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In this paper I propose to discuss briefly the testing of the hearing powers for high and low notes by air-conduction. In recent times the importance of this means of diagnosis has become more evident, and it now takes rank as one of the most valuable aids in the differential diagnosis between diseases of the sound-conducting and of the sound-perceiving apparatus.

Lucae was the first to draw attention to the value of testing the hearing with notes of low pitch, and it is to him, and more recently to Bezold, that the introduction of this means of diagnosis is due.

The latter has elaborated the means of examination, and is now able with his instrumentarium to produce any tone within the limits of hearing. The instruments he uses are, ten tuning-forks in ascending series, two covered organ-pipes, and Galton's whistle.

For testing the hearing powers in the lower parts of the scale, tuning-forks are essential, though expensive. No other instrument is so free from overtones, and even when these are present with tuning-forks they are far removed from the fundamental, and are therefore unlikely to cause confusion; and further, they die away so rapidly that by waiting for a few moments after the instrument has been bowed or struck, the fundamental will alone be heard.

Testing the hearing capacity for high notes is a more uncertain procedure than testing it for the low notes. There are two reasons for this: in the first place, the instruments employed necessitate the production of accompanying sounds in addition to the particular tone with which we wish to test the hearing. Thus, in using Galton's whistle it is, even for practised ears, by no means always easy to say when the high note becomes lost and replaced by the highly pitched hiss of the air rushing past. With König's cylinders there is not quite so much difficulty, because the metallic ring of the hammer against the steel is unmistakably lower than the note excited by the longitudinal vibration of the rod. But even with this instrument the patient must have a good idea of what he is to listen for. This is best done by sounding one of the lower pitched cylinders, the note of which he can undoubtedly hear and distinguish from the accompanying metallic ring of the steel, and then proceeding up the scale he will be able to say when the proper note of the cylinder is no longer heard.

In the second place, the pitch of the highest audible note varies greatly in individuals whose hearing may still be considered normal. We are, therefore, not justified in assuming the existence of any real pathological condition, unless the patient is unable to perceive notes as low as 15,000 to 12,000 vibrations per second. For this purpose I have constructed short brass bars which give approximately from 8,000 to 12,000 vibrations per second. They are suspended at each end by a cord, and are excited by drawing a well-resined violin bow across them. The note produced is very high and correspondingly disagreeable, but is much louder than that excited by either Galton's whistle or König's cylinders, and the insignificant noise of the rubbing of the bow which accompanies the note could not cause confusion. Of course the note is only produced as long as the bow is being drawn across the cylinder, for rods of such high pitch cannot continue their vibrations for any appreciable period after the exciting force has been withdrawn in the way that rods of lower pitch, such

as tuning-forks, can. The vibrations of the rods are transverse, and not longitudinal like those produced by König's cylinders.

In testing the hearing power for the lower notes it is not necessary to close either ear, but in the case of the higher notes the ear which is not being tested should be firmly closed or fallacies will occur.

As regards the value of the results obtained by testing the hearing for different parts of the scale, from my own observations I would unhesitatingly say that the examination by the low notes gives us the most reliable information, and when we come to consider the principle upon which the testing depends, the reason will be clear. Out of fifty cases of middle-ear disease, in which I tested with the low-toned tuning-forks, I found that in only one case was there no loss of perception for some of the low notes. This was the case of a man who worked in a room where copper-boilers were made, and there was a loud noise constantly going on. The results of treatment seemed to indicate that it was a case of middle-ear disease, in spite of the fact that he heard the notes down the lowest part of the audible scale.

On the other hand, although I have found that the hearing for high tones is lost first in most cases of deafness due to affections of the sound-perceiving apparatus, yet I have seen not a few exceptions to this rule. Moreover, when the deafness is due to disease in the central nervous system, or in the trunk of the auditory nerve, the rule does not hold at all. Thus, in a very interesting case observed by Christ and Siebenmann ("Ueber d. Central. Hörbahn," etc., *Zeitschr. f. Ohrenh.*, Bd. xxix., s. 81), the high notes were perceived up to 1·5 on Galton's whistle, that is, almost to the normal extent, whereas the notes below A_{-1}, an octave and a half, were lost.

There is no doubt, however, that in affections of the cochlea it is a very general rule that the upper notes are lost first, and several patients in giving the history of their complaint volunteered the remark that the first time they were

aware of any deafness was when they found they did not hear the singing of the lark while companions present at the time were able to do so. The most interesting of these cases is the following.

Two or three years before seeing me the patient suffered from a very severe attack of pneumonia following influenza. His physician despaired of his life, but recovery took place after eleven days' illness. The shock of the disease, however, he had not got over when I saw him, and it is doubtful if at his age (53) he ever will get quite over it. He has, moreover, suffered from considerable business worries since his illness.

When I first saw him I observed that his hair had turned white in patches, and he informed me that this first appeared about a year after the pneumonia. Two years after the pneumonia he became aware of the fact that he was deaf when walking in the country with his wife, who remarked that she heard the lark singing, he himself being unable to hear it. A year later than this he complained of aching in his eyes, and on examination by an oculist it was found that he was almost blind in the left eye, the condition being diagnosed as thrombosis of the vein. The right eye was healthy.

On examination of the ear I found that he was deaf for notes above a^5 (6826 *v.d.*), and he only heard faintly those for some considerable distance lower in the scale even when they were sounded loudly. (The note of the lark is of course lower than a^5, but it must be remembered that when the bird is singing at some distance the sound is faint.) The membrane was normal and the bone conduction diminished.

Since that time the affection of the ears does not seem to have progressed. He can hear the thrush and the blackbird easily, and in conversation it would not be suspected that he is deaf. The hair has returned to its original colour, but the eye appears to be in the same condition as it was when he was first examined.

