Degeneration of the Hearing Nerve and Its Detection by Distorted-Speech Testing

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Abstract: A detailed description of the physiology of the auditory system (including new essential knowledge) is provided, followed by the description of five morphological levels of acoustic signal analysis, of which four play a significant part in establishing the selection capacity of human hearing. As an essential phenomenon connected with loss of the analyzing capacity of the ear, ascending degeneration of the afferent nerve fibers of the inner hair cells and of the hearing nerve (after destruction of the inner hair cells) develops. A distorted-speech test is submitted that offers a simple and easily performed calculation of a ratio, which value renders a reliable estimation of the pathological analyzing capacity of the ear caused by ascending degeneration. The test is recommended as a reliable basic component of an audiometric battery of tests.

Key Words: degeneration; distorted speech; hearing nerve; testing

In otolaryngologists' offices, simple speech tests using monosyllabic words and two-digit numbers, such as the monosyllabic CID-W-22 Silberman and Hirsh Test [1] employed in the United States or the Freiburg Hahlbrock Speech Discrimination Test [2] employed in Germany, have proved to be very effective in routine examinations, as their designs are easily adapted to the average patient. They are easily understood and can be performed quickly. However, they have disadvantages as regards the many patients suffering from inner ear hearing impairments in the high-tone frequency range, such as presbyacusia due to advanced age or noise-induced hearing loss due to work noise, environmental noise, or noises connected with military activities. In these cases, the speech discrimination measurements carried out in the quiet surroundings of the audiologist's office apparently do not correspond with the patient's hearing sensitivity in real life. The correlations between the pure-tone threshold levels and the speech comprehension ability, which are gathered easily from the alpha$_1$ value for speech hearing loss (gap between the scores for normal two-digit numbers and pathological numbers on the 50% line) in the speech audiogram, mainly refer to the tone frequencies 500, 1,000, and 2,000 Hz. However, in cases of minor and medium basocochlear inner ear hearing loss, the hearing loss of speech usually is damaged only slightly.

The cocktail-party effect that affects these patients—or of which they generally complain—may reduce the perimeter of their speech discrimination capacity to a few centimeters between their ear and the person communicating with them. Therefore, speech discrimination tests with a competing noise are used to establish the pathological camouflaging effects in the individual patient. As discussions about the most practical method of testing speech discrimination capacity have so far not produced satisfactory solutions, we decided to develop a test that permits us to assess a patient's impaired selective hearing capacity as compared to normal hearing, using an easily performed, quick, and quantitatively reliable test based on tests commonly used in otolaryngologists' offices and by clinical audiologists.

Several investigations have shown that ascending degeneration of the hearing nerve, as described by Spoendlin [3,4], is responsible for the cocktail-party effect as long as the central auditory functions remain intact. According to our experience, ascending degeneration can be established best by a supplementary distorted-speech test.

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DEGENERATION OF THE HEARING NERVE AND ITS SIGNIFICANCE IN SPEECH DISCRIMINATION

In the last decades, extensive experimental and clinical studies of the hearing organ in humans and animals have disclosed with growing exactitude the multistage functional efficiency of the auditory system regarding various damage and possible vulnerability criteria (Fig. 1). According to current knowledge, five separate morphological levels of speech perception are distinguished. They represent principal stages in the hearing and selection capacity of the auditory system (see Fig. 1; Table 1). Of these, level 2 (i.e., the tympanic membrane and the ossicular chain, being linear amplifiers) may be ignored as regards selection capacity.

Level 1 (the outer ear) exerts a stereophonic effect ("stereophone coding"). Level 3 represents the cochlea, including the cochlear amplifier and afferent transmission, and cochlear analyzing functions. Level 4 is the area of chiasmatic selection, also called the *selection of interconnection*. Level 5 represents the primary auditory cortex and the cortical centers responsible for active acoustic selection.

