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The scope and application of current audiometric tests

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AUDIOLOGY covers many different activities from the cradle to the grave. Generally, hearing tests can be discussed from prophylactic, diagnostic and therapeutic points of view. In this paper I am going to concentrate on the following three topics:

Identification of young deaf children.

Preoperative hearing tests in the diagnosis of middle-ear lesions, and auditory test profiles in lesions of the cochlea, the VIIIth nerve and the central auditory pathways.

Identification of young deaf children

The early identification and management of the auditorially handicapped child has been shown to be of paramount importance for the general development of the child, as well as the development of his speech and language. Thus exact knowledge of the auditory function is necessary for planning a training programme for children with communicative disorders. This points to the problem of identification. The majority of babies are now born in maternity hospitals. Many different audiological centres have recommended that all newly-born children should undergo some form of hearing test. As a rule, this means eliciting the eye-blink reflex or using some form of arousal audiometry. The frequency of deafness occurs in about 7 out of 10,000 live births. It is questionable if these screening methods of newborns are the most suitable methods or whether some other method is better. One factor, which to a certain extent is opposed to mass examination, is that one gets a large number of false negatives. The hearing reflex is only noted in 5 per cent of the newborns

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in the third or fourth week of life, and the absence thereof can create unnecessary worry to the parents. Those advocating mass examination point out, however, that even false negative results can be valuable as they may denote neurological disturbances. However, it is generally agreed if one postpones the examination to 4 or 6 months of age, more reliable tests can be used. For this reason, in our hospital we now concentrate the auditory testing to the so-called high-risk infants from the age 4–6 months old.

The majority of children with recessive hereditary deafness may be missed if one only examines the high-risk children. It is therefore necessary to co-operate closely with the well baby clinics, and the children's hospital, who are instructed at the slightest suspicion of communicative disorders to send the child for hearing tests. Generally, when the child is 4 to 6 months old, we call the mother and the child for examination. At that time a hearing history is taken, with emphasis on the mother's description of the child's behaviour since birth. The examination of the child's hearing starts by observing his reaction on different low- and high-pitched sounds (Ewing and Ewing, 1947). The eye-blink reflex is tested and if the child happens to fall asleep, arousal audiometry according to Wedenberg (1956), is used. Finally a more exact recording of the child's tone threshold is made with visual reinforcement audiometry (Lidén and Kankkunen, 1969a). This method is a modification of Suzuki and Ogiba's (1960) conditioned orientation reflex audiometry. Instead of using the sound localization as a response criterion, we use a non-directional technique. The tone is first presented in the loudspeaker and then, as reinforcement, the child sees the picture. The child is never instructed to respond in a particular way and neither is he expected to give a specific type of response. Consequently, a broad variety of responses can be observed. We have noticed four main types of response: reflexive behaviour, investigatory, orientation and spontaneous responses. By decreasing the sound intensity, we are able with this technique to get a reliable audiogram from about 6 months of age.

Visual reinforcement audiometry can also be used in hearing aid evaluation on young hard of hearing children (Lidén and Kankkunen, 1969b). The tone thresholds without and with a hearing aid are determined. These thresholds are helpful in obtaining optimum setting of the hearing aid. The aided thresholds give a good idea of how much amplification the child is using.

In the age period of 3 to 6 years, the children are tested by play audiometry (Barr, 1955) or peepshow (Dix and Hallpike, 1947).

Pre-operative hearing tests in the diagnosis of middle-ear lesions

The interest of otologists and audiologists during the last 20 years has focused on the problem of diagnosing and treating middle-ear lesions.

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The scope and application of current audiometric tests

Unfortunately, there is no single test that predicts when the conductive loss is due to stapes fixation or disruption of the ossicular chain. However, the actual type of lesion can be determined with a very high degree of confidence by combining the history, the otological findings, and conventional pure-tone and speech test results with special tests discussed in this section of the paper. These special tests include the sound probe test, the Géllé test, the prosthesis test, tympanometry, and stapedial and tensor muscle reflex tests.

The problem can be illustrated by reviewing two cases with frequently encountered diagnostic problems. The first case gives a history of hereditary progressive hearing loss with a perfectly normal tympanic membrane, considerable air-bone gap in the tone audiogram and the Carhart notch on the bone-conduction curve. A diagnosis of stapes fixation is easy to make.

