The Audiology Primer
for Students and Health Care Professionals
3rd Edition

contributions from and compilation by the VA Audiology staff at

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Long Beach, California

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Department of Veterans Affairs

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The Audiology Primer

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PREFACE

This primer is a revision and extension of *Audiology: An Introduction and Overview for Residents and Medical Students* (1982) developed by Cynthia G. Fowler, Ph.D., Howard C. Jones, M.A., Janet E. Shanks, Ph.D., and Richard H. Wilson, Ph.D. at the VA Medical Center, Long Beach, California. In 1997 the *Primer* was revised with contributions from Lisa Gibbs, M.S. (Long Beach), Anne Strouse, Ph.D. (Mountain Home), Cheryl Longinotti, Ph.D. and Vallarie Smith Cuttie, M.A. (San Francisco), and Doug Noffsinger, Ph.D. (West Los Angeles). This work represents the 3rd revision of the *Primer*. As with the previous *Primers*, the current primer is intended (1) to introduce audiology to clinical and rehabilitative health science students, medical students, interns, residents, medical staff, and allied health professionals, and (2) to serve as a reference for the future audiological needs of these professionals. Contributions to the current primer were made by the following VA Medical Centers:

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INTRODUCTION

Audiology is the science of hearing that deals with the evaluation of hearing disorders, with the rehabilitation of individuals with hearing impairment, and with research pertaining to the auditory mechanism. The field of audiology started in military aural rehabilitation centers during the last years of World War II. The term "audiology" was applied to the field by Raymond Carhart, a speech pathologist, and by Norton Canfield, an otologist, who combined their specialized areas to focus on the aural rehabilitation of service men with hearing impairment. Following World War II, audiology centers were established both in Veterans Administration (Affairs) hospitals and in the civilian sector. As graduate programs were established to educate audiologists, the scope of practice of audiology was widened to include diagnostic services as well as aural rehabilitative services. In 1965 the American Speech-Language-Hearing Association (ASHA), which certifies audiologists on a national basis, established the master's degree as the entry level for audiologists. Slowly during the subsequent 35 years two things happened to audiology. First, audiology was defined legally by each state enacting licensure laws that were aimed at ensuring quality professional services. Second, the scope of practice increased substantially to include all aspects of auditory and vestibular function. As a result of this expanded scope of practice, the educational institutions determined that the educational offerings likewise needed to be enhanced. To meet this need, effective in 2007 professional education in audiology was increased from a two-year masters program to a four-year doctoral program. Currently, audiologists are educated only at the doctoral level with the Doctor of Audiology degree (AuD) focusing on clinical activities and the Doctor of Philosophy degree (Ph.D.) focusing on research and other scholarly activities.

According to the American Speech-Language-Hearing Association, 28 million people in the United States are affected by hearing loss. The most common cause of hearing loss is advancing age. In individuals between 45-64 years of age, the incidence of hearing loss is estimated at 14%. This incidence increases to 23% in people 65-74 years of age, and to 31% in individuals over 75 years. Within the 45-64 years age group, two-thirds of all individuals with hearing loss are males. Noise-induced hearing loss is the most common occupational disease and the second most self-reported occupational illness and injury. Two issues (the definition of hearing loss and how the "hearing loss" is measured) make these estimates of the incidence of hearing loss conservative, especially for the older population. Because the VA patient population is predominantly aging males with a significant history of noise exposure, a large segment of this population can benefit from the diagnostic and/or rehabilitative services of an audiologist.

Traditionally, in the private sector, the audiologist has not functioned as the primary care provider for individuals with ear pathology. Rather, most individuals with hearing disorders are seen by pediatricians, family practitioners, and internists. These patients frequently are referred in turn to otolaryngologists or neurologists for further evaluation. The audiologist then receives referrals from these physicians to perform functional tests of hearing to determine site of lesion and extent of hearing loss. Within the VA, the pattern of referral is different. In most VA medical centers, patients with a primary complaint of hearing loss enter health care through the audiologist. Historical information is obtained and functional tests of hearing are performed; site of lesion and extent of hearing loss is subsequently determined. Patients requiring medical intervention are referred to the appropriate medical specialties; those demonstrating hearing loss not medically treatable are referred for audiologic rehabilitation including the provision of hearing aids and other assistive listening devices, tinnitus maskers, and speech reading/aural rehabilitation classes.

This primer presents an overview of the diagnostic and rehabilitative procedures used by audiologists in the evaluation and management of patients with impaired hearing. The first section describes the sites of lesions in the auditory system that produce hearing loss. The second section presents the auditory tests used in the audiologic test battery for differential diagnosis and outlines the auditory test results associated with the various sites of lesions in the auditory system. The third section describes the aural rehabilitation of patients with hearing loss. The last section presents twelve case studies that exemplify the various sites of lesions and the corresponding auditory test results. Finally, a list of professional organizations, a list of abbreviations, and a list of references are presented.

TYPES OF HEARING LOSS

Basically, there are eight types of hearing loss, seven of which are categorized according to anatomic sites of lesion along the auditory pathway. The eighth type of hearing loss (pseudohypacusis) is not related to an anatomic site of lesion.

CONDUCTIVE

Conductive hearing loss results from an obstruction to the flow of acoustic energy in either the outer ear or in the middle ear. Common etiologies of conductive hearing loss in the outer ear include blockage of the external auditory canal by cerumen, by foreign bodies, by external otitis, or by congenital or acquired atresia of the external canal. Common etiologies of middle-ear obstruction include otitis media, fixation or disarticulation of the ossicular chain, and trauma to the tympanic membrane and other middle-ear structures. Conductive pathologies are demonstrated audiometrically by air-conduction thresholds worse than bone-conduction thresholds by more than 10 dB. Nearly all pathologies in the outer and middle ear are responsive to medical and/or surgical intervention; most patients with conductive hearing loss also respond well to amplification when necessary.

SENSORY

Sensory hearing loss results from pathology involving the sensory end organ in the cochlea. The most common sites of lesion include the outer and inner hair cells within the Organ of Corti, and the stria vascularis within the scala media. Common etiologies include presbycusis, exposure to intense noise, systemic diseases like ototoxicity, infection of the inner ear labyrinths, and heredity. On the audiogram sensory hearing loss is demonstrated by decreased air-conduction thresholds equivalent to decreased bone-conduction thresholds. Sensory hearing loss is differentiated from neural pathology by a battery of behavioral and physiologic test protocols including measurement of the auditory brainstem responses (ABR) and otoacoustic emissions (OAE). Some sensory pathologies are medically and/or surgically treatable (Ménière's Disease, autoimmune disorders); most, however, are not. Patients with sensory pathology typically respond well to amplification.

