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ECHO-DETECTION ABILITY OF THE BLIND: SIZE AND DISTANCE FACTORS[1]

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The ability of 5 blind Ss to detect metal discs placed in front of them by use of echoes was measured. S was instructed and trained to respond to the presence or absence of these targets after uttering any sound of his choice. Response thresholds were obtained for various size targets at distances ranging from 24 to 108 in. As distance increased, threshold target size increased. The mean auditory angle subtended by a target calculated to be at threshold was 4.63° with an SD of .21°. These data provide a basis for comparing performance using a vocal echo signal with performance using signal characteristics as independent variables.

In recent years the works of Griffin (1958), Kellogg (1961), and Rosenzweig, Riley, and Krech (1955), have all demonstrated the ability of nonhuman species to use auditory information, particularly echoes, in navigational and food-seeking activities. It has also been learned through the work of Supa, Cotzin, and Dallenbach (1944), and others, that both blind and normal people can use echoes effectively to avoid obstacles which loom in their path. The names "facial vision," "echo location," and "echo detection" have been applied to this sonic distance-sensing technique. The great differences in the psychobiology of the bat, porpoise, rat, and human echo detectors makes direct comparison of their abilities difficult, to say the least. Few measurements have been made which quantify the limits of echo-detection ability of any species, though some efforts in this direction have been made with humans by Kohler (1964), Myers and Jones (1958), and Kellogg (1962). Evidence which has been presented to date suggests that the nonhuman species are more skillful than humans and that they are biologically better prepared for obtaining information from echoes.

The physics of sound indicates that the higher the frequency of a sound, the better the resolution of the echoes reflected from small targets or obstacles and, hence, the better the acuity for echo-detection tasks. Since bats and porpoises have the ability to emit and perceive sounds well above the frequency response range of the human auditory apparatus, it seems reasonable to expect that human *S*s, unaided by technical assistance, would have considerably less ability than these nonhumans on echo-detection tasks. The current study is designed to secure a measure of echo-detection ability which represents *S*'s skill using only his natural vocal resources. Specifically, response-threshold measurements were made of the ability of blind *S*s to detect different size stimuli at several distances, as an index of "echo acuity."

METHOD

Subjects.—The *S*s were five blind males, ranging in age from 23 to 30 yr. All *S*s had been blind for at least 5 yr. They were selected on the basis of: (*a*) near total blind-

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ness, (*b*) the ability and inclination to travel with relative independence in the course of daily work or recreational activities, (*c*) at least normal intelligence as measured by having made satisfactory progress during their school careers, (*d*) relatively normal audiograms. Three *S*s had no light perception whatever, while the other two could detect very bright light if shone directly into the eye. The audiograms for all but one *S* were within the normal limits of hearing. This *S* (DB) had a "sensorineural loss of mild degree." The *S*s were paid an hourly wage and appeared to be well motivated throughout testing.

Apparatus.—The research was carried out in a laboratory designed to provide a near constant auditory environment. The room was 12 × 24 × 9 ft. The walls and ceiling were covered with acoustical tile and the floor with a wall-to-wall carpet. Isolation from external noise was obtained by use of double doors and walls with intermediate air spaces. The modal noise-level measurement was 42 db. on a General Radio 1551C sound-level meter C scale, 32 db. on the B scale, and 26 db. on the A scale. Within the room, 5 ft. from the wall and parallel to the 12-ft. dimension, an 8-ft. wide partition extended from floor to ceiling. It was also covered with acoustical tile. This partition served as the background for stimuli presented to *S*s. The stimuli were circular, .050-in. thick aluminum discs of varied size. A general view of the laboratory room and apparatus is shown in Fig. 1.

The apparatus for presenting the stimuli extended down through the ceiling from a cupola on the roof. A metal track by which the stimuli could be raised and lowered into position extended 30 in. beneath the ceiling. It was located 4 ft. in front of the partition and 6 ft. from either side wall. Stimulus targets were presented to *S* at approximately ear level. This was accomplished by attaching them, by means of a permanent magnet, to a $\frac{1}{4}$-in. square rod, and lowering the rod along the track to the floor. An apex of this rod was toward *S*. A quiet Slo-syn motor was used to move the stimuli up and down the track. The *S* was seated in a testing chair before the partition and at the appropriate distance from a target. The chair legs were placed in a metal channel, thus assuring the proper orientation to the target. An adjustable headrest on the chair was equipped with a microswitch and buzzer that signaled *S* when his head moved too far forward. In order to control further for auditory and visual cues, *S*s were blindfolded and a white noise source located above *S*'s head was activated between trials.