Very often, however, one sees problem cases with an obscure history of hearing loss and cloudy scarred drum. Here, the Carhart notch and the pronounced conductive loss may be misinterpreted as a stapes fixation instead of a disruption of the ossicular chain. This is an example when pure-tone and speech audiometry do not provide sufficient information for distinguishing stapes fixation from other types of conductive deafness.

The surgeon can avoid gambling in the pre-operative assessment, and thus, avoid finding it necessary to switch from a planned stapes operation to a tympanoplasty if special tests are applied to these cases. I would now like to describe these special tests.

The sound probe test is carried out by placing the probe first on the umbo, and then on the osseous meatus. The probe with its bone vibrator, is connected to the bone-conduction output of the audiometer, and the frequencies 500–2,000 Hz. are used. In stapes fixation, hearing is better on the umbo than on the osseous meatus. In cases with disruption of the ossicular chain, however, these curves will be superimposed.

In Géllé's test the loudness of a bone-conducted tone is assessed in relation to an increase of air pressure in the ear canal. Normal hearing subjects with mobile stapes will experience a decrease of loudness when the air pressure increases. In cases with stapes fixation, as well as in cases with disruption of the ossicular chain, no such change in loudness takes place.

The prosthesis test is carried out by covering the perforation, for example, with a small piece of cotton dipped in paraffin oil and checking the hearing of 500–2,000 Hz. before and after covering the perforation. These techniques can be easily applied in routine office practice. If still in doubt, and if facilities are available, more elaborate laboratory tests can be utilized.

In tympanometry (Terkildsen and Thomsen, 1959; Lidén, 1969), a pure tone is fed into the ear canal and the static air pressure is continuously

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changed from −200 mm. water pressure, to +200 mm. water pressure (Fig. 1). Depending on the stiffness and mobility of the drum, and the function of the middle ear, a greater or smaller portion of the tone will be reflected back to a microphone and recorded. Four different patterns can be distinguished, depending on the condition of the middle ear and the tympanic membrane (Lidén, 1969). The normal air-filled middle ear gives a V-shaped curve (Fig. 2a). Stapes fixation does not distort this pattern. In cases where stapes fixation is combined with adhesions, or with effusion in the middle ear, the tympanogram results in a straight line (Fig. 2b). A 'W' on the curve (Fig. 2c) will indicate a super-mobile tympanic membrane due to an atrophic scar or to a disruption of the ossicular chain. When negative pressure is present in the middle ear, the low point of the notch is shifted away from zero in the negative direction (Fig. 2d).

The equipment employed in tympanometry is also used for *impedance audiometry* (Metz, 1946; Klockhoff, 1961) involving measurements of the stapedial and tensor muscle reflexes. The stapedial muscle reflex is usually elicited by acoustic stimulation. The tensor muscle reflex, on the other hand, by an airjet directed towards the cornea (Klockhoff and Andersson, 1960).

The stapedial muscle reflex generally is absent in all conductive lesions. Thus, it can be used for differentiation between conductive and sensorineural hearing impairments. Beside this advantage, I also want to mention that the stapedial muscle reflex can be used as an objective recruitment test and as a test for detecting malingerers and for the topical diagnosis of paralysis of N VII. The tensor tympani reflex is impeded by adhesions in the middle ear but is unusually great in cases with disruption of the ossicular chain.

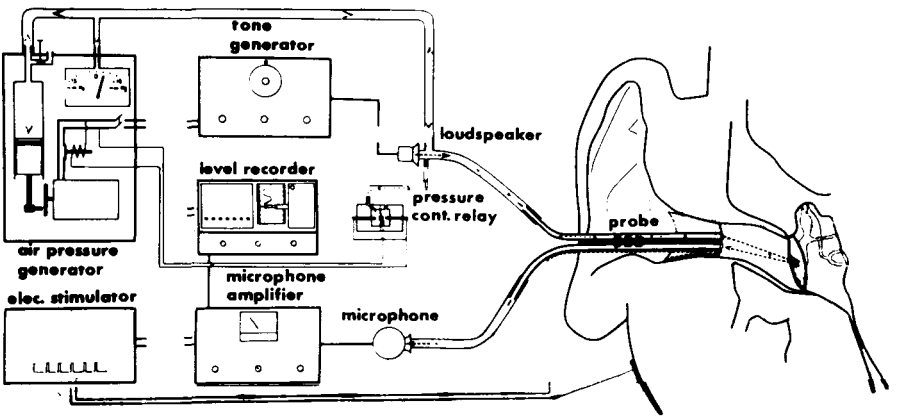


FIG. 1.
Equipment for tympanometry and impedance audiometry.

