THE SIGNIFICANCE OF INTENSITY—SUM IN BINAURAL LOCALIZATION.

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IN the various contributions on sound localization, numerous references have been made to the *difference in intensities* at the ears as an important factor in sound localization. That it is an important factor none can dispute, but there is no evidence that it is the most important intensity factor. The object of this paper is to consider the *sum of intensities* as a factor in practical localization. Obviously the relative importance of these two factors depends upon the conditions imposed in the experiments. If the head and the source of sound are stationary, then the intensity-difference and intensity-ratio are probably the only intensity factors. But if the observer is allowed to turn his head at will and if the sound is of sufficient duration, then he has the opportunity of comparing different intensity-sums with different positions of the head.

Theory.—In a previous theoretical investigation[1] the writer assumed that the apparent intensity of sound was the sum of the intensities at the two ears, phase not being considered, and accordingly curves were plotted showing the variation in this intensity-sum with different positions of the head. The character of the dependence of this variation upon wave-length was so different from that of intensity-difference and intensity-ratio and so unexpected withal that an experimental test was arranged to show whether or not the intensity-sum is a factor of importance. The results of the theoretical investigation of intensity-sum are reproduced in Fig. 1. Here the ordinates are relative values, unity at 0°, for the intensity-sums with different wave-lengths, and the abscissæ give the position of the head, 0° being the position with an ear toward the source, 90° the position with the source directly in front, and 180° with the other ear toward the source. The distance of the sound source is 477 cm. In the assumption involved in the theory, viz., that the head is a rigid sphere with the ears diametrically opposite, there is no distinction between front and rear and therefore the rotation of the head from 180° to 360° is secured by duplicating the curves shown in Fig. 1.

The results for wave-lengths of 240, 120 and 60 cm. are not surprising when one considers that with the shorter wave-lengths the head is more

[1] Stewart, PHYS. REV., XXXIII., No. 6, December, 1911, p. 467.

of an obstacle. That the curve for 30 cm. did not follow this general trend was a surprise. A check on these results is obtained from the results of Lord Rayleigh for a source at a great distance, for the variation

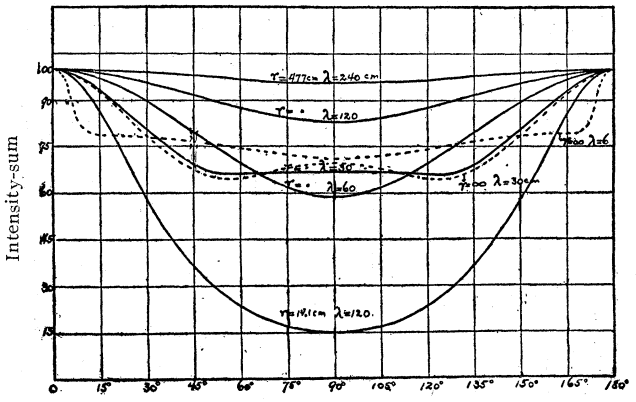

Fig. 1.

in intensity in the shadow of the head with the source at 477 cm. is not greatly different from that with the source at a great distance.[1]

The intensity-sums obtained from Lord Rayleigh's results are represented in the figure by dotted lines. These additional curves also indicate that a curve obtained for a wave-length of 6 cm. would show a greater flattening. More theoretical curves would have been computed if the computations had not been very laborious or if there had been any doubt in regard to the conclusions that can be drawn.

The intensity-differences and intensity-ratios give curves of a very different character. Fig. 2 gives the results of such computations, utilizing the same values of intensities as before. The meaning of 0° and that of 90° are the same as before. It is obvious that these two sets of curves are similar in that the effect of changing the wave-length is a progressive one. In this respect they are not like the curves in Fig. 1. If the intensity-sum is of practical importance in the localization of sound, then the observer, when facing the source (90°), should have less difficulty in locating a source of wave-length 60 cm. than one of wave-length 30 cm. or 120 cm., for with the first named there is a greater variation of the intensity-sum with a given small rotation of the head, than with either the 30 cm. or 120 cm. wave-length. In other words, when the observer faces the source of sound, a given variation of intensity-sum is ob-

[1] Stewart, loc. cit.

tained with a less rotation of the head in the case of a wave-length of 60 cm. The curves do not show that 60 cm. is the "critical" wave-length. Additional curves would need to be plotted to get nearer the truth in this respect. But Fig. 1 does indicate that there is a critical wave-length. The question to be determined experimentally is whether or not this theoretical deduction can be observed in practice. If it can be observed then the intensity-sum must be an important factor in practical sound localization. But more than this. The curves in Fig. 2 indicate that