Recent investigations of noise-induced hearing loss, supported by experimental and histological evidence from the cochlea, the hearing nerves, and the cortical acoustic centers, demonstrate the intricate connections between these specific regions (e.g., the outer and inner hair cells, the spiral ganglia, the upper sections of the auditory pathway, and the cortical acoustic centers). The findings call for new proposals for precise assessment of specific hearing capacity, previously called *selection ability*. Electron-microscopical reproductions of the structures of the cochlea, hearing nerves, and spiral ganglia after long-term dose-controlled noise exposure show the resulting destruction first of the outer, then the inner, hair cells and, eventually, of the corresponding afferent nerve fibers, including the spiral ganglia [5]. In extensive investigations in the late sixties and beginning of the seventies, Spoendlin [3,4] identified the entirely different functions of the outer and the inner hair cells and of their various nerve supplies. These findings and the conclusions drawn from them opened new dimensions in the field of hearing physiology. Consequently, the outer hair cells, being by far the more sensitive hair cells, have been shown merely to steer the tuning of the sensibility of the inner hair cells.

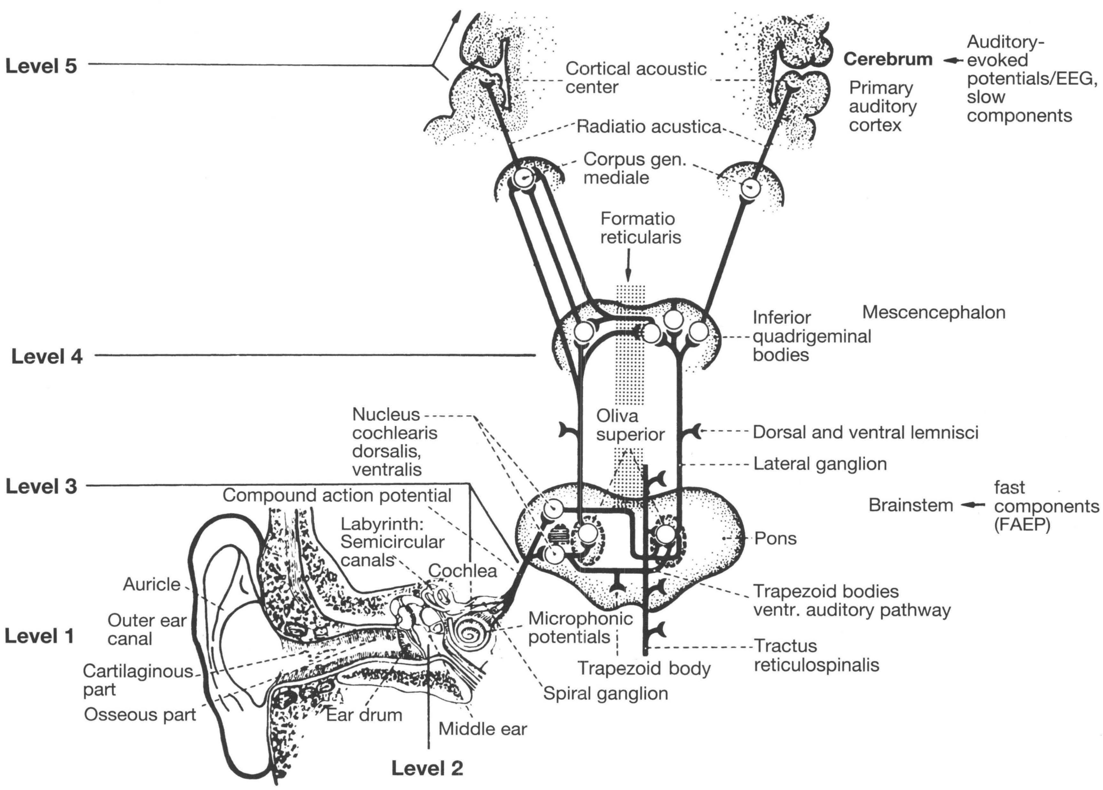

Figure 1. Topodiagnostic classification of the hearing system. (EEG = electroencephalography; FAEP = fast acoustic evoked potentials.)

Table 1. Proposals for Precision Measurements of Specific Hearing Capacities of the Hearing System

Level	Capacity
1 (outer ear)	Stereophonic outer ear effect ("stereophone coding")
3 (inner ear)	Cochlear analyzing functions
4 (auditory nuclei and pathways)	Chiasma selection
5 (primary auditory cortex and superior auditory centers)	Active selection

Note: Specific hearing capacities previously were known as *selection ability*.

This is achieved by the specific active motor capacity of the outer hair cells [6].

