EXPERIMENTS IN SOUND LOCALIZATION¹

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It is not necessary to give the historical background of the problem since that has already been given in several recent studies.² It should be said, however, that new interest was aroused concerning the investigation of sound localization because of very urgent questions that arose in connection with the war, questions which indeed made both the physicists and the psychologists realize the dearth of material on the subject. For example, practically nothing of scientific value had been done in either of these sciences with the problem of sound localization through mediums other than air. The need for accurate and rapid detection of sapping activities on the part of the enemy and the necessity of localizing with equal precision and speed the presence of enemy submarines made it clear that we should know facts concerning the localization of sound through the solid earth and through water, in addition to more detailed information concerning the localization of aeroplanes in flight. Accordingly, both physical and psychological scientific societies undertook, through specially appointed committees to make further specific investigations into these matters.³

¹ These experiments were undertaken by a group of students doing advanced or graduate work in the Department. The experimenters who were responsible for various sections are: Miss Harriet Anderson, Miss Hilda Kohl, Miss Anna Polkowski, and Mr. A. W. Gross. To these and to the many observers, the compiler of the results wishes here to give suitable recognition.

² One of the best summaries of the literature is given in Klemm, O., *Untersuchungen über die Lokalisation von Schallreizen*, *Arch. f. d. gesam. Psychol.*, 1918, xxxviii, 71-114.

³ Besides coöperation with the physicists, through consultations and the lending of apparatus, the author undertook to contribute his share of the work of the Committee on Audition, appointed by the American Psychological Association, by supervising three or four pieces of research in this field.

I

Without going into the controversy regarding the question of the binaural ratio, we attempted to indicate the influence of relative intensity in the localization of sound under conditions that should guard against certain psychological errors of which experimental research on the part of physicists is not always free. In particular we attempted to duplicate, in principle at least, the work of Myers and Wilson,⁴ two investigators who seem not sufficiently to have considered errors of this sort.⁵

Apparatus: We used two quiet rooms in the psychological laboratory, one of them a large dark room (Fig. I). In the outer room, a large wooden box enclosed a Stern variator (No. 2, 150 vd. to 300 vd. Opposite the lip of the instrument a large eight-inch tin funnel was inserted, with its outer edge bound by rubber and directed towards the variator. Its narrow orifice was extended by means of rubber tubing $\frac{3}{4}$ " in diameter to the operating table in the inner dark room. The Stern variator was set at three different pitches in the course of the experiment, 193 vd., 200 vd., and 217.5 vd. Rubber tubing from the compressed air service piped into the building conducted air through a reducing valve to the intake of the Stern variator. The inside of the box was thoroughly stuffed with cotton waste and the outside of the box was wrapped with deadening material made of seaweed. All openings between the two rooms were tightly sealed, and several observations were made to determine whether any sound could be heard in the inner room when the valves were closed and the Stern variator was operating. The large rubber tubing passed through a carefully packed opening in the wall between the two rooms to two sliding valves. Before coming to these valves the tube bifurcated through a glass Y. The sliding valves were so arranged that the full diameter of the

⁴ Myers, C. S., and Wilson, H. A., The influence of binaural phase differences on the localization of sound, *Brit. J. of Psychol.*, 1908, ii, 363-385.

⁵ The author would like to see some of the experiments on the intracranial localization of sound repeated under rigid conditions. It seems remarkable, for example, that (in our experiments) no localization was reported, as referring to either ear, or to any position "in the head."

FIG. I

tube was maintained but could be reduced by the experimenter. Since the question arose in the preliminary series whether a valve of this sort might not, when partly closed, produce eddies in the current of air, later in the main series we used glass tubes of nine different diameters, .15, .2, .4, .42, .45, .6, .65, .9, and 1.1 cm. These were always used in pairs, one on each side of the Y. From this point on a pair of $\frac{3}{4}$ " tubes was continued for about 10' and ended each in a small 2" tin funnel, the outer edge of which was bound in rubber. The funnel on each side was held in a standard opposite the ear of the observer, and the observer's head was fixed in a head-rest.

Procedure: It must be understood, of course, that none of the observers ever knew, in the course of the experiment, the arrangement of the apparatus or the nature of the problem. The observer was led blindfolded into the dark room and great care was

exercised by the experimenter that, as he sat down and inserted his head in the head-rest, his head should not touch either funnel. The four observers who took part in the experiment never realized that two separate sounds were coming to their ears, and, in fact, when subsequently told of the conditions, they could hardly be persuaded to believe the situation to be as described.

When the observer had been seated he was instructed to visualize a sphere with his head at the center and the zero point directly in front, and to keep clearly in mind the quadrants to the left, right, above, and below. He was further instructed that a sound would be produced in the room and that he was to localize this sound in terms of the imaginary sphere and by such designations in the sphere as would enable the experimenter to record the results. In some cases these symbols were adjusted to the preferences of the observer. He was also required to estimate the distance that the sound was away from his head.

