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Sound localization

Part II: A clinical procedure

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THE investigation to be described employed a test of localization in the horizontal plane based upon the procedure described by Nordlund (Nordlund, 1964).

A total of 114 normal hearing subjects without symptoms of otological disease and 50 subjects with various otological or neurological disorders were tested. Criteria obtained from the normal hearing subjects were utilized to assess the responses of the subjects with pathology.

The Apparatus and Test Procedure

The localization tests were carried out in two anechoic rooms used consecutively over the test period. In each room the apparatus was similarly arranged (Fig. 1). The arrangement differed from that described by Nordlund in the range of the graduated scale and the siting of the chair and loudspeakers. The tester sat in an adjacent control room.

The stimuli employed were a 500 Hz pure tone and a narrow band noise centred at 500 Hz. The signals were of sufficient intensity to enable all subjects, except those with a severe unilateral hearing loss, to listen binaurally.

Angles at which the stimuli were presented were selected by means of a random number generator and extended over the range 64° to 117°. There were 20 presentations of the pure tone and 10 of the noise. The duration of the signal was for a period of 5 seconds.

Estimated positions of the sound source were read aloud by the subject and were given to the nearest degree.

Body movement was discouraged during the localization procedure but the head was free to move.

Subjects were not informed about the accuracy of their estimate nor given any incentive.

Analysis of the Results

Tests were carried out in two anechoic rooms and so the results of two groups of normal hearing subjects were utilized separately to obtain criteria for the assessment of subjects outside the group tested in the same acoustic conditions.

The mean error and standard deviation of the errors were calculated for each subject for both the pure tone and noise stimuli. This was in

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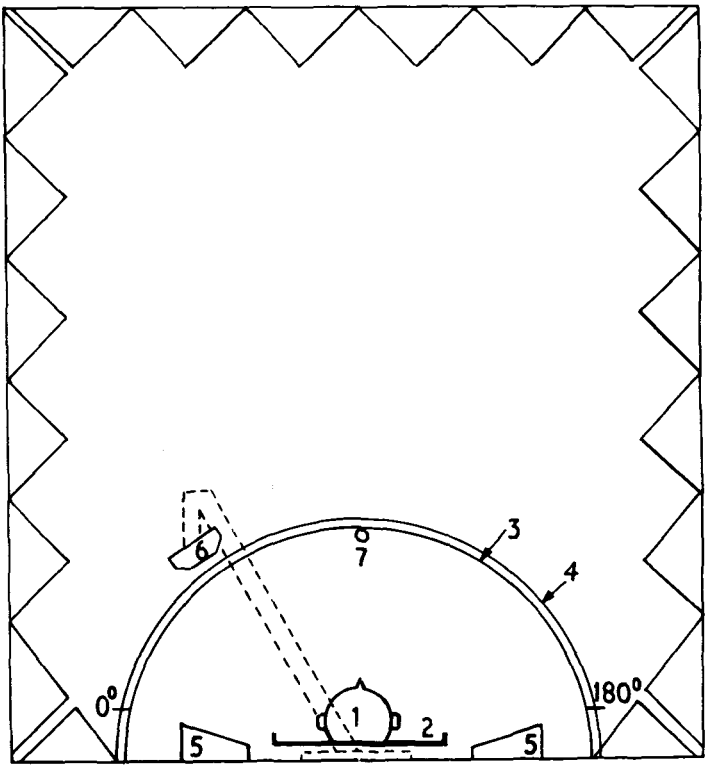


FIG. 1

Diagrammatic representation of the arrangement within the anechoic room.

1 Subject
2 Chair
3 Graduated scale
4 Curtain
5 Masking loudspeakers
6 Artificial voice
7 Microphone communicating with control room

accordance with Nordlund's procedure. The 99 per cent limits of the mean errors and the 99 per cent limit of the standard deviation of the errors were determined for each stimulus in the normal hearing groups. An abnormal response was considered to be any response outside these limits.

The effect of age and sex upon the results obtained from the normal hearing subjects was examined in each group separately.

The normal hearing subjects

Those included in this category had normal hearing within the frequency range 250–4,000 Hz. Tympanograms showed normal mobility of the tympanic membrane with middle-ear pressures within the range 0– —150 mm. H_2O.

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Group A

This group was composed of 63 subjects, 31 male and 32 female. They were represented within the age range 20 to 69 years. 't' tests were carried out on each of the four measures obtained for each subject to determine the effect of age upon the test results. For this purpose, the division according to age was from 20 to 29 years, and from 30 to 69 years (Table I).

TABLE I

EFFECT OF AGE AND SEX UPON THE DISTRIBUTIONS OF PURE TONE AND NOISE ERRORS

Variable	Value of 't' (significance level in brackets)			
	Pure tone		Noise	
	Mean errors	Standard deviations of the errors	Mean errors	Standard deviations of the errors
Sex	2·33 (0·02)	1·25 (0·22)	0·30 (0·77)	0·56 (0·58)
Age	1·01 (0·32)	2·64 (0·01)	0·09 (0·93)	3·15 (<0·01)

Group B

There were 51 subjects in this group, 25 male and 26 female. Their ages ranged from 18 to 54 years. The results of the four measures obtained for each subject were tested for normality and not found to depart significantly from it (Table II). The critical level of significance was 0·01.

