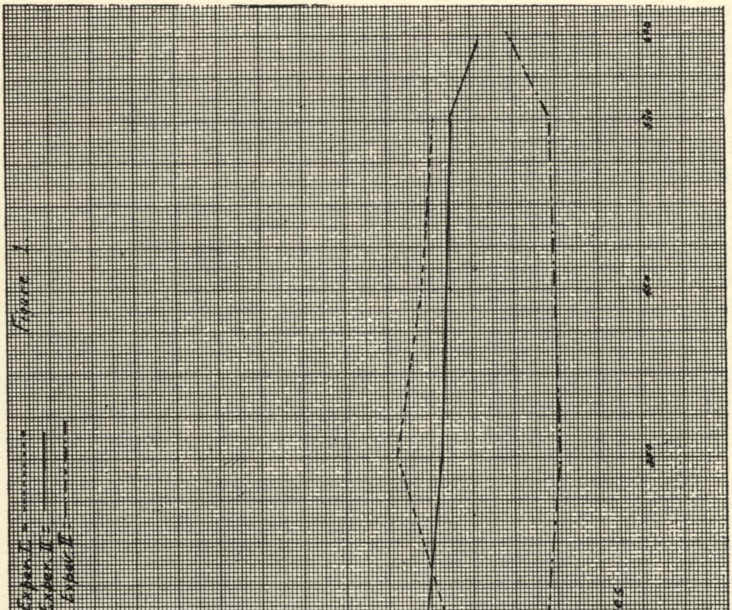
Figure 1.
Stimulus values

being a measure of the variability of the judgments. Culler has already demonstrated the relationship between P, as a measure, and L, as a measure.[1] He offers four reasons for his preference for P. First, P is more reliable; second, P avoids any difficulties of the "doubtful" judgment, since it is not necessary to accept judgments in the intermediate category when using this method. Third, the P-method makes the observer more cautious; and, fourth, P is more simple and convenient to compute than is L. He made a comparison of the true limen, L, with P when both were derived from the same data. His study showed that the conclusions based on L are borne out by P, and, although the absolute values for the L's were smaller than those for the P's, the relationships between the members of a series of L's were the same as the relationships between the members of a series of P's.

The results of the present experiments bear out Culler's conclusions. He stopped with the values of absolute P and L, because he was not testing at many or widely separated levels of the stimulus. The experiments presented here yield evidence of the agreement between relative P and relative I. U. over a rather wide range of the stimulus, as shown in Figure 2. Here it was necessary to use the relative values rather than the absolute ones, because the chief interest was in finding the variability of these measures with a change in weights, rather than their variability among subjects.

A scrutiny of the curves for relative P and relative I. U. when plotted against the stimulus shows that there is not constancy of sensitivity over the whole range of stimuli. In fact, using either of these measures, the ratio of sensitivity for the lower stimuli to the medium stimuli is one to three. The shape of these curves agrees with the results of previous investigators in the field of sensory discrimination.

Hecht, after building an hypothesis about the visual sensory system, wanted to find the basis of Weber's law

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[1] Culler, E., loc. cit.