Approximately 30 outer hair cells are supplied with a single afferent nerve fiber, whereas some 20 afferent nerve fibers are connected to a single inner hair cell. The inner hair cells, therefore, are considered the true sensory cells of the auditory system. Their sensitivity is steered by the active movement of the outer hair cells and olivocochlear efferent nerve fibers. The interacting function of the outer hair cell layer has the effect of a "cochlear amplifier" responsible for the sensibility of the inner hair cells in the hearing level range of approximately 0 to 40 dB. Functional outer hair cells produce otoacoustic emissions (OAEs) [7], which are assessed routinely in an objective test that is both reliable and practical.

Spoendlin [4] further proved that destruction of inner hair cells after overexposure to noise may cause an ascending degeneration of the hearing nerve—with devastating consequences for speech discrimination. Ascending degeneration and its direct effect on speech discrimination become apparent in the slowly developing cocktail-party effect. Quantitative assessment, however, is difficult, especially with regard to comparable data from quantitative audiometric assessment.

Similarly, the assessment of recruitment was a matter of common knowledge [8] until the recruitment phenomenon emerged as corresponding with a dysfunction of the cochlear amplifier (i.e., of the outer hair cells only). Discovery of the OAEs has rendered it possible to abandon widely varying test results.

Oeken [9] recently confirmed and statistically supported the finding that in cases of noise-induced hearing loss, the distortion product OAEs continually decrease in correspondence with high-frequency tone hearing loss (i.e., the basocochlear frequency range) and eventually disappear altogether in relation to duration of exposure. As a consequence, the author recommended measuring exclusively the distortion product OAEs when assessing noise-induced hearing loss.

Although the proposals for OAE measurements when examining functional disorders of the cochlear amplifier are explicit, the fact that failing OAEs also may indicate ascending degeneration has, until now, not been accepted clinically. However, Pangert [10] submitted some interesting new findings in this direction. In animal experiments, he exposed guinea pigs to 10 single-spark impulses with peak values of 164 dB. As a result, an accompanying ascending degeneration of the hearing nerve was verified by measurements of a reduced action potential density in the hearing nerve that correlated with noise exposures lasting several weeks to months in three groups of subjects. In group 1, after 6 and 7 weeks of impulse noise exposure, the result was cross-sectional dam-

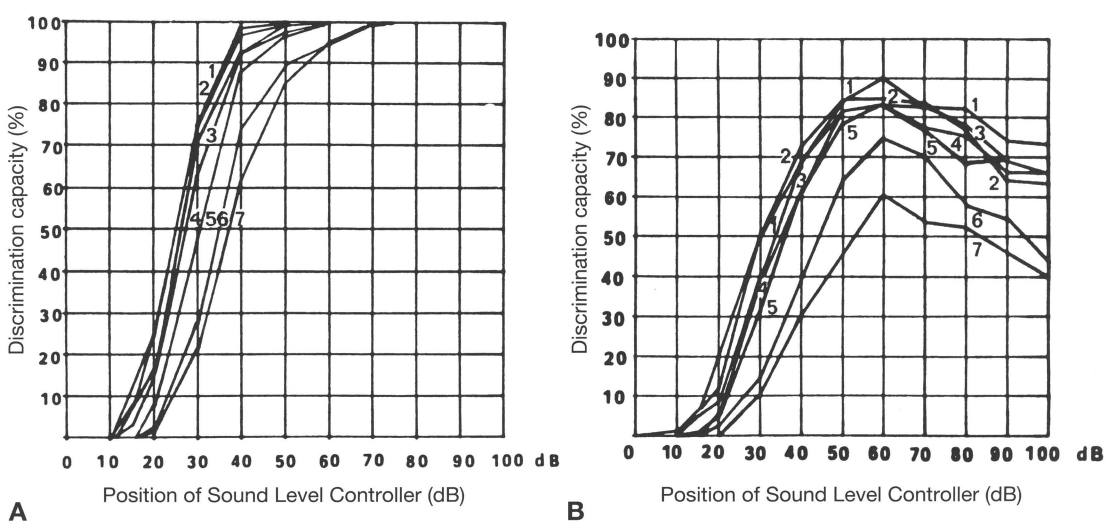

Figure 2. Discrimination curves in age groups 1–7 for (A) nondistorted monosyllables and (B) distorted monosyllables at reverberation grade –15 dB (Freiburg Hahlbrock Word Test).

age to the hearing nerve of 10.6%. In group 2, after 17 and 19 weeks of impulse noise exposure, the damage amounted to 27.2% of the cross-section of the nerve, which is a significant increase. Group 3, measured 9 and 12 months after noise exposure, showed an almost identical value of 26.1% cross-sectional nerve damage. As regards the time-related behavior of ascending degeneration, the findings give evidence of an asymptotic process within given periods of noise exposure.

