THE PSYCHOLOGICAL REVIEW.

CONTRIBUTIONS FROM THE PSYCHOLOGICAL
LABORATORY OF THE UNIVERSITY
OF CHICAGO.

FURTHER OBSERVATIONS ON THE MONAURAL LOCALIZATION
OF SOUND.

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The present paper is a sequel to one published in the May number of the REVIEW for the current year. In the latter we reported an extended series of experiments upon a man totally deaf in one ear, showing that he possessed a somewhat surprising ability to locate certain kinds of sounds, *i. e.*, complex sounds of medium tonal range, although entirely unable to locate pure tones. Without attempting to restate in detail the conclusions we felt warranted in drawing from our observations, it may suffice to say that we connected the subject's localizing capacity with the modifications of timbre which complex sounds undergo when they come to the ear from different directions. These modifications are due to the damping or reinforcing of their constituent partials by the pinna, the external meatus, the bones of the head, etc. The present report is offered as a supplement confirming the main thesis of the previous paper by investigations upon other subjects. It brings out with special clearness the variations in monaural localization which are connected with the duration of deafness. The cases afford from this point of view a somewhat striking explanation of the contradictory reports emanating from aurists with reference to the effects of unilateral deafness upon sound localization.

Like case *A* of the earlier paper, these new cases are all

instances of internal ear deafness. We shall designate them as *C*, *D*, *E* and *F*.¹ They display in a striking manner the differences between the localizing capacity of persons who have recently lost their hearing in one ear and those who have been deaf long enough to accommodate themselves to the abnormal conditions. It does not follow from this that all persons deaf in one ear necessarily develop their latent capacities of monaural localization, and it seems probable that this is less likely to occur when deafness has come on in mature life than when it exists from early childhood. All our subjects, however, have shown ability to improve somewhat rapidly under the training afforded by the experimentation, although they have, of course, been kept in entire ignorance of the correctness or incorrectness of their judgments during the course of the tests.² *C* is a man of thirty, who has been deaf from early childhood. The precise time and conditions of the onset of deafness cannot be verified. The subject is under the impression that the trouble followed a

¹We regret that Dr. Politzer's paper on 'Paraculis Loci' (*Archiv für Ohrenheilkunde*, Bd. XI., p. 231), which is the only account of extended observations on monaural localization to which we have had access, does not enter into more of detail concerning the exact methods he employed and the clinical features of the cases. These were in the main apparently instances of middle ear deafness with various degrees of defect in the hearing of one or both ears. It seems improbable that in such cases habituation to the abnormal condition, in contrast to the usual binaural capacities, should have become thoroughly established, as our tests show it may after a considerable period of unilateral total deafness. Dr. Politzer appears to have used as sounds principally the ticking of a watch and whispering. Our tests show that both of these sounds can be localized with considerable accuracy monaurally, the whispering better than the ticking. But they are less easily located than many other sounds, owing to the peculiarities of their physical composition. These peculiarities of various kinds of acoustic stimuli are more fully discussed in our first paper. This statement will, however, explain our inability to compare our results more explicitly with Dr. Politzer's.

²The apparatus employed is described in the first paper. In the experiments recorded here the subject had the head placed at the center of the spherical cage and not the intact ear. Our observations upon *A* seemed to indicate that localization occurred with reference to the whole body and not with reference primarily to the ear. The variations due to alteration of the position in this particular are small and we have not felt warranted in taking the additional time necessary to test the matter conclusively, although the gentlemen who have served as subjects for us have been most generous in their sacrifice of time and convenience.

febrile disease. In later childhood there were transient attacks of severe vertigo. *D* is a man of twenty-four, who lost the use of one ear when ten years old, in connection with an acute attack of osteo-myelitis. *E* is twenty years old. He lost the hearing of one ear six years ago as a result of hemorrhage in the labyrinth following a severe fall. *F* is sixty years old. He was operated upon a year ago for acute suppuration of the mastoid accompanied with labyrinthine symptoms. At the time of the experiments the wound was still open. Taken in connection with *A*'s case, already reported, this gives us observations upon two persons deaf at least twenty-six years, one ten years, one six years, and one deaf for a single year.

When compared with one another the results show increased capacity of localization with increasing periods of deafness. The new cases show precisely the same relative accuracy with the different forms of auditory stimuli employed as did *A*. The more nearly a pure tone is approximated as a stimulus, the more inaccurate the localization. An improvement in the method of giving tuning-fork tones, which was also employed with *A*, resulted in securing a practically pure tone without any of the noise elements incident to setting the fork in vibration. Under these conditions all the subjects failed uniformly to localize. Occasionally such tones would seem opposite the intact ear, but quite as often no location could be assigned, and it seems quite safe to say that in monaural hearing really pure tones are unlocalizable.¹ Very high-pitched tones like those of the Galton whistle are subject to rather large errors of localiza-

¹ The earlier tests on *A*, employing tuning-forks, had been made with as perfect suppression of the composite sounds accompanying the starting of the vibrations as the means at our disposal seemed to permit. We were aware, however, that the result was not wholly satisfactory, and that we did not always secure the purity of tone desiderated. The results of the tests confirmed this in a demonstrable inability to localize most of the tones, combined with an anomalous certainty and accuracy in the localization of occasional sounds of this type. The method finally employed involves having the subject stop the intact ear with the finger until after the fork has been struck and all the overtones thus produced have died away. He is then touched with a long rod by the operator in such a manner as to convey no indication of the direction of the operator or the fork. Upon this signal he opens the ear and attempts to localize the sound. Under these conditions the localization appears impossible, regardless of the intensity of the tone.