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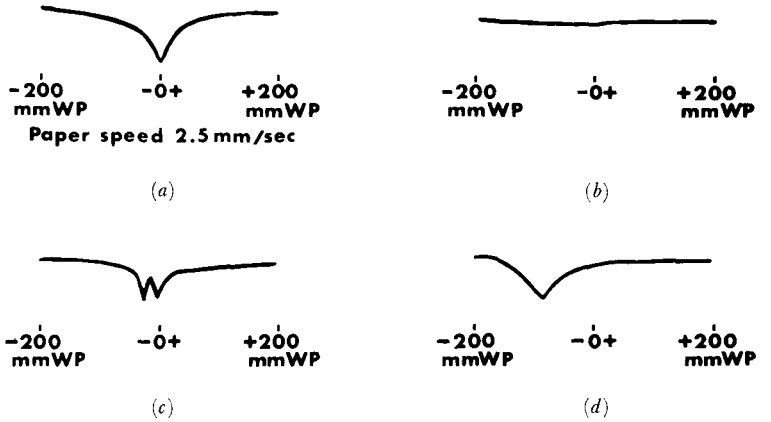


FIG. 2.

Tympanograms in cases with
(*a*) Stapes fixation with otherwise normal middle ear.
(*b*) Adhesive otitis with stapes fixation.
(*c*) Disruption of the ossicular chain.
(*d*) Negative pressure in the middle ear.

Test results in cases with intact tympanic membrane and conductive loss

Fig. 3 shows the results of the special tests discussed in a typical case of otosclerosis where stapes fixation is the only pathological change in the middle ear. The sound probe test shows better hearing on the umbo than on the osseous meatus, the tympanogram has a normal configuration and the stapedial reflex cannot be elicited, but the tensor reflex is present. The Géllé test gives no change of loudness when the air pressure in the ear canal is increased.

The auditory behaviour of stapes fixation in combination with adhesions in the middle ear is demonstrated in Fig. 4. In this case the tympanogram is especially valuable and shows the immobility of the drum. This kind of information cannot be obtained from any other oto-audiological test in current use. Moreover, no stapedial or tensor reflexes could be elicited. The sound probe test shows that the transmission of sound is rather good and no indication of disruption is present. With this kind of information as background the result of the Géllé test, in this case, will give further support to the presence of stapes fixation.

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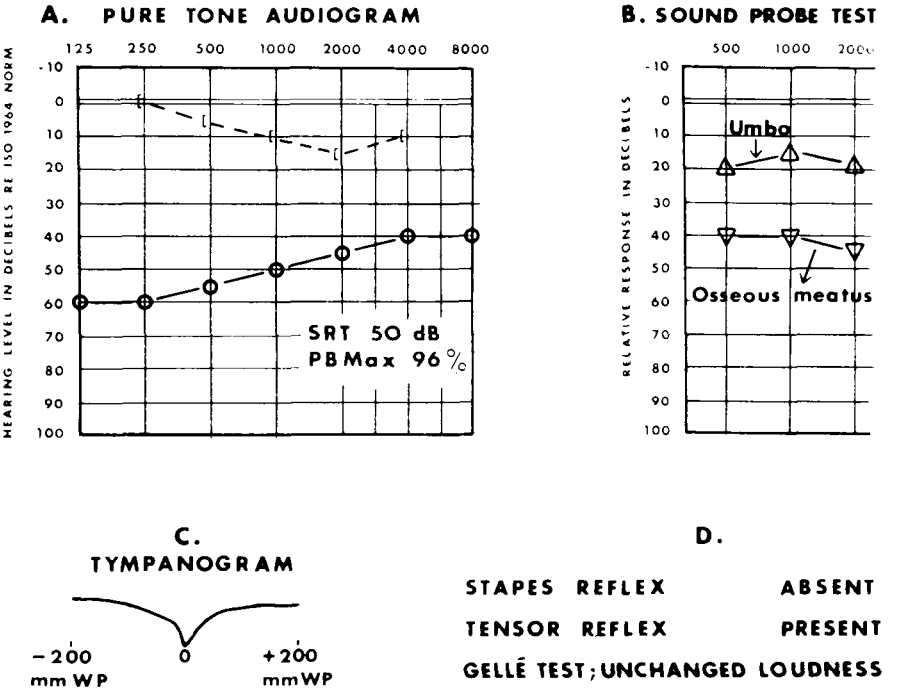


FIG. 3.