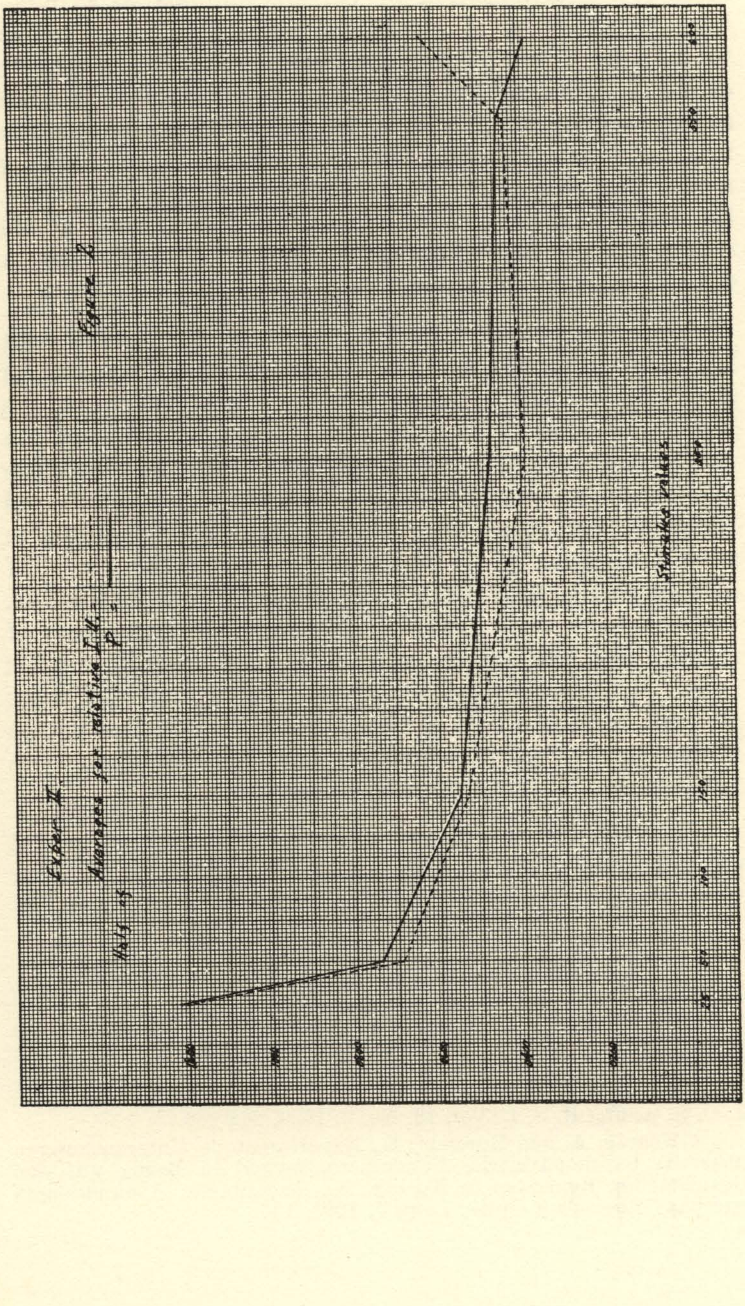
Figure 2
Exper. II
Stimulus values

in terms of it. He started this by investigating the intensity discrimination of certain animals experimentally. In experimenting with the clam, Mya, he was able to measure the discriminative response to the intensity of light. This he did by adapting the clam to certain amounts of illumination and then measuring the reaction time of the retraction of the syphon with varying amounts of change in light intensity. With this technique, he found that the Weber ratio, dI/I, was not at all constant. He found, however, that this ratio has a regular mode of variation.[1]

In a later paper,[2] Hecht shows that his results with Mya are compatible with the results of other experiments done within the last seventy years. In all of these, the Weber ratio, dI/I, has the same mode of variation. In this paper, and in a still later one,[3] Hecht presents the results of experiments done by Aubert, Koenig and Brodhun, and Blanchard. These results are presented in a way to show the relationship between the value of dI/I and the logarithm of the intensity of the stimulus. There is very close agreement between the three sets of results, and the values of dI/I decrease rapidly as the strength of the stimulus increases, in the case of weak stimuli; then there is a range during which the values remain quite constant, but with stronger stimuli there is a tendency for the values to increase.

Koenig and Brodhun have done, perhaps, the best experimental work on the measurement of dI/I.[4] Their measurements were taken over the whole range of in-

[1] Hecht, S., Intensity Discrimination and the Stationary State, Jour. Gen. Physiol., 1924, vol. 6, No. 4, 355-373.

[2] Hecht, S., The Visual Discrimination of Intensity and the Weber-Fechner Law, Jour. Gen. Physiol., 1924, Vol. 7, No. 2, 235-267.

[3] Hecht, S., The Nature of the Sensitivity of Animals to Light, J. O. S. A. and R. S. I., Vol. 18, No. 3, 1929, 264-286.

[4] Koenig, A. and Brodhun, E., Experimentelle Untersuchungen über die psychophysische Fundamentalformel in Bezug auf den Gesichtssinn. Reprinted in Koenig, A., Gesammelte Abhandlungen zur physiologischen Optik, Leipsic, 1903, 135.

tensities, from the lowest perceptible brightness to the point where the illumination becomes painful. Their results agree closely with those of Aubert, but are more extensive. They investigated higher intensities than did Aubert and they found that the ratio, dI/I, starts to increase again when the value of the stimulus gets beyond the intermediate range into very high intensities. Blanchard[1] later repeated these experiments with another method and obtained the same results. There is still further and more recent evidence against the constancy of the ratio, dI/I, in vision.[2] In fact, it seems to be only approximately constant even within the intermediate range of intensities. Measurements of it in several independent investigations show it to vary always in the same way.

Evidence for the existence of a similar relationship between stimulus strength and discriminability of intensity in the auditory modality is presented by Troland.[3] The Weber fraction is shown to be very much greater for the lower intensities than for those in the medium range, where it approaches constancy.

Crozier and Pincus found, working with the geotropic behavior of rats, that the angle of orientation on the inclined plane varied when the angle of the incline varied, but the relationship was not constant.[4] The angle of orientation can be thought of as being the response of the animal to a certain amount of pull of gravity which is furnished by the angle of the plane. This, and the fact that the angle of orientation is also a measure of excitation, has been pointed out by Hoagland.[5]

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[1] Blanchard, J., The Brightness Sensibility of the Retina, Phys. Rev., 1918, 11, series 2, 81.

