MINOR STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF WELLESLEY COLLEGE.

(COMMUNICATED BY PROFESSOR ELEANOR A. McC. GAMBLE.)

I.

Intensity as a Criterion in Estimating the Distance of Sounds.

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The purpose of this study was to find evidence for or against the ordinary assertion that the distance of a sound is estimated mainly on the basis of its intensity. The investigation falls into two divisions. In the first division the evidence was sought by an indirect method. The experiments constituted an attempt to determine the just noticeable divergences from a number of standard distances. The argument on which the work was based is as follows:

1. The intensity of a sound varies inversely as the square of the distance. If the relative distance of two sounds is expressed by the ratio 9 : 16, then, other things being equal, their relative intensity must be expressed by the ratio 4 : 3.

2. If the relative distance of sounds is judged in terms of their intensity, then a just noticeable difference in distance may be expected to imply a just noticeable difference in intensity. This means that if a sound at a distance of 9 feet is just noticeably nearer than the same sound — *i. e.*, a sound produced by the same stimulus — at a distance of 16 feet, then the just noticeable difference in intensity must be one third of the intensity of the weaker stimulus. It should be noted, however, that it is conceivable that intensity is the main criterion in judging only gross differences in distance, and that variation of overtones is highly important in judging liminal differences.

3. If Weber's law holds for sounds in general, then a just noticeable variation from the intensity of two or more standard sounds produced by the same stimulus must be approximately

the same fraction of the total intensity of these standard sounds. If we grant all these premises, then we must infer that whenever we find a just perceptible difference between distances of the same sound, we shall find that the intensities as determined by these distances always bear about the same ratio to one another. Several investigators have found that one third is the 'Weber's law fraction' for the noise of small falling bodies. Let us suppose that this fraction holds for sounds in general, whether noises, tones of different pitches, or clangs. Then one sound will always be just noticeably nearer and louder than another when the intensity ratio is approximately 4 : 3. Whenever we find a just noticeable difference in distance, we shall find that the distances are as 9 is to 16 and that the intensities are as 4 is to 3.

The fraction one third has been taken only for purposes of illustration. It is more than probable that it does not apply to sounds at large. Let us then represent two just noticeably different distances of the same sound by m and n. Now on the assumptions of the foregoing argument, one will find that the ratio which holds between m^2 and n^2 always holds between the squares of any two just noticeably different distances of this sound. Therefore, if in various instances of just perceptible difference in distance, we find no such equality of ratios, then either Weber's law does not apply to the sound-stimulus used, or else intensity is not the main criterion in estimating liminal differences in its distance, or else the validity both of Weber's law and of the intensity-criterion are ruled out in the particular case. If, on the other hand, the equality of ratios is found to hold repeatedly, then there is a strong presumption both that Weber's law does apply to the stimulus in question, and that intensity is indeed the main criterion in estimating liminal differences in the distance of this particular sound. Of course, a negative conclusion will be warranted only if the experimental conditions are good or if the results are so numerous that the effects of accidental variations in the conditions may be supposed to cancel one another.

In the second division of the experiments the method was more direct. The subjects, who knew little or nothing of the

object of the experiments, were required to describe repeatedly the difference in two sounds, which varied sometimes in initial intensity and sometimes in distance, or which were altered in intensity when they were supposed to be altered in distance. The purpose of these experiments was to determine the degree to which the subjects were likely to confuse one difference with the other. For brevity, the experiments of the first division will be called the 'Weber's law experiments,' and those of the second division will be called the 'confusion experiments.'

Experiments of both divisions were made in the academic years 1897–1898, 1898–1899 and 1899–1900.[1] Throughout the experiments the sounds were given with a telephone receiver and the distance from the subject's ear was measured upon a board supported at such a height that the opening of the receiver when held close above it — with only the experimenter's fifth finger inserted between receiver and board — could be approximately on a level with the opening of the ear of the subject whose chair could be raised or lowered according to her height.