The reports of the Obs. were taken down by the experimenter on a mimeographed blank which designated the number of the trial; date; observer; position left, right, above and below; intensity; distance; and "remarks." There were over 650 trials recorded and results tabulated. In the preliminary series, nine positions of the valve were marked on each side, and a haphazard series was arranged in advance to include the various combinations of these positions. The same plan was followed in the main series, in which the glass tubes were used in place of the valves.

It is clear, then, that since the length of the tube on each side was kept precisely the same, and since the only change introduced was a change in the opening through which the sound waves passed, there could be no modification of the wave save amplitude, a modification calculated to produce a difference of intensity for the two ears. This is especially true of the second part of the investigation in which eddies were avoided.

The experiments were conducted during the academic year of 1917-1918 and during the summer session of 1918, in the Psychological Laboratory at the University of Illinois. The observers were well trained advanced students in the department.

Results: In the preliminary investigations the results do not show marked correlations with the different positions of the valves unless the opening on one side was much greater or much less than on the other. We find, however, that the summation of apertures had a marked effect on the distance of the sound. When both openings were large the sound was reported as much nearer than when they were small. The modes varied respectively from a distance of 20 ft. in the case of one-ear presentations to a distance of one foot in the case of two-ear presentations.⁶ Another way of illustrating this fact lies in percentages obtained for loud sounds, *e.g.*, 60% of the two-ear presentations were reported as "loud" or "very loud," while only 42% of the one-ear presentations were so described.

While our results on the matter of the binaural ratio are preliminary and tentative, a study of the individual tables points to the conclusion that there is a tendency to localize a sound more and more toward the median plane as unity in the binaural ratio of intensity is reached. The data on this point are not as yet sufficiently free from the errors of the ordinary "sound-cage" procedure to permit of precise mathematical formulation. One of the chief difficulties which confront the investigator in this field is the inability of the observer faithfully to reproduce his judgments in an imaginary sphere either by the visualization method or by the pointing method. But expressed in percentages, there are indications in our experiments that the ratio of intensities, as transmitted independently to the two ears, was the controlling factor in the localization. Eighty-six per cent. of the sounds presented to the two ears with unlike intensity were localized on the side of the greater intensity. Sixty per cent. of the sounds produced with equal intensity were localized in the median plane. It must be remembered, of course, that the fewest errors occurred when the difference in intensity was marked and that some sounds with a moderate difference in intensity were localized in the median plane. Although all the observers were tested for acuteness of hearing and fell well within the

⁶ This ratio is somewhat larger than the summational effect reported by Klemm, *op. cit.*, 79, but, of course, not so precisely obtained.

normal, there was still an individual difference in the results of our experiments, due largely, it is assumed, to variations in ability to designate the localization.

Conclusion: On the basis of our results we can not, of course, speak with absolute assurance concerning the rôle of binaural intensity in sound localization. Our experiments, confined to a limited number of observers and subjected to the usual methodological difficulties, convince us, nevertheless, that no factor outside of intensity could be held responsible for the results obtained, and that the results themselves were far above the figures for chance variation. We should like to see the experiments repeated under better conditions, perhaps out-of-doors, and with a larger number of observers, but with a strict adherence to the procedure "without knowledge."

II

Investigations were also under way regarding the difference in the ability of an observer to localize sound due to the position of his body. One does not have to recall here the questions that have arisen in the literature concerning the dependence of sound localization on the semicircular canals and the muscular adjustments due to the inner ear. It was assumed that, if the reflecting surfaces in the room could be kept uniformly constant for each position, any differences in sound localization within a sound-cage would be due to these disturbances.

Apparatus and Procedure: In our normal series we placed the observer in a sitting position within the standard form of Stoelting sound-cage whose telephonic click was modified by introducing a vibrating induction coil. The telephone receiver was connected to the secondary circuit of this coil. Over 400 observations were made including the series in the sitting position. In connection with the other positions, a couch was provided and so braced that the head should be projected beyond one end and that it should then be approximately at the same point as it was when the observer was in the sitting position. An equal number of observations were taken with the observer lying on his right, on his left, on his back, and with face down. The room used

was the largest in the laboratory and, so far as possible, reflecting objects within the room were removed.

Results and Conclusions: In calculating the errors for each position we find no conclusive evidence of any marked differences due to inclination of the body. We eliminated, however, from each series the first five judgments on the ground of inaccuracy due to making judgments in unaccustomed positions. This part of the investigation also might well be repeated under better conditions and with more observers. Care must be exercised, of course, that the couch used does not itself add new reflecting surfaces of any consequence and that it is, at the same time, fairly comfortable for the observer.