TABLE II

CHI-SQUARE TEST APPLIED TO THE DISTRIBUTIONS OF PURE TONE AND NOISE ERRORS

Stimulus	Distribution	χ^2	d.f.	p
Pure tone	Mean errors	5·54	5	N.S.
	Standard deviations of the errors	7·62	3	N.S.
Noise	Mean errors	3·46	7	N.S.
	Standard deviations of the errors	6·81	3	N.S.

The results of the group were subjected to an analysis of variance to determine the effect of age and sex (Table III). The division according to age was from 18 to 32 years, and from 33 to 54 years, enabling the groups to contain approximately equal numbers.

Sex was not found to influence any of the results.

The age of the subjects was found to have a statistically significant effect upon the standard deviations of the errors under both the pure tone and noise conditions, the older age group tending to have on the average a greater spread of errors. Examination of results for groups A and B suggested that the spread of errors in the older age group might vary more from individual to individual than in the younger age group.

The finding in groups A and B that age had a statistically significant

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TABLE III

EFFECT OF AGE AND SEX UPON THE DISTRIBUTION OF PURE TONE AND NOISE ERRORS

Source of variation	Value of F (significance level in brackets)			
	Pure tone		Noise	
	Mean errors	Standard deviations of the errors	Mean errors	Standard deviations of the errors
Sex	0·01 (0·94)	0·07 (0·79)	0·78 (0·38)	0·04 (0·84)
Age	<0·01 (0·97)	7·71 (0·01)	0·33 (0·57)	0·88 (0·35)
Interaction	0·47 (0·50)	0·60 (0·44)	0·44 (0·51)	0·18 (0·67)

effect upon the standard deviations of errors may be a feature of the small numbers within the groups. A further investigation with greater numbers would be necessary to determine clearly the effects of age. Pending such an investigation, one set of criteria was employed for the assessment of subjects outside the normal hearing groups tested in the same acoustic conditions irrespective of age or sex.

Subjects with otological or neurological disorders

Fifty subjects were included in this group. The majority had not been selected but had been referred for audiological assessment during the test period. A few with a severe unilateral sensori-neural hearing loss had been assessed previously but were included in order to provide adequate representation within this category.

The subjects were divided into the same main groupings employed by Nordlund (Nordlund, 1964). These were: severe unilateral sensori-neural hearing loss (12); middle-ear conditions (13); cochlear lesions (8); brain lesions (8) and cerebello-pontine angle lesions (9). There was no group corresponding to the category described by Nordlund as having vestibular dysfunction associated with normal hearing.

Those having a severe unilateral hearing loss all had normal hearing in the 'good' ear. The 'poor' ear either had a complete sensori-neural hearing loss, or some hearing was present only at low frequencies. In no instance was the air conduction threshold in the 'poor' ear better than 80 db HL at 500 Hz. The suspected aetiology of the hearing loss in this group included Menière's disease, virus infections and trauma.

The group with middle-ear conditions included three subjects with otosclerosis and ten with evidence of secretory otitis media. The otosclerosis was bilateral and there had been no surgical intervention. Two of those with secretory otitis media had normal hearing. The remainder had a slight low frequency hearing loss not worse than 40 db HL. The loss was bilateral in all but four instances.

Subjects having cochlear lesions included three where the loss was unilateral. This loss was of milder degree than was described in the group

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with a severe unilateral sensori-neural hearing loss, but was of similar aetiology. All had been investigated to exclude retrocochlear pathology.

Eight subjects had been diagnosed as having brain lesions. Five had demyelinating conditions and in all five there was evidence of brain-stem demyelination. These results were examined separately from the three remaining subjects, one of whom had an oligodendroglioma, one a sarcoid cyst and the third, cerebello-ectopia.

The final group investigated was composed of nine subjects having cerebello-pontine angle lesions which had been surgically and pathologically confirmed. Six were found to have an acoustic neuroma and three a sub-arachnoid cyst. Two of those having an acoustic neuroma had normal audiograms and three others had normal hearing at 500 Hz.

Results

The group having a severe unilateral hearing loss had difficulty in locating sounds. All had abnormal standard deviations and the majority an abnormal mean error.

Each of the three subjects with otosclerosis had at least one standard deviation outside the normal limits. Four of the group with secretory otitis media had abnormal standard deviations and one of the remaining six had an abnormal mean error.

Six of the eight subjects in the cochlear group were found to have normal test results.

The majority of those included in the category of brain lesions had no difficulty in locating sounds. Only one subject within this group had an abnormal standard deviation. There were no mean errors outside the normal limits.

The six subjects with an acoustic neuroma had impaired ability to localize sound. Five had one or more standard deviations outside normal limits and one had an abnormal mean error for the noise stimulus. Two of the three subjects with a sub-arachnoid cyst localized the test stimuli without difficulty. The third had an abnormal mean error for the noise stimulus.

The results of the groups are summarized in Table IV.