NEURAL

Neural hearing loss results from pathology to the auditory branch of CNVIII. Etiologies may include presbycusis, space-occupying masses [particularly at the cerebello-pontine angle (CPA)], demyelinating disease such as MS, or infection. Audiologically, neural lesions present as equally reduced air- and bone-conduction thresholds; neural lesions may be differentiated from sensory lesions by a battery of behavioral and physiologic test protocols including measurement of the ABR and OAE. Most neural pathologies entail risk to the patient and require medical/surgical intervention. Patients with neural hearing loss may not respond well to amplification, but recent innovations in hearing aids require investigation of this option if any residual hearing persists following medical/surgical intervention.

SENSORINEURAL

Ideally, this term is used to identify hearing loss resulting from both sensory and neural sites of lesion, perhaps also including brainstem and cortical pathways. As with neural lesions, common etiologies include presbycusis, space-occupying lesions, demyelinating disease, or infection; vascular lesions may also present this type of hearing loss. Audiologically, the hearing loss may be demonstrated as sensory or neural, and the site-of-lesion test battery may produce findings suggestive of either site or both sites. Intervention requiring medical/surgical or audiologic measures is dictated by the site of the lesion and the underlying pathology.

The term sensorineural is more commonly used to identify hearing loss resulting from either a sensory or a neural site of lesion, but the necessary differentiating tests were not conducted and may not be ordered because the site is assumed to be sensory and the lesion non-threatening.

MIXED

A mixed hearing loss is caused by a disorder of the external and/or middle ear (conductive) in combination with a disorder of the cochlea and/or auditory branch of CNVIII. It presents audiologically as a decreased response to bone-conducted stimuli with an overlying conductive loss of at least 15 dB. Treatment is appropriate to the site of lesion.

BRAINSTEM

Brainstem lesions occur along the auditory pathways central to and including the cochlear nuclei and distal to and including the acoustic radiation emanating from the medial geniculate body of the thalamus. Common etiologies include vascular accidents, space-occupying masses, traumatic brain injury (TBI), infection, and demyelinating disease. In the absence of peripheral hearing loss, brainstem pathology will frequently yield normal pure-tone audiometric results; disruption of the auditory system at this level may be demonstrated behaviorally by more subtle tasks that tax the integrative functions of the brainstem and mid-brain auditory pathways, and by means of electrophysiological testing. Treatment is specific to the underlying pathology; these patients typically are not candidates for hearing aids. They may receive benefit, however, from assistive listening devices in understanding speech under less than ideal listening conditions.

CORTICAL

A cortical hearing disorder usually involves a site of lesion in the temporal lobe, or the corpus callosum. Common etiologies include vascular accidents, space occupying masses, infection, and head trauma. In the absence of peripheral hearing loss, cortical pathology will frequently yield normal pure-tone audiometric results; disruption of the auditory pathway at the cortical level may be demonstrated behaviorally by more subtle auditory tests that tax the processing function of the cortical structures, and by electrophysiological measures. These patients are not good candidates for conventional hearing aids, but may receive benefit from assistive listening devices when listening to speech under less than ideal listening condition.

PSEUDOHYPACUSIS

Pseudohypacusis refers to hearing loss that is feigned or exaggerated by the patient. Seldom is a hearing loss feigned in the presence of entirely normal hearing; more commonly, a pre-existing hearing loss is exaggerated in severity in one or both ears. There is no test protocol that can specifically isolate pseudohypacusis in all situations; rather, an interactive process between clinician, patient, and selected test protocols may demonstrate the presence of pseudohypacusis, and frequently determine true organic hearing levels.

DIAGNOSTIC AUDIOLOGY

The primary goal of an audiologic evaluation is the assessment of the integrity of the auditory system and the determination of degree of handicap imposed by any auditory deficit identified in the course of the examination. This goal is accomplished by several test procedures that enable the audiologists to infer the degree of communicative handicap from the pure-tone audiogram, from speech audiometry results, and from the comments of the patient and family, and to determine the site of lesion of the auditory pathology from the results of a complete audiologic test battery. The degree of hearing loss is specified as normal, mild, moderate, moderately-severe, severe, or profound, whereas the site-of-lesion is specified as conductive, sensory, neural, sensorineural, mixed, brain stem, cortical, or pseudohypacusis.

The auditory system is multidimensional and responds to three auditory stimulus characteristics (frequency or spectrum, amplitude or level, and temporal or time) and the multitude of combinations that these three characteristics generate. As was mentioned earlier, hearing loss can be categorized according to seven anatomic sites throughout the auditory system from sensory to cortical. In a similar, almost parallel manner, hearing loss is used to describe any one or a combination of domains of auditory function. The domain of auditory function that is the gold standard is the pure-tone audiogram that is a frequency by amplitude measure that reflects predominantly functioning of the end organ (cochlea). Other common domains of auditory function include the ability to understand speech in quiet and in background noise. The test instruments described in this section are used to access the gamut of domains of auditory function.

Audiologic tests are comprised of two basic types. *Sensitivity tests* measure threshold auditory behavior and *acuity tests* measure supra-threshold auditory behavior (Ward, 1964). All audiologic evaluations are preceded by a case history and an otoscopic examination of the external ear.

CASE HISTORY

Prior to a formal case history, the medical chart is reviewed for information that may necessitate a modification of standardized test procedures (e.g., history of cerebral vascular accident or laryngectomy) or that may help in the interpretation of the test results (e.g., CNVII disease or history of ear surgery). The formal case history provides subjective and objective impressions regarding the status of the patient's auditory mechanism (e.g., general complaints of decreased hearing, differences between ears, prior ear disease and treatment, vertigo, noise exposure, tinnitus, familial history, and prior use of a hearing aid).

For children, the case history is usually more comprehensive. In addition to questions such as the ones mentioned for adults, detailed questions about the mother's pregnancy and child's birth are included. The development of fine and gross motor skills and the development of speech and language also are queried. The medical history of the child is reviewed with special emphasis on childhood diseases (e.g., measles, mumps, meningitis) capable of producing a hearing loss.]

OTOSCOPIC EXAMINATION

Following the chart review and case history, the pinna and external ear canal are examined. An otoscopic examination will reveal the presence of cerumen or foreign bodies in the ear canal and/or of a collapsible ear canal, which is especially common in older patient populations. If these problems are not identified at the beginning of the evaluation, then the test results will be invalid. Finally, the otoscopic examination will reveal problems such as an active ear infection that require immediate medical referral.