TABLE I.

Showing comparative accuracy in auditory localization of a normal person and a practiced monaural subject. Entry VI. introduces for additional comparison an unpracticed monaural subject. Of each pair of lines the upper one represents the percentage of correct judgments, the lower one showing the average error in degrees. The tests upon which the table is based involve the localization of sixteen points (eight on the equatorial circle, four above and four below), as explained in the May number of this REVIEW (Vol. VIII., p. 232). 1,449 tests are incorporated in the table, of which approximately one-fourth were made upon normal individuals.

¹ Confusions between front and back (180°), give the average error in this case a somewhat misleading magnitude. Apart from this confusion, the errors are generally small.

² In this case the number showing the average error (32°), is approximate and not exact. A wayward record sheet prevents accurate verification. The possible error is small.

tion for reasons canvassed in our first paper. Complex noises like the rapid clickings of the telephone plate are localized with considerable accuracy. Similarly, complex tones near the middle of the musical scale are well localized. An ordinary reed pitch-pipe (middle G) was employed for the purpose.¹ In the case of this complex tone it proved, as in binaural hearing, considerably more difficult to effect a confident localization when the tone was continuous than when it was interrupted. Not to mention other possible reasons for this, it is certain that the identification of the tonal modifications, which are in monaural

TABLE II.

Showing by the percentage of correct judgments the variation in the capacity of monaural localization of the telephone click (eight points on the equatorial circle), as connected with the duration of deafness.

hearing the indices of direction, is much assisted by rather rapid repetitions of the tone.

It does not seem essential to present a complete tabular statement, such as was given in the report of *A*'s case, for each form of test with the four new subjects. The differences are purely matters of degree, which can be exhibited satisfactorily in a briefer way. We have come upon no new principle, nor have

¹ This series, in the case of *A*, was not contained in the original report, but his results with this stimulus fall in perfectly with our general hypothesis.

we failed in any case to verify the hypothesis we have offered. We may first represent graphically the differences in the capacity of localization between a well-trained monaural subject like *A* and a normal person, when sounds of varying complexity are used as stimuli. Table I. exhibits these relations.

Table II. presents the variations among persons deaf in one ear, as connected with the duration of their deafness and the period at which they became deaf. The percentage of correct judgments is used as the basis of the table, the same sound, a telephone click, being used throughout the tests.

TABLE III.

Showing in degrees the average amount of error made by the several subjects in attempting to localize eight points upon the equatorial circle. Telephone click used as stimulus.

Table III. shows the same general relations, but the average error in degrees is made the basis of the comparison, instead of the percentage of correct localizations. Table III. is probably more truly indicative of the differences between monaural and binaural hearing, and of the variations among monaural individuals themselves, than Table II.

In Table IV. we have shown graphically, on the basis of results from all the monaural cases we have examined, the variation in accuracy of localization, as compared with the noticeable

complexity in the sound. The fact should be emphasized, that all the subjects agree in their judgment of the relative ease of localization of the general kinds of stimuli, that, furthermore, their subjective impressions are verified by their objective accuracy, and that the diagram is, therefore, representative of an average, which does no violence to the relations in any individual case, as so often occurs in averages based on statistical evidence. The tuning-fork tests are included for tabular completeness only. It is perfectly certain, we think, that pure tones are unlocalizable in monaural hearing. Mere chance might be expected to produce a larger percentage of correct judgments than is here presented. But neither the percentage test nor the

TABLE IV.

Showing by percentage of correct judgments for various forms of auditory stimuli the connection between accuracy of localization and discriminable complexity of sounds (eight points on equatorial circle).

average error test is to be weighed beside the overwhelming deliverance of consciousness itself, which in the case of pure tones is absolutely different from that in the case of complex sounds.

So many of the aurists' tests are made with a watch and by means of whispering (this is true in Politzer's tests already referred to), that in view of the frequently asserted inability of monaural subjects to localize those sounds, it seems desirable to refer briefly to our own tests, which show clearly enough that such sounds, although more difficult to localize than some others, are still capable of decidedly accurate localization. The

occasional inability to localize is, therefore, probably to be connected with conditions of aural irritation, or with the lack of adaptation to the new monaural conditions.