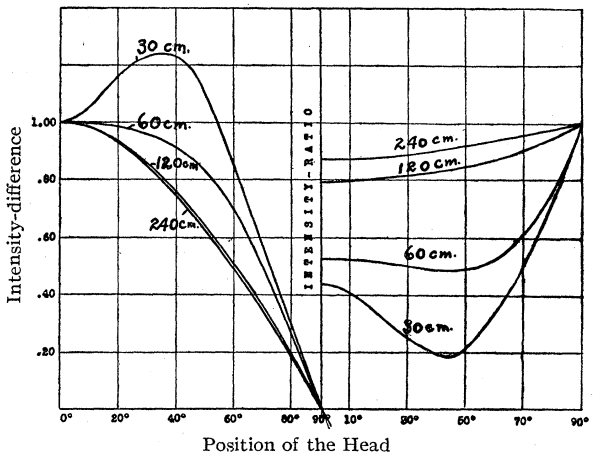

Fig. 2.

when the observer faces the source and rotates the head through a small angle, there is the greatest change with the smallest wave-length, since in each set of curves the slope for the 30 cm. curve is the greatest of the four at 90°. It would therefore seem that a search for this critical wave-length indicated in Fig. 1 would determine whether or not the intensity-sum theory is of greater importance under usual circumstances than either the intensity-difference or intensity-ratio theory. It seems to be a matter of common experience that very low or very high pitch tones are the most difficult to locate, but this is not sufficient to prove the point.

Experiment.—In a room with reflecting walls sound localization becomes a very complex problem. Experiments in the open air without reflecting surfaces are practically impossible. The results here recorded were obtained upon an open piece of ground thickly covered with grass. The sources of sound were tuning forks mounted upon resonators. No accurate measure of ability to localize was sought. The degrees of ability were graded in an arbitrary manner.

Any of the observers could without difficulty point directly to the

source of sound, so readily were all the tones localized. When the observer, facing the source of sound 477 cm. distant, was asked to rotate his head back and forth and to indicate with a large pair of dividers the angle within which the sound seemed to be located with certainty, he found no serious difficulty in reaching a conclusion. The observer made his adjustment of the dividers with his eyes closed and the distance between the points of the dividers was taken as a measure of the angle within which the sound was definitely located. The angle varied with different tones. The results obtained are presented in Fig. 3.

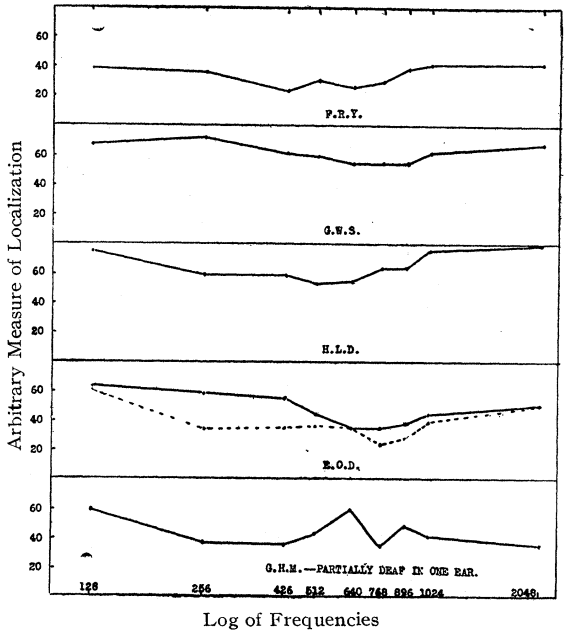

Fig. 3.

Nine forks were used and any order of presentation was carefully avoided. The results are averages of several observations for each fork. The observations of the first three are satisfactory. The observations of the fourth set, E. O. D., were taken upon windy days and were not satisfactory to the observer. The full line and the dotted line represent the results of experiments on different days. The fifth observer was partially deaf in one ear. In this case the curve shown is not obtained from a large number of observations but indicates in a general way the irregularity of his observations. The curve strengthens rather than weakens the conclusions derived from the other curves. The

existence of a minimum is obvious for the percentage change in the arbitrary measure of angle of localization is very great. In fact in some cases the change is 100 per cent. of the minimum.

Although the experiments are somewhat crude and should be carried out with greater degree of accuracy, the results are unmistakable. The curves show that the frequency 512 to 640 is localized with the greatest accuracy, a confirmation of the theoretical deductions based upon the intensity-sum as a factor. That is, there is a critical wave-length in the neighborhood of 60 cm., frequencies 512 to 640. An inspection of the curves for intensity-differences and intensity-ratios shows that neither of these possible factors furnish an explanation of the experimental results, that indeed they would point toward very different results. The conclusion is that the intensity-sum is an important factor in practical localization where the observer can and does rotate the head in the interval of the sound duration. Indeed, the confirmation is so definite that one is inclined to believe that, in practical localization, the intensity-sum is the most important intensity factor.

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