PURE-TONE AUDIOMETRY

Pure-tone audiometry is used to determine the lowest levels at which a person can hear pure tones in the 250-Hz to 8000-Hz range. A pure tone is a sinusoidal waveform (so named because it can be expressed mathematically as a sine function) that can be described in terms of frequency, amplitude, and duration. Frequency refers to the number of cycles per second (cps) of the waveform and is measured in Hertz (Hz) (1 Hz = 1 cps). *Pitch* is the psychological correlate of frequency. The amplitude (volume) of a signal can be expressed either as an absolute value [e.g., voltage is measured as the peak-to-peak or root mean square (rms)] or as a relative value [e.g., decibels (dB)]. The decibel is the logarithmic ratio of two pressures [$dB = 20 \log_{10} (P1/P2)$] or two powers [$dB = 10 \log_{10} (P1/P2)$] . In both formulas, P1 and P2 are the two pressures or powers. Because the decibel is a relative value, it always must be expressed with an appropriate reference [e.g., decibels sound-pressure level (dB SPL) or decibels hearing level (dB HL)]. *Loudness* is the psychological correlate of amplitude. Duration refers to the length of time the signal is present. In audiology most signals have a duration that is measured in milliseconds (ms) or seconds (s).

The ear is differentially sensitive across frequency, i.e., the level (amplitude) required to reach the threshold of audibility varies with frequency. The differential sensitivity of the ear is illustrated in **Figure 1** in which normal air-conduction thresholds in decibels sound-pressure level [re: 20 microPascals (μPa)] are shown as a function of frequency in Hertz (Hz). Sound-pressure level (SPL) is the energy reference commonly used in physical acoustics and in psychoacoustics. Although the normal human ear is capable of hearing pure tones from 20 Hz through 20,000 Hz, the ear is most sensitive in the 750-4000 Hz range and is least sensitive at frequencies <750 Hz and >4000 Hz. It probably is not coincidental that most energy in speech falls within the frequency range of greatest sensitivity. As shown in Figure 1, average normal hearing (through a TDH-50 earphone) is equal to 7.5-dB SPL at 1000 Hz and 25.5-dB SPL at 250 Hz. For convenience, the pure-tone audiometer is calibrated to compensate (normalized) for the differential sensitivity of the ear across frequency.

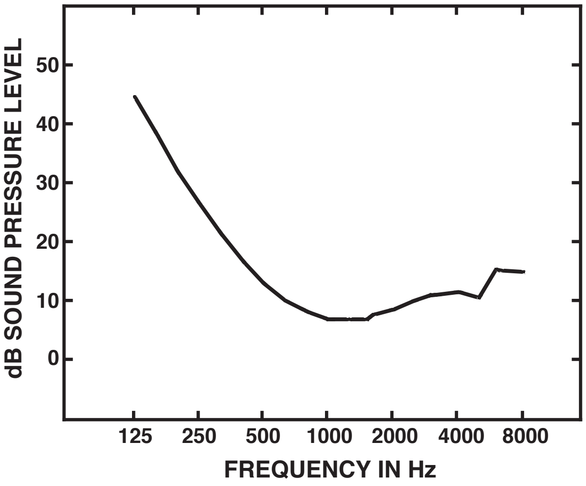

Figure 1. Thresholds in decibels sound-pressure level for a typical young adult with normal hearing tested with supra-aural earphones plotted as function of frequency (in Hertz).

Pure-tone audiometry can be traced to the invention of the tuning fork (ca. 1711) by John Shore who was a musician in England. As the name implies, the tuning fork was developed as a reference for tuning musical instruments. In the 1800s the classic tuning fork tests, which are described later, were developed and used widely in the diagnosis of hearing disorders. Shortly after the advent of electrical instruments, Helmholtz (1863) developed an electrically driven tuning fork and Alexander Graham Bell (1876) developed the transducer. Then, independently Hartmann in Germany and Blyth in England combined the two inventions to produce an instrument that could be used to test hearing. The term audiometer was applied to the tuning-fork instruments in 1879 by an Englishman, B. W. Richardson. In 1913, Brunings developed an electrical resonance circuit that replaced the tuning fork as the signal source. Two German groups in 1919 developed the first electronic audiometers whose signals were generated with vacuum-tube oscillators. The Western Electric 2A audiometer, which was the first commercial audiometer introduced in the late 1920s, had eight frequencies (octave intervals from 64 Hz through 8192 Hz) with adjustable levels (Jones and Knudsen, 1924). (Feldmann, 1960, provides a detailed history.)

Pure-tone audiometry provides frequency specific information about the auditory mechanism at octave intervals from 250 Hz through 8000 Hz, including half octaves above 500 Hz. A pure-tone threshold is established at each frequency for each ear using a bracketing technique to vary the level of the tone. The pure-tone threshold is the hearing level in decibels at which the listener responds approximately 50% of the time. The testing technique uses the following three simplified rules:

1. if the patient responds positively to the presentation, then the level is decreased 10 dB for the next tone presentation,

2. if the patient does not respond to the tone presentation, then the level is increased 5 dB for the next presentation; and

3. if there are two positive responses at one level, then that level is designated threshold for that frequency and the next frequency is tested.

The pure-tone thresholds are recorded on an audiogram, which is a frequency by level plot of the patient's thresholds. For air-conduction thresholds, "Os" and "Xs" are used for the right and left ears, respectively. An example (blank) audiogram is shown in **Figure 2**. On the audiogram the decibel Hearing Level (re: ANSI, 2004) is plotted on the ordinate with the frequency in

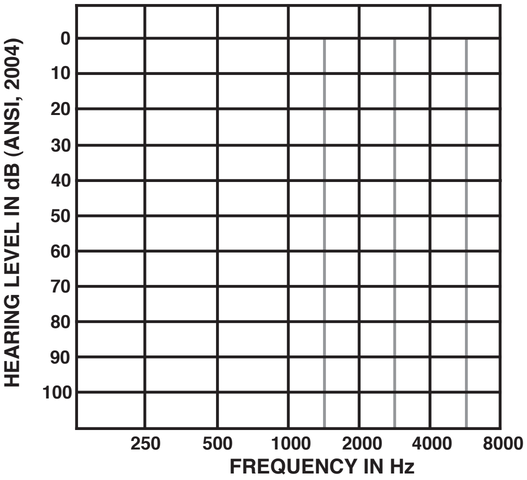

Figure 2. An example of an audiogram.