In the first year of the experiments, this board was about two inches wide and was raised on supports about 16 inches from a table 36 inches wide. In the last two years the measuring-board was only half an inch thick, had a bevelled edge graduated in half-centimeters, and was held, edge-up, by slender supports which rose from the floor. The room is which the experiments were made is 47 feet long and 15½ feet wide. The subject's end of the board was about 10 feet from one end of the room and the board ran parallel with the longer walls of the room and practically in the center crosswise. From this end of the room all furniture unnecessary to the experiments was cleared away. The room was reasonably but not ideally quiet. Rude as the conditions thus indicated may seem, by far the most serious drawback to the experimental conditions consisted in the nature of the sound itself. The sound used was not a telephone-click; the click was considered too weak and irregular ('sputtering') for the purpose. The sound employed

[1] The experiments were made in the three successive years by Miss Louise S. McDowell, Miss Amy G. Whitney and Miss Inez Mathews, who were all students in a second-year course in psychology. The work was directed at different times by Professor Calkins, by Dr. James E. Lough and by the writer.

was a 'musical tone' produced by passing the alternating lighting-current of the college, or a secondary current induced by this current, through the telephone receiver. The coil on the magnet of a discarded piece of apparatus was thrown into the circuit by way of resistance. When the primary current was used, the opening of the receiver was plugged with cotton to reduce the loudness of the sound. The secondary current produced a sound which erred in the direction of being too weak, but the intensity could be further reduced at will by sliding out the induction-coil. The great defect in the experimental arrangements consisted in the fact that the intensity of the sound varied considerably from one sitting to another according to the number of electric lamps through which the current was passing. A minor difficulty consisted in the 'humming' of the induction-coil. In the first year of the experiments no induction-coil was used; diminution in the initial intensity of the sound (*i. e.*, diminution in its loudness near its source and not as determined by distance) were produced by screening the receiver with the hand. In the second year the induction-coil was used only in the confusion experiments. In half of these experiments the initial intensity of the sound was altered by sliding out the coil; in the other half the screening-method was used. In the third year, the induction-coil was used in all the experiments because in consequence of a change in the dynamo supplying the alternating current, the sound produced by the primary current had altered to a harsh bray. In all cases, the experimenter made and broke the circuit by means of a push-button on a shunt.

Throughout the experiments reasonable precautions were taken to cancel the effect of the time-error, the expectation-error, and the like. (The experiments were scarcely elaborate enough to merit a detailed account of program.) At least in the last two years, the sounds to be compared were given two seconds apart and the subject was required always to judge the sound with reference to the first as a standard. The subjects with one exception were all students in a first-year course in psychology. In the confusion experiments they were blindfolded, but in the other experiments they were simply required 'not to look.'

The Weber's law experiments of the first two years led to no

very definite outcome. The work of these two years consisted in skirmishing to hit upon the divergence from a number of standard distances which would give 80 per cent. of right cases in comparing the two distances. Perforce, a number of different subjects were used — three in the first year and four in the second and only one of them trained — because no one subject was available for extended work. With each subject several different distances were used as standards, ten different distances were compared with each standard, and only ten comparisons were made with each pair of distances. (Comparisons of the same standard with different distances were interspersed with one another.) In view, on the one hand, of the variations which must arise under experimental conditions of so rough a nature, and in view, on the other, of the scattering of the experiments over so many subjects and distances, it is scarcely surprising that little regularity appears in the figures obtained. The results of the second year are rather less regular than those of the first. The latter may be summarized as follows, if one averages the results of the three subjects and if one assumes that about 80 per cent. of right judgments indicates a liminal difference between two stimuli:

Standard distances in cm.:	20	30	40	60	80	100	120	140	200	300
Ratio between intensity at standard and distance just noticeably greater:	$\frac{100}{69}$	$\frac{100}{74}$	$\frac{100}{86}$	$\frac{100}{76}$	$\frac{100}{61}$	$\frac{100}{82}$	$\frac{100}{82}$	$\frac{100}{72}$	$\frac{100}{86}$	$\frac{100}{80}$
Distance just noticeably less:	$\frac{100}{111}$	$\frac{100}{138}$	$\frac{100}{111}$	$\frac{100}{111}$	$\frac{100}{120}$	$\frac{100}{145}$	$\frac{100}{110}$	$\frac{100}{150}$	$\frac{100}{125}$	$\frac{100}{125}$