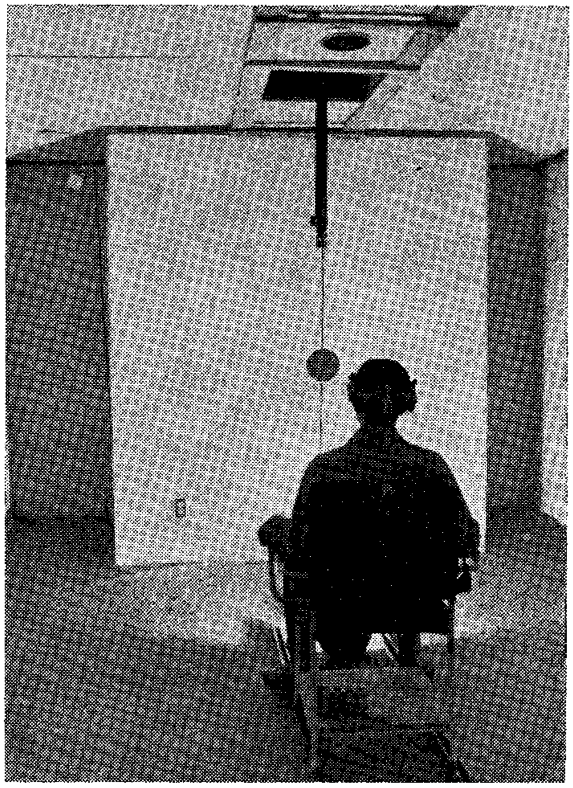

FIG. 1. View of *S* and apparatus with target in position for judgment.

Procedure.—The training of *S*s was divided into two parts: a pretraining procedure and a warm-up period designed to maintain reliable performance.

Pretraining began during the initial visit to the laboratory. After examining the laboratory, *S* was seated in the testing chair and standardized instructions were read. The *S* was told to begin his chosen "noise" after the "ready" signal and then to make his judgment as to presence or absence of the target on future trials.

The *S*'s chair was then adjusted so that there was a distance of 18 in. from his ears to the target. A target, 19.4 in. in diameter, was positioned in front of *S*. He was then required to utter some sound on the signal "ready" and to make a judgment of "yes" or "no" as to presence or absence of a target. This sound was to be any vocalization of *S*'s choice which he felt enhanced his ability to detect the targets. A series of practice trials was run, using an equal number of target and no-target trials in a counterbalanced order. The *S* was given immediate feedback concerning the accuracy of his judgment. When *S* could successfully discriminate between target and no target, a new, smaller target was introduced. This procedure was continued until the smallest target estimated to be detectable with 90–100% accuracy was found. This target was then used as the *largest* in a series of five subsequent stimuli. Each of the four smaller targets was 60% by area of the next larger. A randomized series of 100 presentations of each of the five discs in this series and 100 no-target trials was then judged by *S* without feedback; the results constituted the echo-acuity data at that distance.

A similar, but abbreviated, procedure was followed in locating a range of five targets suitable for measuring echo-detection ability at 24, 30, 36, 42, and 48 in. In addition to these five distances, it was felt desirable to make some measurements of the maximum distance at which targets could readily be discerned. Accordingly, three measurements were made beyond 48 in., extending the distance to a maximum, allowable by the apparatus. The data obtained from the measurements at 24–48 in. suggested that the auditory angle subtended by a target was related to the probability of a "yes" response at any distance from *S*. Using this hypothesis, targets predicted to have high, medium, and low probabilities of detection were made for each of the longer distances: 67, 87, and 108 in.

It was eventually found to be necessary to delete data obtained at the 18-in. distance because some *S*s were detecting the ¼-in. rod being used to suspend the target in front of them. Tests in which a target and rod, no target or rod, and rod alone, were presented demonstrated this problem. Similar tests at the 24-in. distance indicated that the rod no longer influenced judgments.