Hertz plotted logarithmically on the abscissa. The aspect ratio of the audiogram is 20 dB/octave. Generally with pure-tone audiometry, the patient responds by pushing a button when he hears the tone. Modifications in this response mode often are made to accommodate children who are unable to push the button. The response modifications usually involve conditioning the child to respond with a play activity, e.g., dropping a block in a box when the tone is heard. For children who cannot be conditioned under earphones, sound-field testing techniques are employed. In sound-field testing, warble tones (frequency modulated) are presented via loudspeakers in a sound-treated room and the child's responses are judged by his behavior, e.g., localization to the sound source or cessation of activities when the tone is presented. A major disadvantage of sound-field testing is that information obtained may only infer the status of the better ear. Inferential data about the ability of a child to hear often may be obtained with combinations of more objective procedures, including acoustic reflex thresholds, evoked otoacoustic emissions, and auditory evoked potentials (each of which is discussed in subsequent sections). Pure-tone thresholds are determined (1) for air-conducted signals delivered through supra-aural or insert earphones and (2) for bone-conducted signals delivered through a bone vibrator placed on the mastoid process or on the forehead. Theoretically, bone-conduction signals bypass the middle ear and measure cochlear sensitivity only (some exceptions do occur). With most patients, the air-conduction and bone-conduction thresholds are essentially the same. When the bone-conduction thresholds are at lower levels (better) than the air-conduction thresholds, however, a conductive (or mixed) hearing loss is indicated. Although the amount of hearing loss is quantified in decibels, the following five descriptors are used to describe the pure-tone hearing loss (see **Figure 3**):

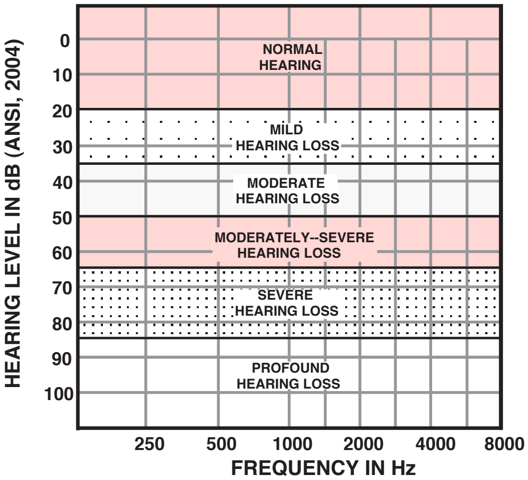

Figure 3. An audiogram with the degrees of hearing loss superimposed.

1. 0- to 25-dB HL--normal hearing,
2. 26- to 40-dB HL--mild hearing loss,
3. 41- to 55-dB HL--moderate hearing loss,
4. 56- to 70-dB HL--moderately-severe hearing loss,
5. 71- to 90-dB HL--severe hearing loss, and
6. >90-dB HL or no response--profound hearing loss.

[Note: no response means that no response was obtained from the patient at the output limits of the audiometer].

To relate the audiogram to everyday acoustic environments, the audiogram in **Figure 4** has been altered to include examples of speech and common environmental sounds that cover the gamut of both the frequency and level domains. The levels for many of the speech sounds are depicted in Figure 4 at their approximate frequency ranges with normal conversational speech occurring at about 50-dB HL. For comparison, a whisper is around 25-dB HL and a shout is in the 80- to 90-dB HL range. The levels for environ-mental sounds range from the sand flowing in an hourglass at 0-dB HL, to a watch ticking at 30-dB HL, to a vacuum cleaner at 60-dB HL, to a dog barking at 75-dB HL, to a jet plane at >110-dB HL.

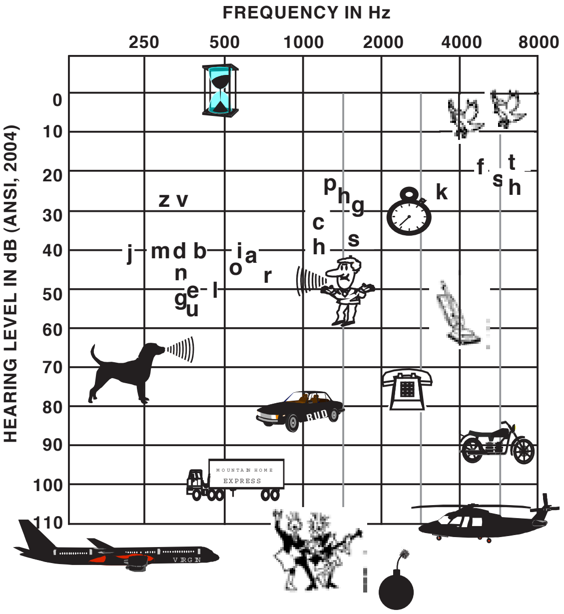

Figure 4. An audiogram with the levels of various speech and environmental sounds superimposed.

MASKING

For most audiologic test procedures, information must be obtained separately from the two ears. If the hearing sensitivity of the ears is considerably different, then a tone presented to the poorer (test) ear at a high decibel Hearing Level can cross the head via bone conduction and be heard in the better (non-test) ear. In this situation, termed cross-over or cross hearing, participation of the non-test ear is eliminated by introducing a masking noise into the non-test ear. The noise effectively creates a cochlear hearing loss in the non-test ear and allows the test ear to be examined independently. For air-conduction tests (through supra-aural earphones), the non-test ear must be masked whenever the air-conducted signal to the test ear is 40 dB or greater than the bone-conduction threshold in the non-test ear. Thus with supra-aural earphones the interaural attenuation is 40 dB, which is a value that is influenced by the mass and elasticity of the head. The use of insert earphones increases the interaural attenuation to 75 dB for frequencies ≤1000 Hz and 50 dB for frequencies ≥1500 Hz.

In contrast, the interaural attenuation for bone conduction is essentially 0 dB. In the absence of masking, the responses to bone-conduction signals reflect the sensitivity of the better cochlea, regardless of the mastoid on which the bone vibrator is placed. Consider for example a patient with one ear that is “dead” (i.e., an ear with no measurable hearing via air conduction or bone conduction) and the other ear that is normal (air- conduction thresholds of 0-dB HL). The bone-conduction thresholds for this patient would be 0-dB HL even when the bone vibrator is placed on the mastoid process of the “dead-ear”. Thus, whenever there is an asymmetrical hearing loss or a conductive hearing loss, the non-test ear must be masked for valid bone-conduction thresholds to be obtained from the test ear.

AUDIOMETRIC TUNING FORK TESTS

Two traditional tuning fork tests, the Weber and the Bing, can be administered by substituting the bone vibrator for the tuning fork. The audiometric procedures have two advantages over the tuning fork procedures. First, the level of the tone delivered through the bone vibrator can be controlled accurately and maintained over time. Second, the results are directly comparable across audiometers and testers.

Weber Test

Although Wheatstone first described the effect in 1822, both Bonafont (1845) and Schmaltz (1846) cited a monograph written by Weber in 1834 proposing the Weber tuning fork test as a clinical procedure. The purpose of the Weber is to determine whether a unilateral hearing loss is conductive or sensorineural. The bone vibrator is placed on the forehead and a tone is presented at ~5 dB below vibrotactile levels of 40-dB HL at 250 Hz and 55-dB HL at 500 Hz. The patient is asked where the tone is heard. The tone will lateralize to the ear with a conductive component or to the ear with the better cochlea. If the tone lateralizes to the poorer ear, then the unilateral hearing loss is conductive; if the tone lateralizes to the better ear, then the unilateral hearing loss is sensorineural. A person with symmetrical hearing will hear the tone in the center of the head.