These figures look very much like the sort of results which might very well be obtained from unpracticed subjects, under rough conditions, if Weber's law applied to the stimulus and the fraction were about one fifth.[1]

In the third year only two subjects were employed — L., a student in a second-year course in psychology, and G., the writer. The plan of the experiments was to find a pair of distances which would give, when compared, from about 75 to 80 per cent. of right cases, and then to work with another or other

[1] M. Wien found the fraction one fifth to hold good for the tone *a* at about 220 vibrations. For the corresponding *e'*, he found the fraction to be one sixth and for the corresponding *a'*, he found the fraction to be one eighth. This statement is made on the authority of Ebbinghaus, *Grundzüge der Psychologie*, 1905, p. 302.

pairs of distances which would involve the same ratio between the intensities of the sounds. The results of these experiments are given in the following table:

RESULTS OF THIRD YEAR OF EXPERIMENTS IN DETERMINING LIMINAL DIFFERENCES IN SOUND DISTANCES.

Subject.	Set of Experiments.	Distances Compared, cm.	Ratio of Corresponding Intensities	Number of Comparisons.	Right Cases, Per Cent.
G.	1	20 and 25	156 : 100	224	91
	2	20 " 22.5	127 : 100	250	89
	3	30 " 35	136 : 100	425	89
	4	30 " 33	121 : 100	475	86
	5	30 " 32	114 : 100	400	66
	6	30 " 32.5	117 : 100	475	76
L.	1	36 and 43	143 : 100	825	71
	2	36 " 46	163 : 100	150	99
	3	36 " 43 5	146 : 100	825	74
	4	26 " 31	142 : 100	725	72
	5	46 " 55 5	146 : 100	325	77

In the case of G., the effect of practice made the '80 per cent. point' hard to find. A difference in distance which at first promised to give far less than 80 per cent. of right judgments would toward the end of a set of comparisons yield far more. Thus, only one difference was finally demonstrated to be liminal, viz., the difference between 30 and 32.5 cm. That this difference was really liminal is shown by the fact that either an excess or a lack of half a centimeter made a great difference in the number of right judgments obtained. It is noteworthy that the intensity-difference implied by this liminal distance-difference is about one fifth of the smaller stimulus-intensity.

The results obtained from L. certainly seem, in so far as they go, to prove the point at issue. In two cases in which the intensity-ratio between the sounds compared was approximately the same, the percentage of right cases was almost exactly the same, and in two other cases in which the intensity-ratio was exactly the same the percentage of right cases was approximately the same. Moreover, the number of comparisons in each case was respectably large. The fraction which measured the just noticeable difference was, however, very large, amounting to two fifths of the smaller intensity.

On the whole the results of the first division of the experiments suggest although they do not prove, that the estimation of sound-intensities in general follows Weber's law, and also forms the basis of the estimation of liminal differences in distance.

The confusion experiments were both simpler and much more fruitful of results. Their conduct may conveniently be described in connection with the following table which summarizes the data obtained:

RESULTS OF 'CONFUSION EXPERIMENTS.'

Year 1.

Difference in Stimuli.	Cases.	Distance in Cm. 30 — Judgments Per Cent.			60 — Judgments Per Cent			120 — Judgments Per Cent			240 — Judgments Per Cent.		
		N	*F*	*E*	*N*	*F*	*E*	*N*	*F*	*E*	*N*	*F*	*E*
Second sound louder.	30	87	7	7	80	7	13	73	13	13	40	37	23
Second sound softer.	30	—	100	—	—	97	3	17	83	10	37	53	10

Year 2.