Results of pure tone and speech audiograms, sound probe test, tympanogram and results of the stapedial and tensor reflex tests and Géllé test in a case with stapes fixation with otherwise normal middle ear.

The results of the tests in Fig. 5 provide useful information if it is suspected that the hearing loss is due to a disruption of the ossicular chain instead of stapes fixation. The sound probe curves are superimposed, and the tympanogram shows abnormal mobility. The tensor reflex is unusually large due to the increased mobility of the drum. The stapedial reflex is absent as it should be. In cases where the disruption is medial to the stapedial tendon, as in fractures of both stapedial crura, the stapedial reflex will be elicited.

In cases with partial disruption of the chain, the sound probe test may show a gap between the curves. This can be due to the fact that even the small pressure with which the probe is applied against the drum, can help to overcome the dislocation of the chain and normalize the sound transmission.

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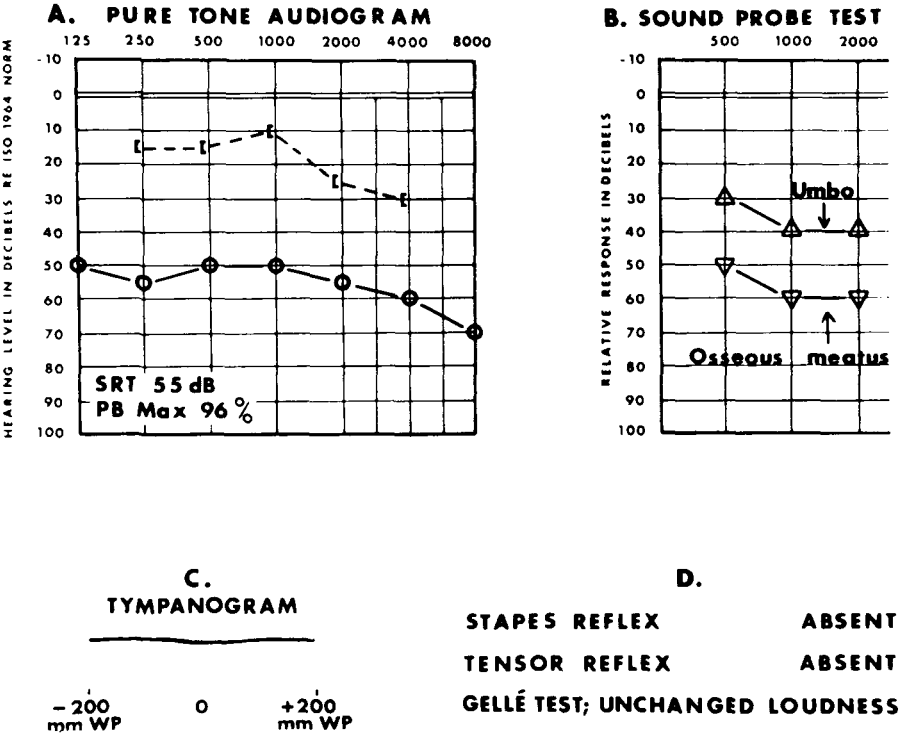


FIG. 4.

Results of pure tone and speech audiograms, sound probe test, tympanogram and results of the stapedial, and tensor reflex tests and Géllé test in a case of stapes fixation with adhesive otitis.

In unilateral hearing loss due to inadequate masking, a sensorineural hearing loss may be overlooked. A low speech discrimination score gives support to the diagnosis of sensorineural hearing loss. Further evidence in the same direction is found if occlusion of the ear canal improves the bone-conduction below 1,000 Hz. Finally if the stapedial reflex can be elicited in the hearing-impaired ear, the hearing loss is very likely of sensorineural origin.

Test results in cases with perforation of the tympanic membrane

Stapes fixation as well as disruption of the chain may also occur in cases with chronic otitis media. Thus checking of the transmission of the chain is very important for correct surgical treatment.