Bing Test

Wheatstone and Tourtual both described the occlusion effect in 1827, and Bing proposed it as a clinical test in 1891. The Bing effect refers to the enhancement of hearing by bone conduction when the ear canal is occluded. The magnitude of the occlusion effect is frequency dependent. Bone conduction is enhanced by approximately 20 dB at 250 Hz, 15 dB at 500 Hz, and is negligible above 1000 Hz. The purpose of the Bing is to verify the presence of an air-bone gap >10 dB. The test generally is performed in conjunction with the Weber. The bone vibrator is placed on the forehead and the patient is asked where the tone is heard (i.e., the Weber). The ear then is occluded by cupping the hand tightly over the pinna or by plugging the ear canal with a fingertip, and the patient is asked if the tone changes. A positive Bing at 250 and 500 Hz occurs if the tone increases in loudness or lateralizes to the occluded ear; a positive Bing is recorded in patients with normal hearing or with a sensorineural hearing loss. A negative Bing, or no change in the loudness or location of the tone with occlusion of the ear canal, occurs in an ear with a conductive component.

The Bing is most useful in verifying the presence of small, low-frequency air-bone gaps such as seen in early otosclerosis or erroneously recorded because of low-frequency leakage from insert earphones or ear-canal collapse. The test, however, is not useful if bone-conduction thresholds between ears are markedly asymmetric.

EXAMPLES OF PURE-TONE AUDIOGRAMS

The following four examples are pure-tone audiograms that illustrate the types of peripheral hearing losses. (For discussion purposes in the examples, other auditory test results used to classify the hearing losses are not shown and masking of the non-test ear has not been included.) The audiogram in **Figure 5** illustrates a conductive hearing loss. The Os represent the right-ear air-conduction thresholds and the brackets represent the bone-conduction thresholds. The air-conduction thresholds demonstrate a mild hearing loss. In contrast, the bone-conduction thresholds are in the normal hearing range. The magnitude of the conductive component, which is quantified as the difference between the air-conduction and the bone- conduction thresholds, is about 30 dB. Stated differently, this case demonstrates a 30 dB air-bone gap.

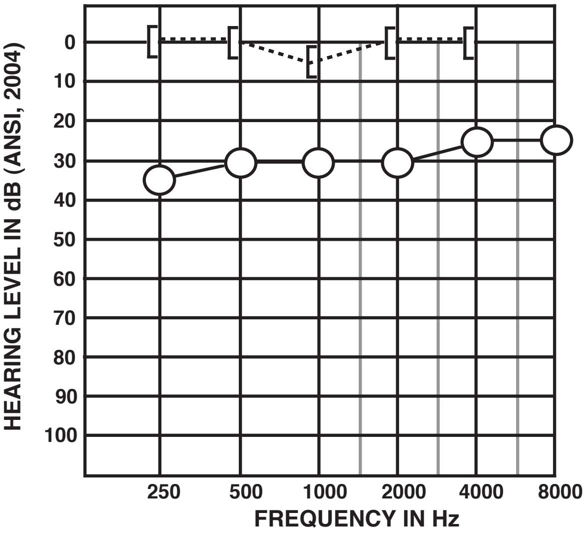

Figure 5. An audiogram illustrating a mild conductive hearing loss on the right ear. The air-conduction thresholds for the right ear are shown as Os and the masked, bone-conduction thresholds are shown as brackets.

The pure-tone thresholds depicted in **Figure 6** exemplify a sensorineural hearing loss in the right ear. The air-conduction and the bone-conduction thresholds (Os and brackets, respectively) are at the same decibel Hearing Levels. This right ear demonstrates normal hearing from 250 Hz through 1000 Hz with a mild-to-moderate, high frequency sensorineural hearing loss from 2000 Hz through 8000 Hz.

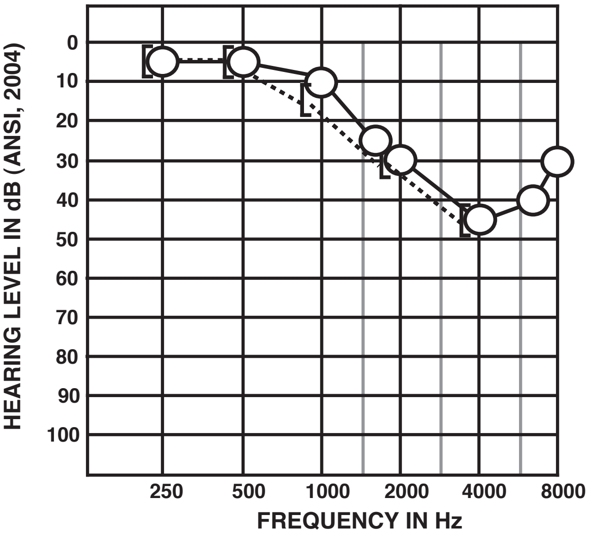

Figure 6. An audiogram illustrating a mild-to-moderate, high-frequency sensorineural hearing loss on the right ear. 1000 Hz with a mild-to-moderate, high-frequency sensorineural hearing loss from 2000 Hz through 8000 Hz.

The audiogram in **Figure 7** illustrates the pure-tone thresholds in a sensorineural hearing loss in the left ear (represented by Xs). The air- conduction and the bone-conduction thresholds interweave. (The threshold symbols with arrows, 4000 Hz bone conduction and 8000 Hz air conduction, indicate the thresholds were beyond the output limits of the audiometer.) In this example, there is a mild low-frequency hearing loss (250-500 Hz), a moderate mid-frequency loss (1000-2000 Hz), and a severe-to-profound high- frequency loss (3000-8000 Hz).

The pure-tone thresholds in a mixed hearing loss in a left ear are shown in **Figure 8**. The difference between the air-conduction and the bone-conduction thresholds indicates a conductive component of about 30 dB. A hearing loss also is present for the bone-conducted signals. Thus, two types of hearing loss, conductive and sensory, are demonstrated in this case.

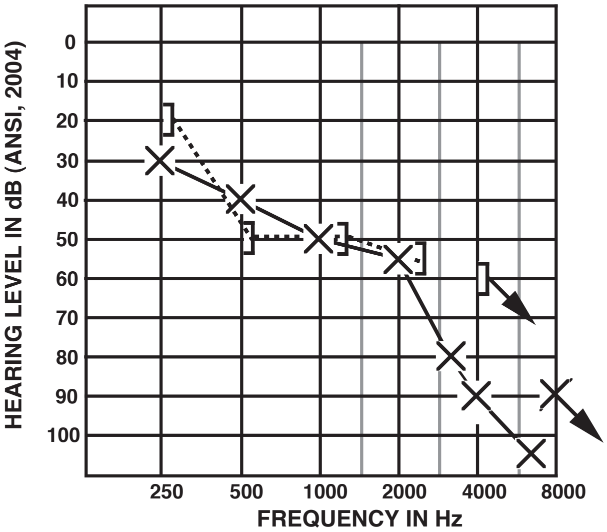

Figure 7. An audiogram illustrating a mild-to-profound, sensorineural hearing loss on the left ear. The Xs are the air-conduction thresholds and the brackets are the masked bone-conduction thresholds. The arrows attached to the symbols indicate that no response was obtained at the output limits of the audiometer.