Two principles for the audiometric assessment of ascending degeneration are being recommended currently: first, various speech tests in connection with specific masking noises or with simple background noises; second, distorted-speech tests with varying but often too-small reverberation grades. For our experiments, we chose the distorted-speech method because not only does it measure the speech signal–masking effect (which is of great importance for detecting such damage) but very often it discloses, in the presence of an ascending degeneration, a marked impairment in the time-related analysis of an acoustic signal [11]. This condition becomes evident in affected patients who are unable to follow broadcast information in echoing surroundings, such as train stations. Bearing this in mind, we developed a distorted-speech discrimination test.

DETECTION OF ASCENDING DEGENERATION OF THE HEARING NERVE BY DISTORTED-SPEECH TESTING

As early as the 1950s, the selection capacity of the ear was interpreted by Schubert [12] as a specific perfor-

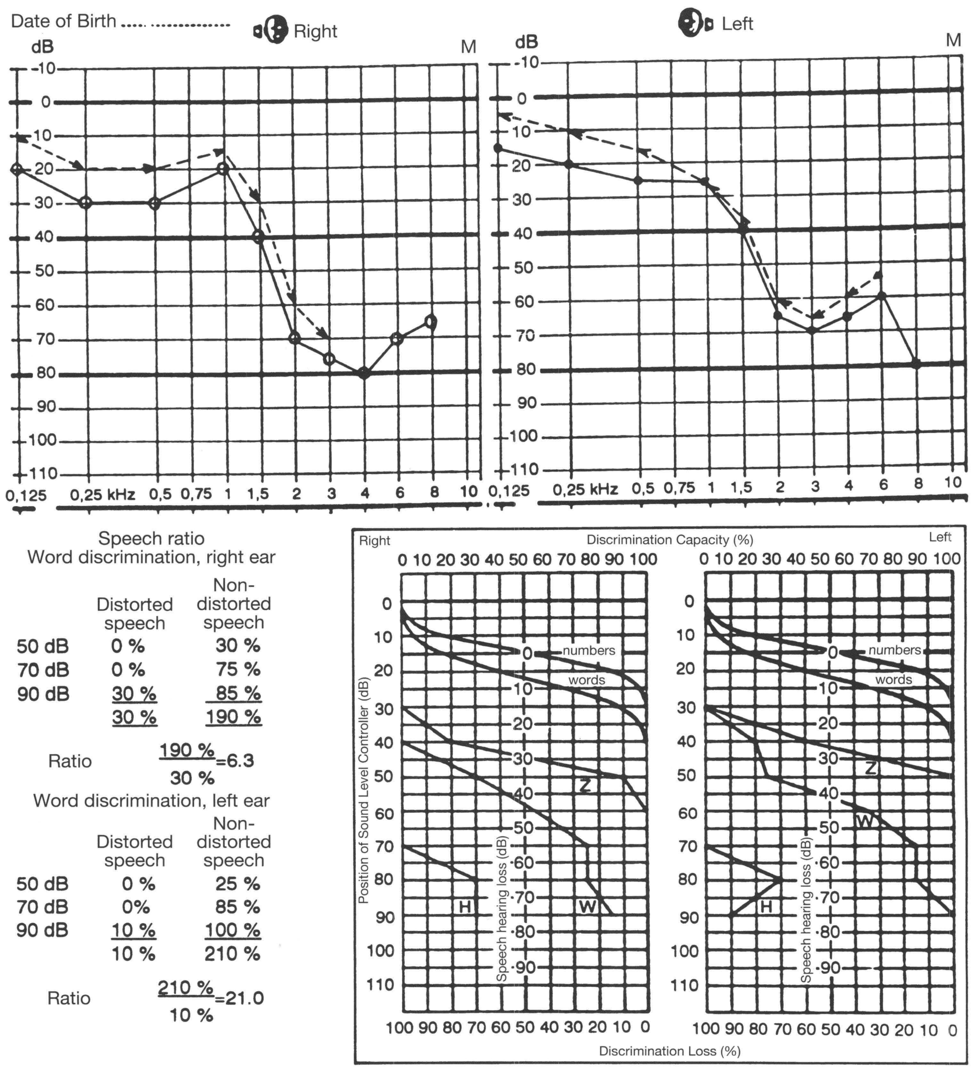

Figure 3. Calculation of speech ratio and distorted-speech ratio. (Nondistorted-speech test: N = numbers; W = words. Distorted-speech test: H = words; M = masking noise; reverberation grade, − 15 dB.)

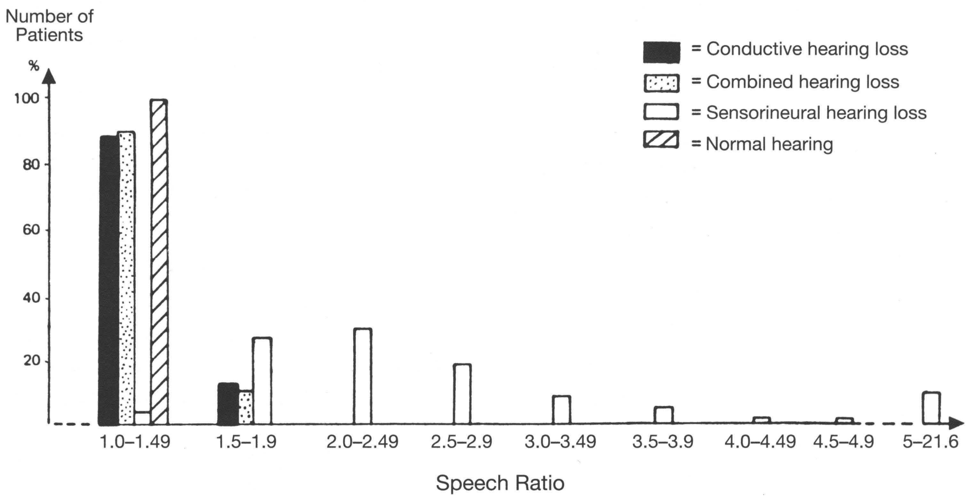

Figure 4. Measurement results of reverberation ratios for hearing, conductive hearing loss, combined hearing loss, and sensorineural hearing loss.

mance of the inner ear, whereas such authors as Keidel [13] and Wedel [14,15] classified it as a central process. As depicted in Figure 1, sound processing is not performed by the inner ear alone but includes several levels of the auditory system. Taking into consideration the complicated mechanisms of hearing, Schubert [12] had recommended several rather intricate speech discrimination tests, among them a distorted-speech hearing test that allowed him to classify selection capacity as an inner ear performance.