Each of the *S*s were given 5–10 min. of warm-up time before each experimental session in all phases of the experiment. In this practice period, immediate feedback was given by *E* as *S*'s judgment warranted and, therefore, constituted additional training. The *S* could stop a session at any point if he became fatigued, ill, or confused. The warm-up session also served to stabilize *S*'s decision criterion and held false-positive judgments below 20%. By setting such a criterion, it was hoped to obtain comparable measures for all *S*s.

A short series of 30 trials was run in which no noise or echo signal was uttered by *S*, but presence or absence judgments were required. This series was used to determine whether ambient noise, odor, or heat cues were affecting *S*'s response criterion. The *S*s were unable to detect the targets without their echo signals.

RESULTS AND DISCUSSION

The amount of training necessary to progress from the initial 19.4-in. diameter target to the range of five targets used for the first response-threshold measurements varied among *S*s. Once the asymptote of training had been reached, *S*s maintained a consistent level of performance. The time elapsed from the "ready" signal, through the uttering of *S*'s sound, to his response, was normally under 10 sec. The time between judgment of one trial and the next "ready" signal was 10–15 sec.

The echo-ranging noises used by *S*s were all different. The signal produced by CB was a harsh "F" sound which was pulsed several times and followed by "hello, hello." DB created a tongue click, "tsk, tsk, tsk," followed by an extended "sssixes, sseven, eight." DD made an intense tongue click which was sharp and repetitive, originating from the roof of his mouth. JP uttered a variety of sounds, including tongue clicks, lip smacks, and throat clearing. WG used a "hiss-hiss" which was elongated up to 5 sec., and then repeated. In each case, *S* turned his head spontaneously from side to side, sending the signal back and forth across and beyond the targets in a sort of auditory scanning similar to that reported by Kellogg (1962). Once a pattern of noise was established for use as an echo signal, *S* used it consistently throughout the experiments.

Response thresholds.—Response curves in Fig. 2 show the relationship between target size and percentage of "yes" responses for 100 presentations of each target at a given distance. These results show that echo acuity by blind *S*s is a function of both target size and the distance between *S* and target; i.e., the greater the distance, the larger the target must be in order to be detected.

Between 24 in. and 48 in., inclusive, it will be noted that the target-size range used is virtually the same for all *S*s. Beyond 48 in. the targets were not necessarily proportional to one another and only three data points were obtained at each distance. In any case, there is a consistent overlap of target sizes used with *S*s at all distances. This indicates that the echo acuity of this group is rather homogeneous, with no markedly divergent level of skill shown by any of the *S*s.

By comparing response curves for all *S*s at a given distance, their performances may be ranked. Arranging them in this manner for all distances through 48 in. reveals that *S*s tend to remain in the same relative position within the group. (Coefficient of concordance = .78, $p < .01$.)

Within the range of distances considered (24–48 in.), *S*s clearly ranked themselves as follows: WG, DD, CB, JP, and DB, respectively, with DB requiring the largest target at threshold.

Using a linear interpolation, a target diameter that would theoretically yield a "yes" response 50% of the time was designated as the response threshold. These interpolated thresholds are shown in Table 1, along with the mean false-positive level, for each *S*, for the group at each distance, and the overall mean and standard deviation of the false positives. The false-positive data indicate that the desired uniform response criterion was obtained for all *S*s. Thus, the response-threshold comparisons were not unduly affected by differences in the false-positive level.

Maximum distance.—The maximum distance at which targets could be detected was not found. The laboratory conditions in the experiment