Relation of Stimuli.	Method. Screening. Distance. 15 cm — Cases	Judgments Per Cent *N*	*F*	*E*	*U*	30 cm. — Cases	Judgments Per Cent. *N*	*F*	*E*	*U*	Use of Induction Coil. Distance. 15 cm. — Cases.	Judgments Per Cent. *N*	*F*	*E*	*U*	30 cm. — Cases	Judgments Per Cent. *N*	*F*	*E*	*U*
Second sound louder.	152	73	5	22	—	153	72	9	19	—	162	65	7	27	1	142	65	8	26	1
Second sound softer.	125	6	78	14	1	124	6	80	12	2	132	9	77	14	—	116	5	84	10	—
Both sounds loud.	31	26	3	71	—	32	16	3	81	—	36	19	8	72	—	27	11	15	74	—
Both sounds soft.	41	15	5	81	—	42	12	10	79	—	45	4	20	73	2	139	10	21	69	—

Year 3.

Difference in Stimuli.	Cases.	Judgments Per Cent. *N*	*F*	*L*	*S*	*E*	*U*
Second sound nearer.	893	22	5	29	8	32	4
Second sound farther.	1159	5	28	6	29	27	5
Second sound louder.	509	21	2	35	8	30	4
Second sound softer.	712	1	28	2	52	13	3

The only abbreviations which need explanation are the initials in the columns under 'judgments per cent.' *N* means that in

a certain percentage of a given set of comparisons (of which the number is given under 'cases'), the second sound was judged to be the 'nearer' of the two. In the same way, *F* stands for 'farther,' *L* for 'louder,' *S* for 'softer,' *E* for 'equal' or 'same,' and *U* for 'uncertain.' All cases in which for any reason the subject failed to pass judgment are gathered under *U*. In the figures for each of the three years, the results obtained from all the subjects are massed (not averaged) as if they had been obtained from one subject. In the first year, the subjects numbered three, and sixty cases — twenty for each subject — were obtained with each distance — thirty with the second sound louder and thirty with it softer. In the second year, the subjects numbered fifteen and each subject made about twenty-five comparisons with each method of altering the initial intensity of the sound (screening and use of the induction-coil) at each distance — about one hundred comparisons in all. In the third year of work, thirty-two subjects were used, and each subject made about one hundred comparisons. In this year no attempt was made to compare the results which might be obtained at different standard distances. The subjects of the confusion experiments were all first-year students of psychology, but those of the first year of work were the same three who had served as subjects in the experiments of the Weber's law division.

In the first two years of the experiments, the subjects were led to think that only the distance of the sound would be varied, whereas, if any difference at all were made in the stimulus, only the initial intensity of the sound was actually varied. As important a point as any which the figures bring out is that the subjects did not detect the imposition which was practiced upon them. (To this rule there are one or two exceptions which are of little practical importance since the subjects' misgivings, which never amounted to more than suspicion, were due to same carelessness or misadventure on the part of the experimenter.) The figures show that in the great majority of cases, difference in intensity produced the impression of difference in distance — in such wise that the louder sounds were interpreted as the nearer — and that equality of intensity produced the im-

pression of equality in distance. Although the sounds were all really equal in the respect in which the subjects judged some of them to be different, and although in the second year some pairs of sounds were given which were really equal in all respects and were judged to be equal, yet no preponderating tendency appears to err in the direction of passing too many equality-judgments. As regards the experiments of the second year, it should be noted incidentally that a greater change of intensity seems to have been produced by screening the telephone than by sliding out the coil. The coil was moved from 3 to 5 cm. according to the strength of the current on the particular day. Since the subjects did not detect the very simple ruse employed, the greater number of right cases obtained with the screening-method can scarcely be laid to any peculiar muffling of the sound.