[2] Cobb, P. W., Weber's Law and the Fechnerian Muddle, Psych. Rev., 1932, Vol. 39, No. 6, 533-551.

[3] Troland, L. T., Psychophysiology, Vol. II, 1930, 206-254.

[4] Crozier, W. J. and Pincus, G., The Geotropic Conduct of Young Rats, Jour. Gen. Physiol., 1926, Vol. 10, 257-269.

[5] Hoagland, H., The Weber-Fechner Law and the All-or-None Theory, Jour. Gen. Psychol., 1930, Vol. 3, No. 3, 351-373.

Graphically, from the results of these experiments, the relation between excitation and the logarithm of the intensity of stimulation is represented by an ogive curve.

Since measurements of acuity in relation to amount of stimulation, in various fields, yield results in close agreement, this relationship seems to be established. The problem then becomes one of explaining the relationship, i. e. the shape of the curves.

The most reasonable explanation seems to lie at the physiological level. Hecht explains his results by making visual acuity dependent upon the number of elements (rods and cones) functional for any particular strength of stimulus. A normal distribution of stimulus thresholds in each set of elements is assumed. The sigmoid curve is, thus, the result of the fact that at low strengths of the stimulus there are only a few elements functional, and discrimination is poor; at very great strengths of the stimulus discrimination becomes poor again as the limit of available receptors to be brought into function is approached.

The sigmoid curve, then, derives its characteristic shape from the relative paucity of receptors with extremely low stimulus thresholds and of those with excessively high stimulus thresholds, since it is only the integral of the distribution curve.

This explanation applies equally well to the results of Experiments I and II, presented in this paper, since the curves for these (Figures 3 and 4) and for Hecht's experiments are essentially similar. The receptors, the stimulus thresholds of which are normally distributed, are, in this case, muscle-fibers.

The assumption that sensitivity is dependent upon the number of muscle-fibers functional is also applicable to the results of the preliminary experiment. Since the shoulder movement included movement of the wrist and elbow, it is probable that more muscle-fibers were in-

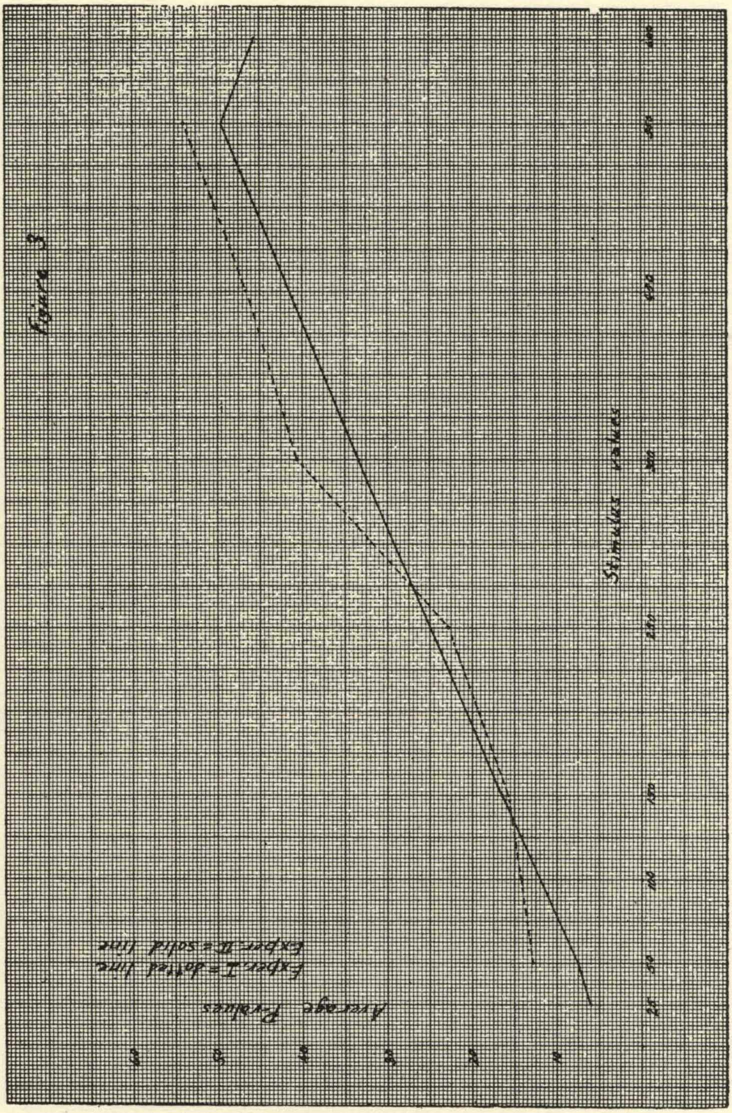
Figure 3
Stimulus values
Exper. I = dotted line
Exper. II = solid line