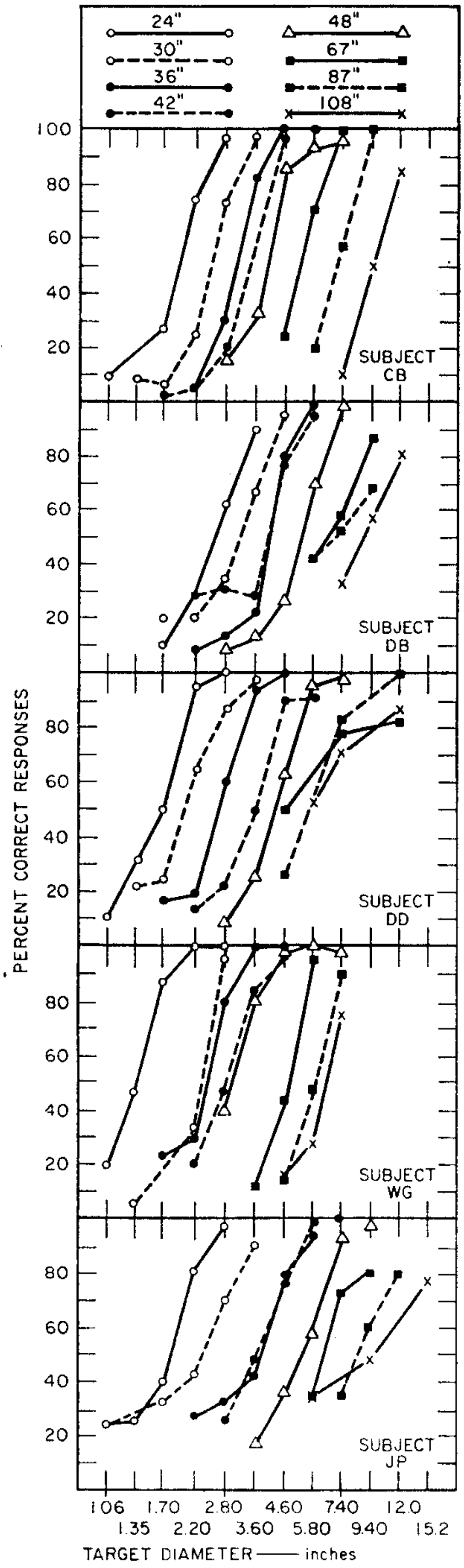

FIG. 2. Percentage of "yes" responses by *S*s to targets of varied diameter at each distance.

TABLE 1

INTERPOLATED THRESHOLD DIAMETERS AND MEAN FALSE-POSITIVE RATES

Distance (In.)	Threshold Diameter (In.)					Mean No. False Positives[a] at Each Distance
	WG	DD	CB	JP	DB	
24	1.4	1.7	2.0	1.8	2.6	10
30	2.4	2.0	2.5	2.4	4.0	9
36	2.5	2.7	3.1	3.8	4.1	6
42	2.9	3.5	3.4	3.7	4.1	6
48	3.0	4.3	4.0	5.4	5.3	4
67	4.7	4.6	5.2	6.5	6.9	10
87	6.0	5.6	6.6	8.6	6.7	9
108	6.5	6.2	9.5	9.8	8.9	8
Mean No. False Positives for each *S*	6	7	4	13	9	

[a] Group mean and *SD* are 7.8 and 2.9, respectively.

prevented moving more than 108 in. back from the targets. As will be noted in the figures and tables presented, no failure in ability to detect the targets occurred. Although fewer data points were used and the proportional relationship of size between the targets was not maintained, the threshold targets are proportionate in size to those at the closer distances. This may be seen in Fig. 3, which combines the data for all *S*s at all distances in group curves. There is less overlap of disc sizes between *S*s beyond 48 in.; hence, mean diameters at the longer distances are based on fewer judgments.

As measurements were obtained, it became apparent that the auditory angles subtended by the threshold targets for all *S*s showed relatively little variability. This observation