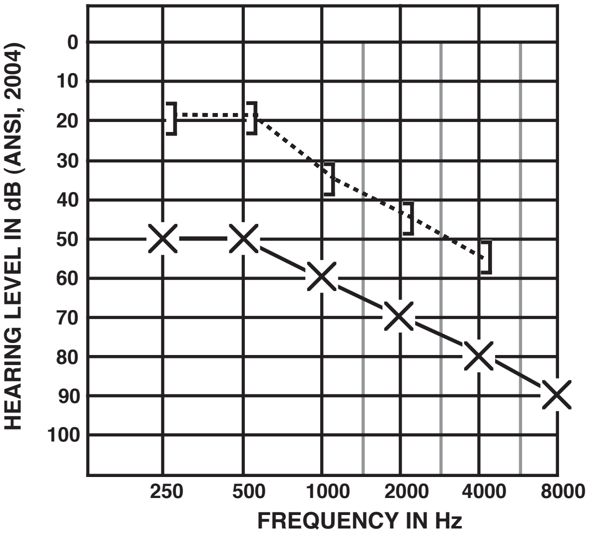

Figure 8. An audiogram illustrating a moderate-to-severe, mixed hearing loss. Both the air-conduction thresholds (Xs) and the bone-conduction thresholds (brackets) indicate hearing loss.

SPEECH AUDIOMETRY

The use of speech stimuli to assess the status of the auditory system was advocated and debated among otologists in the late 1800s. For example, in 1891, Gruber wrote, “Oscar Wolf considers this the most perfect method of testing the hearing power, in as much as it embodies the most delicate shades in the pitch, intensity, and character of sound. Hartmann thinks, on the contrary, that the test is too complicated to insure accuracy.” Hartmann’s objection was overcome by a sequence of scientific inventions that provided quantitative control of speech stimuli. First, in 1876 Alexander Graham Bell developed a transducer that converted sound energy into electrical energy and vice versa [actually, Antonio Meucci is credited with inventing the telephone]. Second, in 1877, Thomas Edison patented the phonograph, after which Lichtwitz in 1889 wrote, “On the Application of the New Edison Phonograph to General Hearing Measurement”. Third, in 1883, Edison devised the vacuum-tube principle, “the Edison effect”, that made possible the development of electronic amplifiers. During the early 1900s, these and other inventions led to the development of electro-acoustic communication systems. Because these systems were used for speech communications, speech materials were devised to evaluate the communicative efficiency of the systems. These developments formed the basis of speech audiometry as it is used today in the assessment of hearing function (Feldmann, 1960).

Routine speech audiometry is comprised of threshold and supra-threshold measures. The speech-recognition threshold (SRT), which is a monaural sensitivity measure, is the level (decibel Hearing Level, re: ANSI, 2004) at which 50% correct performance is achieved with a standard list of spondaic words. Word-recognition performance, which is a monaural acuity measure, is the percent correct achieved at selected supra-threshold increments in response to standard lists of 25 or 50 monosyllabic words (Hirsh et al., 1952; Hudgins, et al., 1947; Tillman and Carhart, 1966). Word-recognition data, which are obtained in quiet and increasingly in background noise, give a good indication of how well the patient is able to understand speech. Word-recognition performance in noise provides the most information regarding the functional auditory abilities of the patient, followed by word-recognition in quiet, and lastly, the speech-recognition threshold. It is important to note that just as word-recognition performance in quiet can not be predicted from pure-tone thresholds, word-recognition ability in noise can not be predicted from word-recognition performance in quiet. The only assured prediction is that word recognition in noise will be poor when word recognition in quiet is poor. All other predictions about recognition performance are tenuous.

Because speech audiometry involves an independent variable (presentation level of the speech signal) and a dependent variable (percent correct response of the patient), it is instructive to review the relations between the two variables in the context of an input/output function (presentation level/percent correct response).

Such a function, termed a psychometric function, is plotted with the percent correct on the ordinate and the presentation level on the abscissa. Usually, as the presentation level of the speech signal increases, there is a corresponding increase in the performance level of the patient. The rate at which the independent and dependent variables interact is the slope, i.e., $\Delta y/\Delta x$, of the psychometric function.

Two aspects of speech audiometry need to be considered, the presentation mode of the stimuli and the response mode of the patient. First, the presentation mode of the speech signal can be by monitored-live voice (MLV) or by a recording (compact disc). The monitored-live voice procedure provides greater flexibility, whereas the recorded materials provide standardization. Second, the response mode typically involves having the patient verbally repeat the target word. With those patients who are unable to verbalize the speech signal (e.g., some children and aphasic patients), the response mode is modified to have the patient write the response or point to a word, picture, or object from a set of response alternatives that includes the target word (Ross and Lerman, 1970). The written response is similar to the oral response in that both are open-set paradigms. In contrast, the pointing response is based on a closed-set paradigm that usually includes four to six choices. The difference between performances obtained through open-set and closed-set response modes is based on probability. The response choices in the open set are restricted only by the patient's experience and vocabulary; thus, the performance level for a list of words ranges from 0% to 100% correct. The response choices in the closed set, however, are limited by the number of alternatives offered the patient. If the closed set contains four response choices, then the patient will get one of four responses correct simply by guessing; thus the performance level with this paradigm ranges from 25% to 100% correct.

Threshold Measures of Speech Signals

During World War II, scientists working at the Harvard Psycho-Acoustic Laboratory introduced the spondaic-stressed bisyllabic word as the stimulus material for measuring "the loss of hearing for speech." The spondaic words were the earliest stimuli developed to measure the auditory threshold for speech. In 1952, the original list of 84 spondaic words was reduced to 36 words by a group at the Central Institute for the Deaf (CID) (Hirsh, et al.). These 36 spondaic words continue in use in audiology clinics (Appendix).