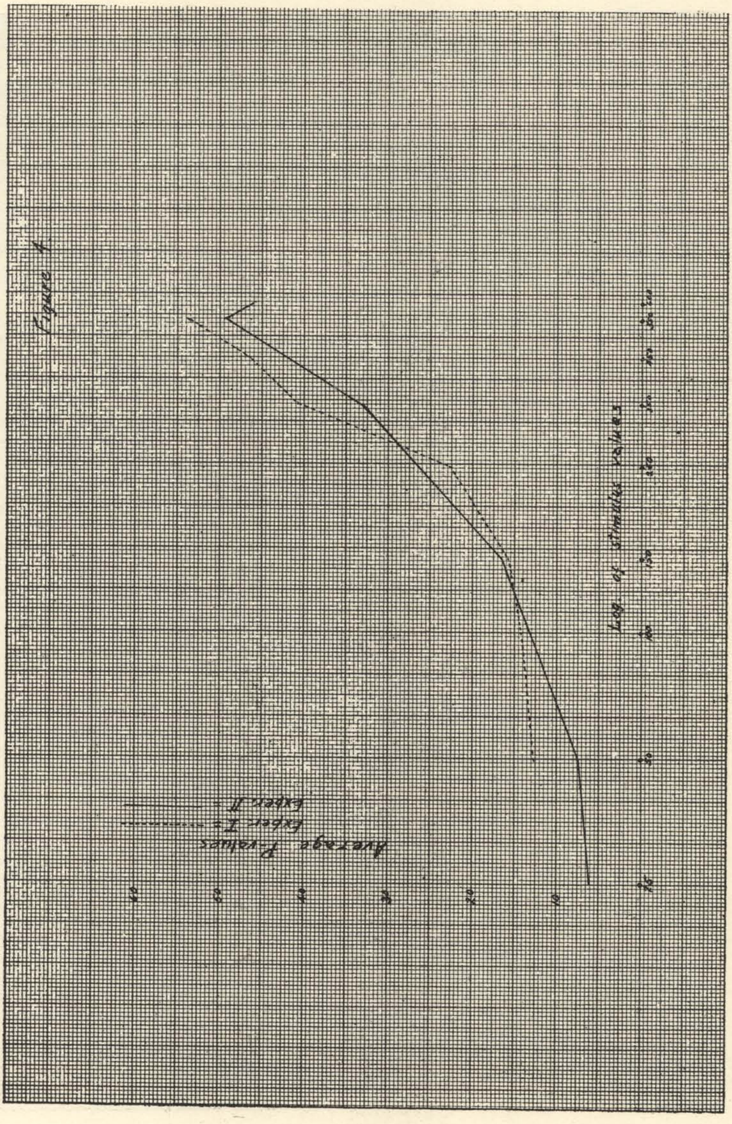
Figure 4
Log of stimulus values
Average P-values
Exper. I = ----------
Exper. II = ———

volved. If sensitivity varies with the number of muscle-fibers in use, greater sensitivity with proximal movement is to be expected. The results of the preliminary experiment show this to be the case.

CONCLUSIONS

In summarizing the results of the present experiments, the following conclusions may be stated:

The relative values of P, the probable error of the distribution, and the interval of uncertainty show themselves, graphically, to be essentially the same, so either may be used as a measure of discriminability. The close agreement between I. U. and P in Experiment II, as well as the agreement between the P-values of both Experiments I and II, shows that the use of the intermediate category, required by the I. U. method, is unnecessary. The easier computation of the P-method makes it preferable to the I. U. method.

Sensitivity is greater with proximal movement than with distal movement. Using the I. U. method in the preliminary experiment, the results show that the values of I. U. were smaller for the shoulder movement than for the elbow movement. Also, the I. U. value for the elbow movement was smaller than that for the wrist movement.

Within certain limits, sensitivity increases with the absolute weight of the stimulus. The relative values of P in Experiment I, and I. U. and P in Experiment II, decreased as the value of the weights approached the middle of the range used.

The mode of variation in sensitivity found in these experiments is what would be expected if the threshold values of receptors were normally distributed. This is particularly evident in the curve which represents the relative I. U. values. These values decrease as the stimuli used increase from the lowest to the medium strength.

Furthermore, increase of the stimuli beyond the medium strength is accompanied by an increase in the value of relative I. U. A decrease in the value of relative I. U. means an increase in sensitivity. As shown in the discussion, these results justify the assumption that the stimulus thresholds of muscle-fibers are distributed normally.

Constancy of kinaesthetic acuity is not upheld by these experimental results. This conclusion is warranted since the relative value of both P and I. U. have been found to vary extensively with a variation in stimulus strength.