Our tests were made in a manner already suggested in the description of the procedure in the experiments with tuning-forks. The operator, having removed his shoes, took his position at any desired distance from the subject (as a matter of fact we used various distances) and in any desired direction from him. The subject during this period kept the intact ear tightly closed. On being touched with the signal rod, he opened the ear and attempted to localize the sound. As the operator moved noiselessly, it was also possible to make tests without the stoppage of the ear. No suggestion was obtained in any case of the direction from which the sound might be expected to come, and no information was given during the series regarding the success or failure of the localization. We may quote the results of a single series of tests with each kind of sound. We quote the first tests of each kind, which represent, therefore, a minimum of familiarity with the sound and a maximum of difficulty in localization. Of twenty-two tests made by gently whispering a monosyllable like 'K' at eight different points on the equatorial circle (average distance four feet), only four mistakes occurred. They involved in no case an error of more than 45° and all four of the confusions were between points immediately opposite the deaf ear and points slightly back of that. If the confusion between front and back, which is so frequent in binaural hearing, be taken into account, this result is quite as accurate as most normal individuals would attain on a first trial. It certainly is difficult to reconcile it with any radical inability to localize.

Similarly, of the first series of tests with a watch (distance two feet) ten out of sixteen positions were correctly judged, the same points being used as in the previous test. No error was larger than 45° , and an error of this amount is frequently met with in first tests upon normal individuals, as our records show. Decidedly the watch must be used sparingly, if accurate localization is desired with either binaural or monaural persons.

In series XIII. of our earlier paper we attempted under the

limitations of indoor work to decide whether the changes in the character of complex sounds, furnishing the basis of determining their direction, were functions of changes of distance also. The indoor tests resulted negatively, the subject showing highly accurate capacity to distinguish changes of distance from those of direction, thereby demonstrating that, within the limits of variation possible under the laboratory conditions, the two series of changes need not lead to serious confusions. It seems judicious to report at this time a more drastic test made out of doors. We may anticipate the result at once, however, in saying that the test failed to show any great difficulty in distinguishing distance changes from changes of direction.

The tests were made at night, with the greatest attainable quiet, in a large open field some eight or ten acres in area. Precautions similar to those adopted in the whispering test were introduced to prevent any suggestion of the direction from which the sound might be expected. We used the same eight directions employed all through our tests, varying in entirely irregular order the distances from five to twenty-five and fifty yards. The sounds might thus come from points on any one of three concentric circles, and the subject was required to judge both the distance and the direction. As stimuli we employed the pitch-pipe previously used, and an automatic counter, resembling a pedometer in its mechanism, and producing when operated rapidly a clear, metallic, clicking sound. Indoor tests had shown that both sounds could be localized very accurately. Seventy-two tests were made, in which the direction was correctly judged 52 times, or 72 %. The average error was 14.3° , and only two errors were made in excess of 45° . These both involved the point immediately opposite the deaf ear. Of the 20 erroneous judgments, 4 also involved errors of distance. In addition to this there occurred 5 errors of distance without errors of direction. All the errors of distance were caused by confusions of sounds 25 yards distant with those 50 yards distant. When it is remembered that at the greater distances the sounds were only with difficulty audible on the side of the deaf ear, this confusion is not remarkable. On the whole, therefore, the test seems to confirm the indoor experiments in its indication that with com-

plex sounds there are relatively few confusions of distance and direction, the modifications which the sounds undergo by changes of the two kinds being differentiable in the main by the single ear. Sounds near the threshold of intensity are, as is well known, very difficult to localize in normal hearing, as well as in monaural hearing. We should expect to meet with a much larger percentage of confusions, therefore, if we employed distances so great that the sounds could barely be heard in any direction. A similar result would accrue from intrinsically feeble sounds near at hand. This is true with the watch tick, for example.

The experiments suggest very pointedly the possibility and desirability of a little training for persons who lose their hearing in one ear. If the disaster occurs in infancy or early childhood, it seems probable from our observations that experience itself serves to build up the new localizing processes. But when the injury occurs later on in life, it appears problematic how far the adaptation is carried. In any case it is well recognized that many patients suffer considerable distress through their lack of confidence in their capacity to localize sounds, and it seems probable that this distress can be largely removed by a little formal drill, by means of which the patient may have opportunity to notice carefully the changes in sounds arising from changes in their position. The most defective case we have examined (*F*) showed an increase after one hour's practice from 12.5% of correct localizations to 25%, and a decrease of his average error in degrees from 70° to 53° . This improvement occurred, too, without the subject's knowing whether his judgments were correct or incorrect. The result is attributable, therefore, merely to systematic direction of attention to the peculiarities of sounds coming from different directions. If to this were added the knowledge from visual sources of the position of the stimulus, there is every reason to anticipate a very great and rapid improvement with considerable, if not complete, relief from the distress already mentioned. The gaining of self-confidence in the matter is a large part of the victory. The discipline suggested is distinctly comparable with the ocular gymnastics prescribed to persons suffering from defects of the oculomotor mechanism, and is herewith respectfully submitted to the attention of aurists who may not employ such methods.