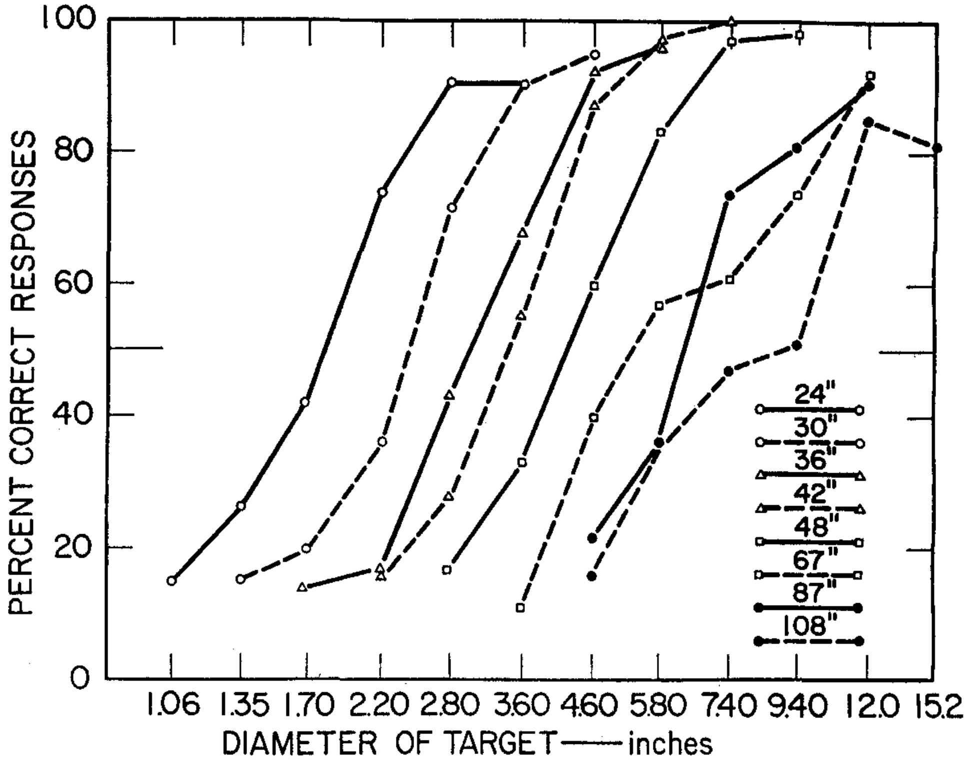

FIG. 3. Group curve at each distance based on mean percentage of "yes" responses for each size target.

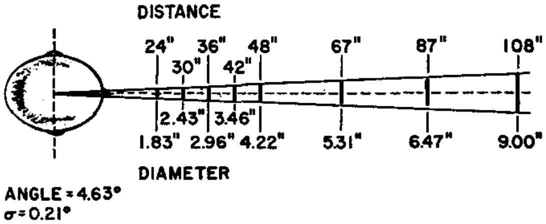

FIG. 4. Group threshold targets at all distances fitted to the mean auditory angle.

lead to the hypothesis that a mean auditory angle for the group might provide meaningful prediction of threshold targets at any distance. This hypothesis was not checked empirically, but post-hoc analysis of the data provide some confirmation.

An interpolated-group threshold target was found for each distance and its auditory angle was calculated. The mean auditory angle for all distances and *S*s is 4.63° with an *SD* of .21°. This angle has been drawn to scale and the group threshold targets were fitted to it in Fig. 4. It appears from these results that, for this group, the auditory angle subtended by the target in front of *S* is a good predictor of *S*'s response threshold at any distance through 108 in. Kellogg (1962) does not specifically state this relationship of auditory angle to size and distance perception in his study, but does present data consistent with our formulation.

Since the auditory angle is regarded as an arc on the horizontal plane at the height of the ears, then it seems likely that width may have been an important factor in detection of the targets. The above hypothesis is consistent with the lateral head movements used by all *S*s to "find the edges of the target." Certainly there is some interaction of width, height, and total area required for sufficient echo information to be obtained.

To our knowledge, no comparable studies of threshold echo discrimination have been reported in the literature for nonhuman species. A bat, however, has been observed (Griffin, 1959) to have a gnat as small as .0002 gm. in its mouth. The resolving power suggested by this observation serves to emphasize the contrast between the natural ability of human and nonhuman skills for this type of task. The results reported here, however, clearly show that human *S*s can gain a measurable amount of information from reflected sound sources. It must be pointed out that generalizations concerning the degree of echo acuity possessed by any experimental group must be qualified in terms of the conditions under which the measurements were conducted. Many variables may affect both the physical sound waves which carry the echo information and the organism's ability to perceive them. It seems at this point, therefore, of minor importance to look at our *S*s' response thresholds as an end in themselves, or to compare our results with those of investigators who have looked at various aspects of echo detection under widely varied circumstances. The present results, nevertheless, serve as a base line or reference point from which to measure the relative importance of each parameter of echo detection to the skill as a whole. Thus, now that it is known what these *S*s can do with their own signals, we are free to investigate the effect of modifying target dimensions, signal characteristics, etc., on their respective response thresholds.

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