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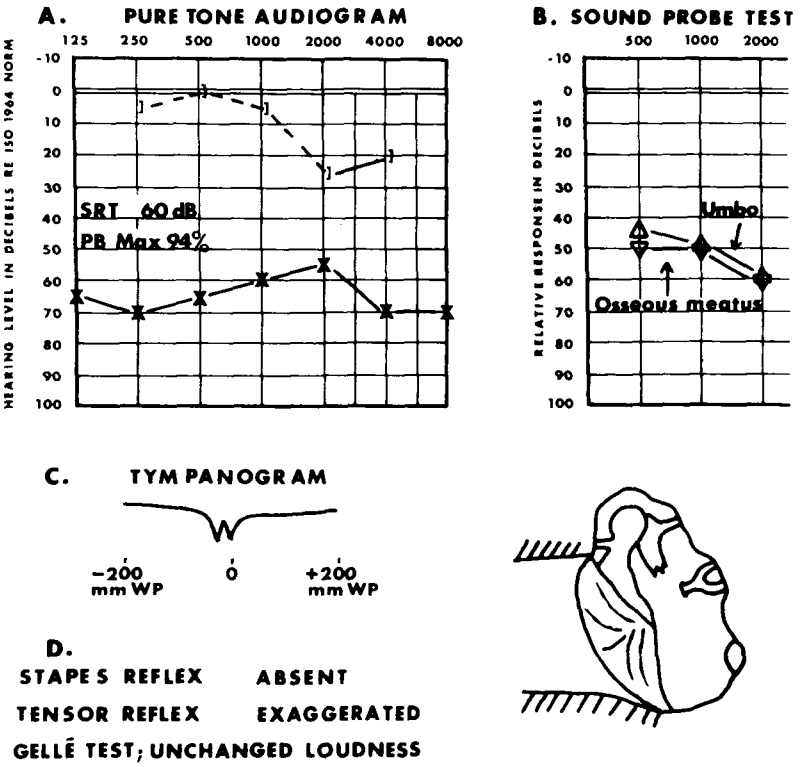


FIG. 5.

Results of pure tone and speech audiograms, sound probe test, tympanogram and results of the stapedial, and tensor reflex tests and Géllé test in a case of disruption of the ossicular chain.

Non-visible stapes. In chronic otitis with a conductive loss of 45 db. a concomitant stapes fixation may be easily concealed. One way to check for this is to test the patient's hearing, then cover perforation with a prosthesis and check his hearing again. If no change in hearing appears, it lends support to the assumption that a stapes fixation is present. If, on the other hand, the hearing gets about 10 db. poorer we should be concerned with a disruption of the ossicular chain. The next step in this test is to push the prosthesis further inward, in contact with the stapes, and again check the hearing. In stapes fixation, the hearing level will not be changed but an improvement indicates that the stapes is mobile.

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Generally, no suspicion of disruption of the chain need arise if the air conduction audiogram is better than 30 db. hearing level and no myringo-stapedio-pexia is present.

The stapes visible. In cases with perforation of the tympanic membrane and with the stapes and the joint between the incus and the stapes visible, direct palpation on the stapes through the operating microscope gives the answer about the mobility and no further tests are necessary.

If the stapes is covered by adhesions and only the head is visible, the elicitation of the stapedius reflex by handclapping or some other acoustic stimulation can often be detected visually through the operating microscope and is a handy way to check for stapes fixation (Hallén *et al.*, 1964).

Auditory test profiles in lesions of the cochlea, the VIIIth nerve and the central auditory pathways

A great deal of the activity in an audiological centre comprises diagnostic investigations on patients with sensorineural hearing loss. In many cases vestibular symptoms or other neurological disturbances are also present. An important task is to locate the level of the lesion. Each cochlea is projected bilaterally. Thus the symptoms of lesions in the central auditory pathways may not be very impressive. This means that the topological diagnosis of central auditory disturbances has to be based both on the results of the neurological and the audiological examinations. From the audiological viewpoint, the tone audiogram gives no definitive information on the location and extent of the lesion, but one must combine this with the results of the following tests: speech audiometry, Fowler's alternate binaural loudness balance test, Békésy audiometry, impedance audiometry, short increment sensitivity index or SISI test, tone decay or adaptation test, sound localization test or directional audiometry and different types of distorted speech tests. Depending on the localization of the lesion, one gets different test profiles.

Cochlear lesions

Hearing loss caused by acoustic trauma and Ménière's disorder are considered to be localized in the cochlea. Due to the anatomical defect there is generally good agreement between the results of tone and speech audiometry in cases with hearing loss due to acute and chronic acoustic trauma. The discrimination loss is often proportional to the extent of the high-frequency loss.