Two types of threshold measures are made with speech signals, speech-detection thresholds (SDT) and speech-recognition thresholds (SRT). Fewer auditory cues are needed for the SDT than for the SRT because the former task of the listener is simply to detect the presence of the signal. In contrast to the detection task, more cues are required for the SRT than for the SDT because the listener must perceive enough of the message to recognize the speech signal. When a speech threshold is measured, usually the SRT is the measure of choice; the SDT is used when circumstances preclude establishment of the SRT. The bracketing technique (similar to that used to establish pure-tone thresholds) is used to determine either the SDT or the SRT. Although the thresholds for pure tones and speech recognition are derived from different tasks (detection and recognition, respectively), and the signals are qualitatively different, the three-frequency pure-tone average (500, 1000, and 2000 Hz) and the SRT are usually highly correlated. The exception to this rule is often observed in those patients with sharply sloping (upward or downward) audiometric configurations; with these patients the SRT may better agree with the two best frequencies within the three-frequency span. The SRT, therefore, is useful in confirming the accuracy of the pure-tone thresholds, especially with patients feigning hearing loss. Typical psychometric functions from listeners with normal hearing for the speech-detection and the speech-recognition tasks are illustrated as the two left functions in **Figure 9**. In the figure, the percent correct performance is shown as a function of the presentation level of the spondaic words in decibels Hearing Level (HL) (ANSI, 2004) on the bottom abscissa and in the corresponding decibels sound-pressure level (SPL) on the top abscissa. (As one can observe from the two abscissae, the reference for the HL scale for speech is based on the average speech-recognition threshold, 50% correct, that is equivalent to 20-dB SPL. For speech, therefore, 0-dB HL corresponds to 20-dB SPL.) For equal performance, the detection task requires 4 dB to 8 dB less energy than the recognition task required.

Word-Recognition Performance in Quiet

Word-recognition performance (in percent correct) indicates the ability of the patient to understand speech, usually monosyllabic words presented in quiet. Examples of these materials include the Maryland CNCs, the Northwestern

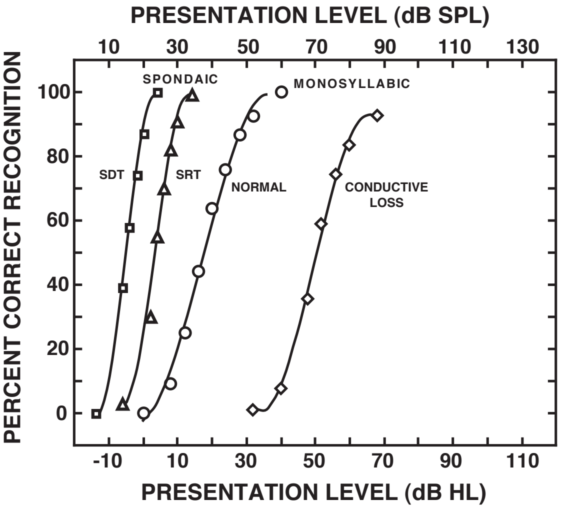

Figure 9. The performance in percent correct on spondaic words (two left functions) and monosyllabic words (two right functions) is shown as a function of the presentation level both in decibels Hearing Level (ANSI, 1996) (bottom abscissa) and decibels sound-pressure level (top abscissa). Both the spondaic word functions and the "normal" monosyllabic function are from listeners with normal hearing. The "conductive loss" function is from a patient with a conductive hearing loss.

University Auditory Test No. 6, and the CID W-22s. Word-recognition performance is established at pre-determined, supra-threshold signal presentation levels, typically between 50- and 90-dB HL. The materials originally used to measure the word-recognition ability of a patient were developed at the Harvard Psycho-Acoustic Laboratory as a set of 20 lists of 50 monosyllabic words each that were phonetically balanced (PB) for the average occurrence of the respective sounds in the English language. Originally, the so-called PB-50 word lists were designed for the evaluation of the efficiency of various communication systems that were under development during World War II (Egan, 1948). Subsequently, the word lists were modified by several auditory research laboratories and incorporated into the clinical procedures currently used in audiology (Hudgins et al., 1947; Hirsh et al., 1952). Most monosyllabic word tests in use today are, by design and standardization, better suited for diagnostic applications than rehabilitative applications.

Monosyllabic words contain less information than do spondaic words. A higher signal-presentation level, therefore, is required to achieve equal performance with the monosyllabic words as compared with spondaic words. This relation is illustrated in Figure 9 in which the average word-recognition performance on monosyllabic words by normal listeners is depicted with circles and labeled "NORMAL". The function for the monosyllabic words required 10 to 20 dB more energy than did the function for the spondaic words to achieve 20% and 80% correct, respectively. The lowest presentation level at which maximum word-recognition performance for young adults with normal hearing is achieved is about 30-dB HL, which is not very loud considering that the average level of a normal conversation is 50- to 60-dB HL.

The ability of a patient to understand speech at a normal conversational level is assessed clinically with a word-recognition task that consists of 25 or 50 monosyllabic words (see Appendix) presented at 50-dB HL. If the pure-tone average at 500, 1000, and 2000 Hz indicates a sensitivity loss >35-dB HL, then the level at which the words are presented is increased. If the performance of a patient is not good at the initial presentation level (e.g., <80% correct), then additional measures are made at progressively higher levels. For practical reasons, maximum performance for a patient is estimated with a limited number of points at 10- or 20-dB intervals on the psychometric function. Finally, the word-recognition performance at a very high signal-presentation level is estimated with monosyllabic words presented at 90-dB HL. For most supra-threshold speech measures, masking should be used in the non-test ear to isolate the ear being tested. The following categories characterize the word-recognition performance:

1. 100% to 80% good,

2. 60% to 78% fair,

3. 46% to 58% poor-to-fair, and

4. 0% to 44% poor.

The effect of a conductive hearing loss on word-recognition performance also is illustrated in Figure 9 as the right-most function. A comparison of the two monosyllabic word functions in Figure 9 shows that a conductive hearing loss simply displaces the psychometric function by the amount of the conductive hearing loss (25 dB on this case). The slope of the function does not change.

The word-recognition performance of patients with sensory hearing losses (cochlear) is more unpredictable than the word-recognition performance of patients with conductive losses. Word-recognition functions for three patients with cochlear hearing losses are depicted in **Figure 10** along with the normal monosyllabic-word function from the previous figure. As illustrated in the figure, cochlear hearing losses produce a word-recognition function (1) that is displaced

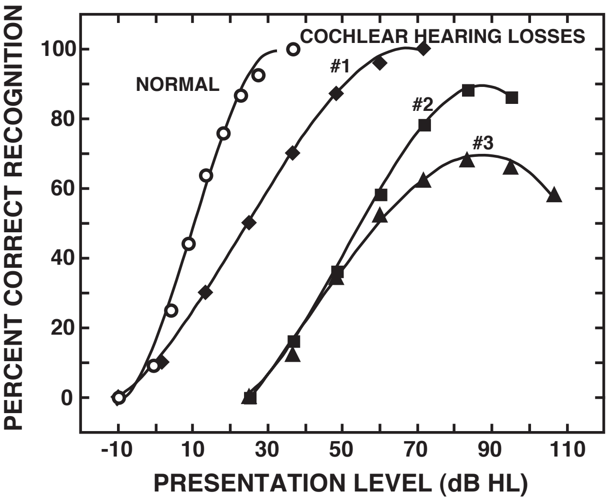

Figure 10. The three psychometric functions labeled #1, #2, and #3 illustrate the word-recognition performance for monosyllabic words often obtained from patients with cochlear (sensory) hearing losses. For comparison, a function from a listener with normal hearing is shown.

to higher hearing levels by the amount of the cochlear hearing loss, (2) that is less steep than the normal function, (3) that can reach a point of maximum performance substantially below 100% correct, and (4) that can demonstrate a decrease in performance as the presentation level of the words is increased above the point of maximum performance.