In the first two years the subjects were under the influence of suggestion when they interpreted differences in intensity as differences in distance. The effect of suggestion might conceivably be great enough to make the subject's image different 'distance-qualities,' if such marks ever exist, with different sound-intensities. In the third year, the subjects were entirely free from the effect of suggestion, as regards the point at issue. They were required simply to tell *how* the sounds in the pairs given them for comparison differed. It was suggested merely that these sounds might differ in distance, in loudness, or in pitch. The statement was purposely made in such a form that the unreflecting subject could think that 'the same' sound might be nearer without being louder. As a matter of fact, the difference was sometimes one of distance, and sometimes one of initial intensity, as controlled by the use of the induction-coil. The extent to which the coil was pulled out and the distances at which the sounds were given differed somewhat from one sitting to another according to the strength of the primary current, but at the same sitting only two distances and two intensities were compared. The one hundred comparisons demanded of each subject were ordinarily made at one sitting. The distance at which the nearer sound was given rarely exceeded 30 cm. The experimenter meant to work with superliminal dif-

ferences both of distance and of intensity, but the figures indicate that the differences were in general not more than liminal.

The third part of the table shows that the judgments of 'nearer' and 'louder,' and of 'farther' and 'softer' were practically interchangeable. The subjects showed a marked tendency, however, to say more often that a sound was louder when it was louder only in virtue of being nearer, than to say that it was nearer when it was merely louder, and so also, *mutatis mutandis*, with the judgments of 'softer' and 'farther.' This fact may be interpreted in three different ways: (1) If one beg the question at issue in this investigation as a whole, one may say that when the initial intensity and the distance of a sound are both unknown, one's attention dwells upon intensity just because one is more accustomed to making intensity the clue to distance than to making distance the clue to intensity. In view of the whole trend of the confusion experiments this seems to the writer the natural explanation of the tendency towards judgments of 'louder' and 'softer,' and the tendency itself seems to be a striking confirmation of the ordinary belief which is here in question. The fact that there were any judgments at all of 'nearer' and 'farther' is, in view of the results of the first two years, sufficiently explained by suggestion. (2) If, however, one believes in distance-qualities, one may say that the subject is more likely to overlook the difference in such qualities than to imagine one. (3) Finally, the tendency in question may (conceivably) be due to the fact that the subjects were reflecting enough to realize, at least dimly, that nearness implies loudness in a way that loudness does not imply nearness, so that the intensity-judgment has a double chance of being right. There are, however, few recorded remarks or other data which lead one to believe that the subjects at large clearly distinguished between the loudness of a sound as determined by its distance and its initial loudness. The failure of our subjects to make this distinction must not be interpreted as telling against the practical value of intensity as a clue to distance. One may associate place-images with intensities for practical purposes in ordinary life — as, for example, when one is estimating the distances of a railway-train which one wishes to catch — and

yet, in spite of these serviceable associations, one may fail to think clearly about the two conditions of intensity on occasions when intensity and distance are alike unknown and are equally uninteresting to the natural man.

Three additional remarks must be made: (1) In these records — for the confusion experiments of the last year — there is a sprinkling of cases in which the same sound was judged to be both nearer and louder or farther and softer, and a still smaller number of cases — about a dozen out of 3,273 — in which the same sound was called both nearer and softer or farther and louder. These double judgments are reckoned in the table as if the first judgment expressed had been the only one. They may be interpreted either for or against the assumption of a sharp distinction on the part of the subjects between the two conditions of loudness.

(2) Differences in pitch or musical quality were very rarely alleged by the subjects — not nearly so often indeed as differences in duration, which were purely accidental. No correlation can be made out between the pitch-differences mentioned and differences in distance.

(3) Curiously enough, throughout the confusion experiments of the three years, the number of right and of pseudo-right cases was noticeably greater when the second sound was the weaker of the two compared. Thus the ordinary time-error was consistently reversed. The writer cannot explain this fact.

The results as a whole offer considerable evidence for, and little or no evidence against, the ordinary belief that intensity is the main criterion in estimating the distance of a sound. The writer is not prepared to explain the divergence between the results of these experiments and the results obtained by Professor Von Kries, in support of a distance-quality or mark, but must be content to point out that the results here presented are the more numerous and that they were obtained by a method which was scarcely less precise than the method of Von Kries.[1]

[1] See Von Kries, 'Ueber das Erkennen der Schallrichtung,' *Zeit. f. Psych. u. Phys. der Sinnesorgane*, I. (1890), especially pp. 246–247.