Occasionally when testing the hearing power we find gaps in the scale; that is, the patient may be unable to hear a

series of tones in more or less close proximity while he is still able to hear tones both higher and lower in pitch. Such a condition indicates an affection either of the cochlea or of the nerve-paths, but so far as I am aware is never found in diseases of the middle ear alone.

Cases of this description are of extreme interest if a post-mortem examination of the organ of hearing can be obtained, because it is from such, examined carefully during life, and then again post-mortem, that a knowledge of the functions of the labyrinth is established. Two cases of this description have recently been described very minutely by Bezold (*Ueber d. funkt. Prüf. d. menschl. Gehör*, s. 173), and they seem to support the view that sound is analysed in the cochlea, although perhaps the author goes too far in assuming that this analysis takes place in the way suggested by Helmholtz.

On account of the importance of the information to be derived from the microscopical examination of the organ of hearing in persons who have been examined during life and found deaf to certain portions of the musical scale, I have added a note at the end of this paper describing a method of preparing sections of the cochlea. After a considerable experience in different methods of making such preparations, I have found it the only one that can be relied upon to give satisfactory results in the *human* subject; there may be others, but I do not know of them.

The causes which bring about loss of hearing in different parts of the scale are, I believe, different according to the part of the scale for which the hearing is lost. Taking that group of cases in which the higher notes are lost, it has been suggested that in these there is destruction of the organ of Corti or the nerve-fibres in the lowest whorl of the cochlea; indeed such a case has been described by Moos (*Zeitschr. f. Ohrenh.*, Bd. xii., s. 96), and if the theory that the basal part of the cochlea is apportioned for the perception of high notes be correct, then an affection of that portion of the organ of Corti near to the fenestra rotunda would obviously produce the loss of hearing power for these notes. Furthermore, it has been suggested that from its

anatomical position that portion of the organ of Corti near the fenestra rotunda and the vestibule is more liable to disease than the more secluded parts. The suggestion appears to be a very reasonable one, but a larger accumulation of pathological evidence of the nature above described, is required before this explanation can be definitely accepted.

It will naturally be understood that an affection of the auditory nerve either in its trunk or in its projection in the brain may bring about a loss of hearing power for notes in different parts of the scale according to the fibres involved. Hence the inability to hear high notes only refers, so far as differential diagnosis is concerned, to affections of the labyrinth, and even in these cases it must not be relied on too implicitly.

The means by which a loss of hearing for the low notes is brought about is a matter of much more importance. And this is so for several reasons. In the first place, as observed above, testing the hearing power for the low notes is more reliable as a means of diagnosis; but what is of still more importance is the fact that the human voice as used in conversation is pitched in the lower portions of the audible musical scale. It follows, therefore, that any means devised for the relief of deafness must be directed more particularly to the restitution of the hearing power for the low notes.

In view of these facts it is remarkable that no attempt has been made to explain the great loss of hearing for the low notes in cases of disease of the middle ear, the condition in which these notes are lost to the patient.

The following explanation appears to me to account for this loss.

The loudness of a sound is, within wide limits, and certainly in the cases under consideration, proportionate to the energy transmitted to the fluid in the labyrinth. Now, since the mass of the ossicles is constant, the energy transmitted is proportional to the square of the velocity with which the ossicles move. Further, the velocity is proportional to the frequency and to the amplitude of the vibrations which the ossicles undergo. When, therefore, the frequency becomes

diminished by lowering the pitch, the amplitude of the vibrations must be increased in order to obtain the same amount of energy. Now, it is just in cases of middle-ear disease that the amplitude of the vibrations is restricted; hence, in this class of diseases the hearing power is much more seriously affected for the low notes than for the high ones.

Note.—The method of preparing the cochlea referred to is modified from one which I obtained from Böhm, and is as follows.

After removing the whole petrous portion of the temporal bone as soon after death as is admissible, file through the convexity of the superior semicircular canal, pierce the fenestra ovalis, and put the mass into a large quantity of a 4 per cent. solution of formalin. After it has been in the formalin solution for forty-eight to seventy-two hours put it into a large quantity of Müller's fluid. Böhm omits the previous fixation with formalin, but, on account of the rapidly penetrating power of this agent, I think it is of great advantage, particularly as a certain amount of disintegration among the cells must have already occurred.

The preparation remains three weeks in Müller's fluid at the temperature of the room, the fluid being frequently changed. At the end of the three weeks the vessel containing it is put into a stove kept at a temperature of 33° C., the Müller's fluid being changed frequently as before. This treatment in the stove lasts other three weeks.

The preparation is then cut down with a fretsaw to the smallest dimensions possible without injuring the structures, and a small hole is filed in the cochlea. It is then washed out for forty-eight hours in running water, and placed in 70 per cent. alcohol, where it is kept for three days in the dark.

It is now ready for decalcification, which takes place in a solution of five parts of strong, fuming nitric acid to 100 parts of 70 or 80 per cent. alcohol. The solution is to be changed twice a week, and the preparation must be kept in the dark. Decalcification is complete in from four to six weeks, at the end of which the preparation is put into a large quantity of

70 per cent. alcohol to extract the acid. It is then put in 90 per cent. alcohol for another fortnight, then for three days into 96 per cent. alcohol, and for two days into absolute alcohol, and is then embedded in celloidin.

The embedding must be very carefully carried out, beginning with a very thin solution for a fortnight, then with a solution of medium thickness for about a fortnight or three weeks, and then with a thick solution for a week.

The orientation must be such that some of the sections show the modiolus from apex to base. In examining the sections particular attention should be directed to the nerve-fibres in the lamina spiralis ossea and to the ganglion spirale.