The results of the 25 subjects with cochlear and retrocochlear lesions were combined and examined to determine whether the test gave an accurate indication of the presence of a cerebello-pontine angle lesion. The group with severe unilateral hearing losses were excluded as these subjects had mainly abnormal results and the presence of such a degree of hearing impairment would limit the application of the test. Table V indicates the results of this examination.

In the group studied the test would appear to have given an accurate result in 80 per cent of the subjects tested. This figure becomes 84 per cent if the true positive results are specified as being indicative of an acoustic neuroma.

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TABLE IV

SUMMARY OF RESULTS OBTAINED FOR EACH PATHOLOGICAL GROUP

Group	Number of subjects	Pure tones		Noise		Number in each group with an abnormal mean and/or standard deviations
		Number with abnormal mean errors	Number with abnormal standard deviations	Number with abnormal mean errors	Number with abnormal standard deviations	
Unilateral hearing loss	12	10	11	10	12	12
Otosclerosis	3	0	2	0	2	3
Secretory otitis media	10	2	2	1	4	5
Cochlear lesions	8	1	0	2	1	2
Demyelinating conditions	5	0	1	0	0	1
Other brain lesions	3	0	0	0	0	0
Acoustic neuromas	6	2	5	3	3	6
Sub-arachnoid cysts	3	0	0	1	0	1

TABLE V

Number of true positives	Number of false positives
7	3
Number of true negatives	Number of false negatives
13	2

Discussion

It has been shown previously that there is an association between severe unilateral hearing loss and impaired ability to locate sounds (Jongkees and van der Veer, 1957; Nordlund, 1964). The loss of binaural cues of time and phase would be expected to reduce the information available for accurate determination of locus of low frequency stimuli.

The same workers have demonstrated that middle-ear conditions affect the ability to locate a sound source. Nordlund's work suggests that the ability to discriminate interaural difference in intensity as well as time and phase are affected by pathology in this area.

Certain brain lesions were not found to affect significantly the capacity to make an accurate determination of the position of a sound source. It has been suggested that binaural analysis of the cues for sound localization probably occurs in the superior olivary nuclei (Casseday and Neff, 1975; Harrison, 1974). Above this level the cues for localization are bilaterally represented and it would not be anticipated that unilateral lesions in this area would result in a significant impairment in localization ability. The absence of a marked depreciation in localization capacity in animals with unilateral lesions at these higher levels has been demonstrated (Casseday and Neff, 1975; Neff and Casseday, 1977).

The discovery that subjects with cochlear lesions and retrocochlear pathology other than lesions of the auditory nerve and pons, had mainly normal ability to locate sounds, led Nordlund to suggest that directional audiometry may be useful in indicating a lesion in the auditory nerve and pons region.

The results of this present investigation have been in general agreement with those of Nordlund. Subjects with lesions of the cerebello-pontine angle, particularly those with an acoustic neuroma, had mainly abnormal mean errors and standard deviations in contrast to the groups with cochlear lesions and certain brain lesions. The standard deviation appeared to be the more reliable indicator as Nordlund suggested. It is of interest that impaired ability to localize sound was found in some subjects with cerebello-pontine angle lesions in association with normal audiograms as previously described by others (Nordlund, 1964; Lidén and Korsan-Bengsten, 1973).

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Assessment of the test in terms of its reliability as an indicator of a cerebello-pontine angle lesion suggested that it was accurate in 80 per cent of the subjects tested. The numbers in the pathological groups were small and accordingly such a conclusion would need to be interpreted with caution. At the present time also it is not possible to verify the false positive and true negative findings. It can only be stated that other tests in the test battery employed on these subjects failed to indicate a retrocochlear lesion.

Summary

Difficulty in localizing sound has been shown to be associated with severe unilateral hearing impairment, middle-ear conditions and lesions of the cerebello-pontine angle. This was in contrast to the performance of subjects with cochlear lesions and certain brain conditions who had mainly normal ability to localize sound.

The investigation appeared to indicate that a sound localization test in the horizontal plane using low frequency stimuli may be a useful addition to the test battery employed in the differential diagnosis of cochlear and retrocochlear lesions involving the cerebello-pontine angle.

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REFERENCES

CASSEDAY, J. H., and NEFF, W. D. (1975) Auditory localization: Role of auditory pathways in brain-stem of the cat. *Journal of Neurophysiology,* **38,** 842–858.

HARRISON, J. M. (1974) The auditory system of the medulla and localization. *Federation proceedings,* **33,** 1901–1903.

JONGKEES, L. B. W., and VAN DER VEER, R. A. (1957) Directional hearing capacity in hearing disorders. *Acta Otolaryngologica,* **48,** 465–474.

LIDÉN, G., and KORSAN-BENGSTEN, M. (1973) Audiometric manifestations of retrocochlear lesions. *Scandinavian Audiology,* **2,** 29–40.

NEFF, W. D., and CASSEDAY, J. H. (1977) Effects of unilateral ablation of auditory cortex on monaural cat's ability to localize sound. *Journal of Neurophysiology,* **40,** 44–52.

NORDLUND, B. (1964) Directional audiometry. *Acta Otolaryngologica,* **57,** 1 18.

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