In view of the rather complicated, time-consuming, and not very practical procedures of Schubert's speech tests, we decided instead to develop further the simple Freiburg Hahlbrock Speech Discrimination Test used widely in otolaryngologists' offices and, to a large extent, corresponding with the American CID-W-22 Silberman and Hirsh Test, using monosyllabic words and two-digit numbers. Referring to Schubert's tests, we at first installed −5, −10, and −15 dB as reverberation grades and a reverberation time of 5 seconds but, when put into practice, the findings at the reverberation grade of −15 dB proved to be the most useful. Only in certain cases do we recommend going back from −15 dB to −5 dB.* From the discrimination scores for nondistorted and distorted monosyllables (reverberation grade, −15 dB) based on the mean values of normal-hearing populations in groups of age decades, curve patterns as shown in Figure 2 were obtained. Group 1 included persons aged 10 to 19 years; group 7 included persons aged 70 to 79 years. The discrimination curves derived from the normal Freiburg test material are in relatively close correspondence up to age 60, whereas the curves for groups 6 and 7 are slightly diverging. By comparison, the distorted discrimination scores show decreased values on the whole but also are in close correspondence up to age 60. However, a clear curve divergence is evident, especially in relation to the 50% words line, for groups 6 and 7. Here, the deterioration of distorted-speech discrimination ability in normal-hearing persons beyond age 60 becomes evident.