In cases with Ménière's disorder showing a flat or slightly rising audiogram, the discrimination is harder to predict. In an early stage of the disease, one often finds great fluctuations in hearing ability. The discrimination loss often reflects the degree and acuteness of the disorder. Such discrimination losses, caused by acoustic trauma and Ménière's

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disorder, may be used as a reference in the assessment of the discrimination value in suspected VIIIth nerve lesions (Lidén, 1954 and 1967).

The audiological investigation in suspected cochlear lesions is completed with recruitment, adaptation and sound-localization tests. Since Hallpike and Cairns' work in 1938, we associate the presence of the recruitment phenomenon with lesion in the cochlea. Abnormal adaptation (tone decay test) and impaired directional audiometry, however, are more typical of lesions in the VIIIth nerve and the brain-stem than the cochlea. The threshold tone decay test (Carhart, 1957) seldom exceeds 20 db. in cochlear lesions. The sound localization test in a free field situation (Nordlund, 1964) shows in end-organ lesions, only slightly impaired values compared with normal hearing subjects.

There is only one real recruitment test and that is Fowler's alternate binaural loudness test (Fowler, 1928). If one can show in a patient with unilateral hearing loss, that loudness equality is achieved at equal hearing levels, recruitment is present and complete. Impedance audiometry can also be used as an objective test for demonstrating the presence of an abnormal loudness function, i.e. the recruitment phenomenon. Such is the case if the stapedial reflex can be elicited at the same hearing level as in normal hearing subjects. Békésy audiometry with continuous and intermittent tracings gives valuable information about the intensity difference limen and the degree of adaptation at threshold level. In end-organ pathology, the tracing for the continuous tone drops below that for the interrupted tone and the Type II pattern emerges (Jerger, 1960).

The short increment sensitivity index, or SISI-test, developed by Jerger *et al.*, 1959, is a simplified version of the intensity difference limen test. Scores exceeding 60 per cent are typical only of patients with end-organ lesions. Table I will summarize our results and give the auditory test profile in cochlear lesions.

TABLE I.
AUDITORY TEST PROFILE IN COCHLEAR LESIONS.

(1) Agreement between results of pure-tone and speech audiometry
(2) Loudness recruitment present (Fowler's A.B.L.B. test)
(3) Békésy type II
(4) Stapedial reflex elicited at same level as in normal hearing subjects
(5) High SISI score
(6) Tone decay (seldom exceeding 20 db.)
(7) Directional hearing shows slight impairment compared with normal subjects

VIIIth nerve lesions

In order to elucidate the audiological picture in lesions of the VIIIth nerve, the cerebellopontine angle, the brain stem and the auditory areas in the cortex, we have summarized the results in forty-one intra-cranial

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tumours referred to us from the neuro-surgical department during the last 18 months. Of these, seventeen were surgically verified as acoustic neuromas, six as tumours in the cerebellopontine angle, and eight as tumours of the pons. Five of *these* thirty-one cases were deaf upon first examination. From the audiological viewpoint, there are no great differences in behaviour between acoustic neuromas and tumours in the cerebellopontine angle. Thus, they are put together as VIIIth nerve lesions. The auditory test profile (Table II) is characterized by disproportionate

TABLE II.

AUDITORY TEST PROFILE IN VIIITH NERVE LESIONS.

(1) Disproportionate speech discrimination loss
(2) Absence of recruitment
(3) Békésy type III or IV
(4) Tone decay (often exceeding 30 db.)
(5) Abnormal directional hearing
(6) Low SISI scores

speech discrimination loss, absence of recruitment, Békésy Type III or IV, abnormal tone decay, often exceeding 30 db., abnormal directional hearing and low SISI scores. The discrimination test, tone decay and directional audiometry are very sensitive tests for detecting early lesions in the VIIIth nerve. However, it must be remembered that some cases, at least in the beginning, behave as cochlear lesions (Johnson, 1965).

Lesions of the auditory pathways in the brain stem

To this group have been assigned those patients who have been operated upon for tumours in the posterior fossa, chiefly infiltrating, growing tumours in the pons and bottom of the fourth ventricle. In certain cases the tumour has issued from the medulla oblongata and vermis but has expanded in and around the fourth ventricle.

Injuries within the auditory pathways in the pons can sometimes give symptoms which resemble the cerebellopontine angle syndrome. However, lesions in the pons give bilateral changes as a rule, because the pathways and nuclei from both sides lie very near each other. Also, one does not expect as pronounced auditory symptoms in pons injuries as a destructive tumour in this area gives other fatal symptoms earlier.

Our material from the last 18 months consists of eight cases of tumour of the pons and fourth ventricle. All of the cases had normal or nearly normal tone threshold and speech discrimination. The special tests gave varying results. Two cases had abnormal directional hearing and Békésy Type IV. Abnormal tone decay and tone perversion are common. The last symptom is characterized by a subjective change in the quality of a pure tone (Parker *et al.*, 1968). In brain stem lesions, the responses to inter-

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rupted and swinging speech tests are more impaired than for filtered or time-compressed speech. In cortical lesions the contrary seems to be true. (Bocca, 1967; Calearo and Antonelli, 1968). Table III gives the auditory test profile in the brain stem lesions.

TABLE III.

AUDITORY TEST PROFILE IN BRAIN STEM LESIONS.

Relatively good pure-tone threshold
Relatively good discrimination score
Bilaterality of pathologic adaptation
Tone perversion
Often recruitment present
Interrupted speech test often abnormal
Swinging speech test often abnormal
Distorted speech test sometimes abnormal

Lesions of auditory cortex

Many investigations have been made regarding the occurrence of tone-audiometric changes in cortical pathology, but the results generally have been disheartening. The tone-audiogram is normal or may show a slight threshold loss which does not differ from a peripheral injury. First, when the tumour gives general signs of increased cranial pressure one may find a symmetrical threshold shift.

In the measurement of speech comprehension, greater demands are placed on the function, but even here, one seldom sees any special changes in the central lesions. Normal speech contains such an abundance of information that the listener, even with relatively widespread damage in the central auditory pathways and cortex, has normal or nearly normal discrimination. During the last decade, the opinion has been put forward that even minor losses of function would be detectable if the speech audiometry test was made more difficult. In this way, increased demands would be placed on the central auditory pathways and on the capacity of the auditory centres to interpret the test material. Promising results have been achieved with various difficult tests, especially the test in which the speech frequency range is reduced with filters (Bocca *et al.*, 1954 and 1963). In cases of damage in the temporal region, there has often been found a reduced ability to perceive frequency-distorted speech in the ear contralateral to the lesion. In our laboratory, we have made (Lindén, 1964) a clinical evaluation of the distorted speech test with essentially the same results as Bocca. Later, Korsan-Bengtsen (1968) demonstrated that time-compressed speech is very valuable in the assessment of diffuse injuries in the central auditory pathways as seen in many aged patients with presbyacusis. Another promising test is the competing message test (Jerger, 1964). The auditory test profile in temporal

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lobe lesions (Table IV) thus is characterized by normal tone and speech audiograms. On the ear contralateral to the lesion, we might find reduced discrimination on frequency-distorted speech tests, on time-compressed speech tests and on competing message tests.

TABLE IV.

AUDITORY TEST PROFILE IN TEMPORAL LOBE LESIONS.

Pure-tone audiogram normal
Speech discrimination normal
Distorted speech test abnormal on contralateral ear
Competing message test abnormal on contralateral ear
Interrupted speech test sometimes abnormal

As a general conclusion about our current audiometric tests, I think we can state that there is no single auditory test indicating the exact location of the lesion. Thus, we have to use a battery of tests and look for different patterns of auditory behaviour. However, the results of these test profiles must usually be combined with the vestibular and other clinical findings in order to make a correct diagnosis.

Summary

The identification of deaf infants is facilitated by observing the child's reaction to different sounds, by testing the eye-blink reflex, by arousal audiometry and by visual reinforcement audiometry. Later in life, between 3–6 years of age, play audiometry is generally used in the assessment of the auditory function.

The second part of this paper reviews the application of several office and laboratory tests for differentiation between stapes fixation and other conductive lesions which produce comparable audiometric findings. The results of pure tone and speech audiometry, the sound probe test, the Géllé test, the prosthesis test, tympanometry and impedance audiometry are discussed, in relation to different middle-ear pathologies.

In the last section of the paper, the auditory behaviour in cochlear, VIIIth nerve and central auditory lesions are reviewed. The typical auditory test profiles in these lesions are discussed. The importance for the diagnosis of combining the auditory, the vestibular and other clinical findings are stressed.

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