By calculating the test results as a function of nondistorted and distorted test data, we were able to set up, relatively quickly even during examination, a quantitative evaluation of the patient's actual speech discrimination capacity, comparable to real-life conditions even under aggravating circumstances, such as a noisy party. The word discrimination capacity is derived from the respective discrimination scores for nondistorted and distorted monosyllables at levels of 50, 70, and 90 dB, and the reverberation ratio then is calculated as demonstrated in Figure 3.

As is shown for the right ear in Figure 3, the nondistorted discrimination 30% value at 50 dB, the 75% value at 50 dB, and the 85% value at 90 dB are summed to 190. For the distorted words, the values 0 at 50 dB, 0 at 70 dB, and 30% at 90 dB are summed. The resulting ratio of nondistorted speech (190%) to distorted speech (30%) is 6.3.

In the testing of persons with normal hearing, patients with conductive hearing loss or combined hearing impairments, and patients with sensorineural hear-

* The German version of this test is available as a compact disc under the specification Disc Nr. 10, formerly distributed by Westra Electronic GmbH, Wertingen and, at present, by their successor Heike Kammermeier, Bergstrasse 16, 89438 Holzheim-Eppisburg, Germany.

ing loss, the reverberation ratio is pathological almost solely in persons with sensorineural hearing loss. With normal hearing, conductive hearing loss, and combined hearing loss, the reverberation ratios predominantly show values between 1.0 and 1.49. With sensorineural damage, however, the values may rise ad infinitum. The histographic distribution (Fig. 4) shows maximum ratio values for distorted speech at 2.0 to 2.49.

As can be seen in Figure 4, the reverberation ratios are significantly higher for sensorineural hearing impairments as compared to conductive hearing loss and normal hearing. Therefore, an inclusion of the distorted-speech test into the audiometric test battery seems essential. In cases of sensorineural hearing loss, it offers a fast method of verifying a dysfunction of selection capacity, to establish the degree of damage and possibly even the

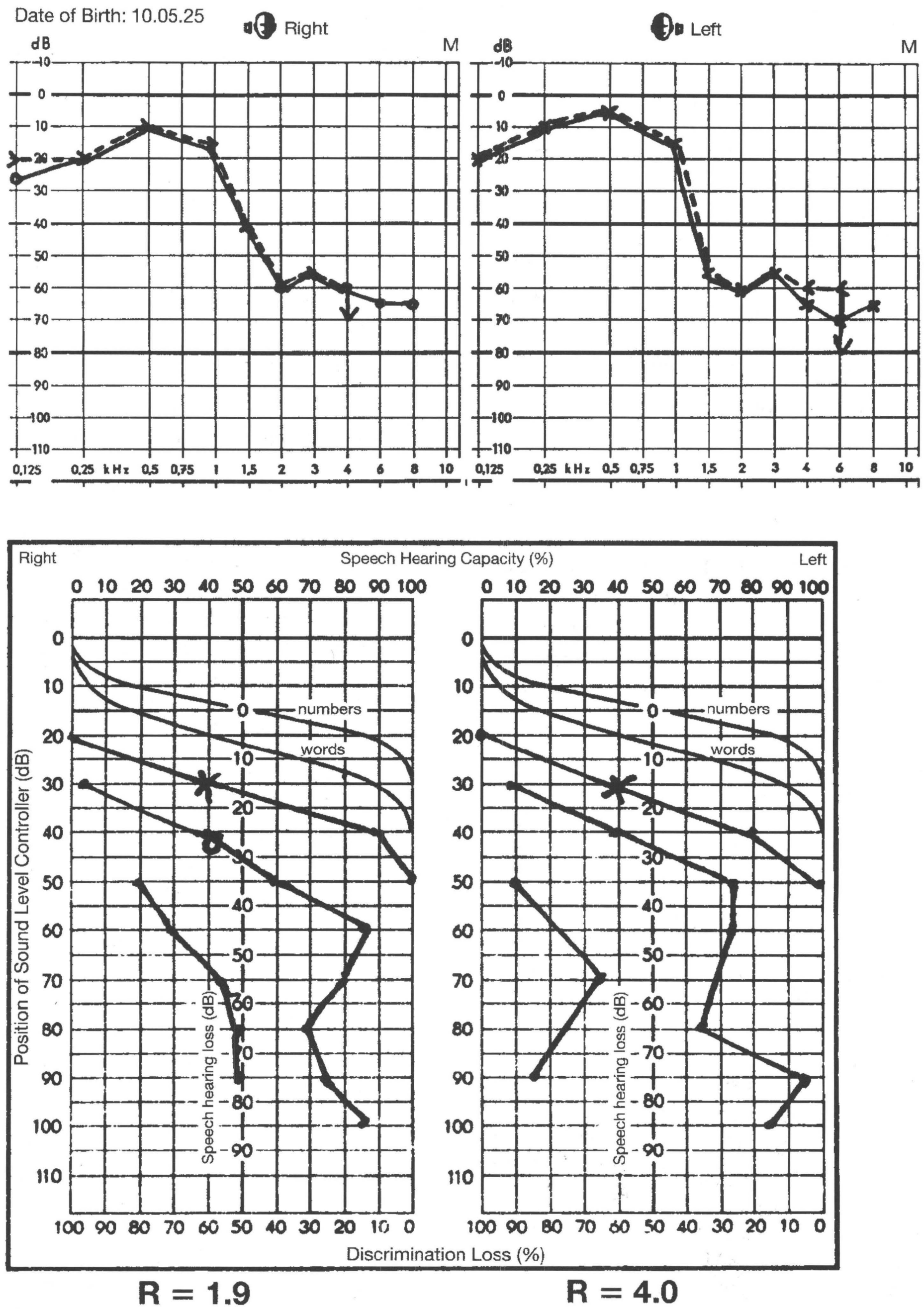

Figure 5. Dissimilar reverberation ratios (R) at approximately symmetrical pure-tone hearing loss in a work noise–exposed laborer. (M = masking noise.)

level of origin by evaluating all audiometric test results combined. Routine follow-up examinations of sensorineural hearing loss often reveal a considerable discrepancy between the two ears (Fig. 5), which is of importance when fitting hearing aids. Also, at regular checkups of patients with noise-induced hearing loss, the onset and progression of ascending degeneration of the hearing nerve may be observed by means of the test [16].

In the process of employing the test continually on a patient, one may find in the reverberation ratio alterations that are generated in the upper brain levels (i.e., levels 4 and 5). In addition, with this subjective hearing test method, the plasticity of the central auditory system may be recorded or assumed. The distorted-speech test, when employed in the described way, even permits a quantification to some extent. We found, as an example, in a patient with congenital unilateral deafness an abnormally reduced reverberation ratio in the contralateral normal-hearing ear, which indicates a certain central compensation of the unilateral impairment. In addition, the test permits verification of a "late-onset auditory deprivation" [17]. Space limitations prevent us from citing further examples here.

DISCUSSION

The development of modern yet, in many cases, rather extravagant hearing test methods allows a steadily growing insight into the localization of damage to the auditory system. The constantly improving topodiagnostic possibilities compel us now to consider five levels of sound perception and processing as basic components of our audiometric test battery and to draw audiological evaluations from diverse, meticulously designed test methods.

Various other modern examination techniques, such as magnetic field audiometry, must be preceded by subtle audiometric examinations because only homogeneous patient cohorts allow conclusions as to specific alterations in the magnetic field and to the diagnostic value of the method [18]. In an audiometric test battery, the distorted-speech test (like any other measuring method) is especially indispensable in localizing distinct damage levels in the auditory system.

The method seems to be of special advantage in cases in which an ascending degeneration and damage to the cortical selection centers are suspected. However, when damage to the outer hair cell layer must be identified, measurement of the OAEs is the first choice [9,19,20]. With damage to the hearing nerve and to superior brain levels, the aggravated-speech tests—speech tests with background noises and distorted speech—are, aside from electric response audiometry, brainstem evoked response audiometry, and magnetic field audiometry, equally useful for diagnostic purposes. Moreover, the best of these tests correspond to the patient's hearing capacity in real-life situations.

Because the distorted-speech test combined with the obligatory speech discrimination test renders information both about pathological masked speech results and about pathological time-related signal-analyzing mechanisms, it is recommended for incorporation into every audiometric test battery as a basic component. Pathological reverberation ratios instantly tell the examiner that specified tests might be necessary in one case or another.

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