The effect of a retrocochlear hearing loss (CNVIII and/or low brainstem) on word-recognition performance is illustrated in **Figure 11**. The psychometric functions are displaced to higher hearing levels by an amount equal to or greater than the hearing loss. Two characteristics help differentiate retrocochlear hearing losses from other types of hearing losses. First, the word-recognition performance may deteriorate rapidly as the signal level is increased. This pattern, termed roll-over, is illustrated by retrocochlear hearing losses #1 and #2 in Figure 11. Second, maximum performance may be well below the maximum performance achieved with other types of hearing losses; retrocochlear hearing loss #3 in Figure 11 is an example.

Word-Recognition Performance in Background Noise

The most common complaint that adult patients have about their hearing is they can hear someone talking but they can not understand what they are saying, especially in background noise. As far back as 1970, Carhart and Tillman recommended that the ability of the patient to understand speech in background noise should be a test component of the routine audiologic evaluation. Only recently have audiologists starting using speech-in-noise tests to determine the ability of the patient to understand speech in noise. There are basically two types of speech-in-noise tests: (1) sentences in noise, e.g., the QuickSIN (Killion, et al., 2004) and words in noise, e.g., the Words-in-Noise (WIN) test that was developed by the VA (Wilson, 2003; Wilson and Burks, 2005; Wilson and McArdle, 2007). For obvious reasons, the WIN protocol is described here. The clinic WIN protocol, which uses the NU No. 6 words spoken by the VA female speaker and is available on the *Speech Recognition and Identification Materials, Disc 4.0* produced by the VA, presents 5 words at each of 7 signal-to-noise ratios (S/N, SNR) from 24- to 0-dB in 4-dB decrements. The metric of interest is the 50% correct point on the psychometric function that is calculated with the Spearman-Kärber equation. This point describes the hearing loss of the patient in terms of the signal-to-noise ratio, i.e., a SNR hearing loss that has been described in the literature (e.g., Killion, 2002). Additionally with the WIN the entire psychometric function at 7 SNRs is available for evaluation and the words-in-noise data can be compared directly to recognition performance in quiet because the words and speaker are the same for the WIN and NU No. 6 materials contained on the VA CD.

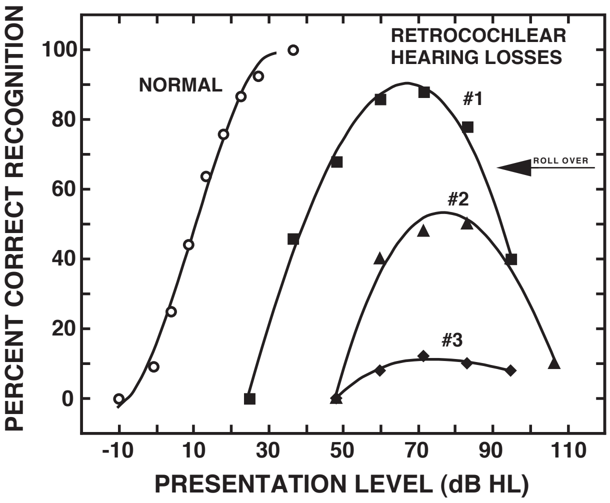

Figure 11. The three psychometric functions labeled #1, #2, and #3 illustrate the word-recognition performance for monosyllabic words often obtained from patients with retrocochlear (neural and/or low brain stem) hearing losses. A comparable function from a listener with normal hearing is shown.

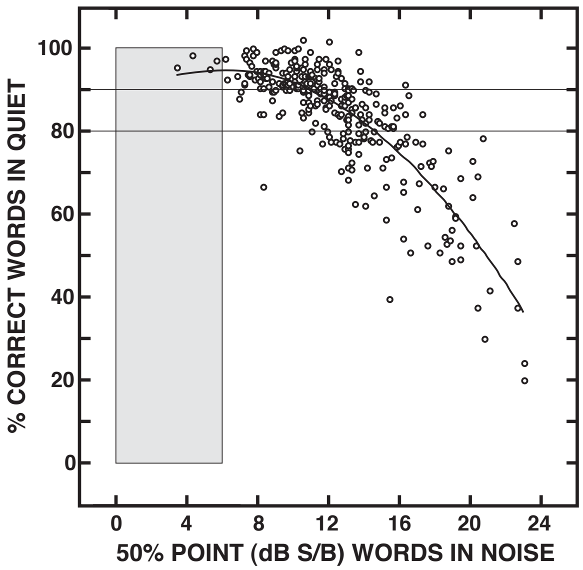

Figure 12. A plot of word-recognition performance in quiet in percent correct (ordinate) versus the 50% point of recognition performance in multitalker babble on the WIN (abscissa). The shaded area represents the 10th and 90th percentiles for individuals with normal hearing on the WIN. The numbers represent the number of listeners who had word recognition in quiet ≥90%, ≥80%, and ≤70% correct on the words in quiet. The data are combined from.

The data in **Figure 12** compare speech recognition performance on the NU No. 6 in quiet (ordinate) with the 50% correct point on the WIN in terms of signal-to-noise ratio (abscissa) by 387 older listeners with sensorineural hearing loss (Wilson and McArdle, 2005). The shaded region represents normal performance on the WIN by young listeners with normal hearing. Two relations are important from the figure. First, only a few of the listeners with hearing loss had performances on the WIN that were normal, i.e., in the shaded region of the graph. Second, over 70% of the listeners with hearing loss had SNR hearing losses >6 dB, with most being in the 8- to 14-dB S/N range. Any SNR hearing loss over a few decibels is substantial and imposes severe limitations on communication. The majority of these listeners had good word-recognition performance in quiet, i.e., >80% correct, but substantial hearing losses in terms of signal-to-noise ratio.

Knowing how good or bad a patient understands speech in background noise helps to address the typical complaint a patient has about her/his hearing. The information from a speech-in-noise task can be used as a basis for the rehabilitation process, including the selection of amplification technologies (e.g., directional microphones) and the shaping of the patient's expectations about the rehabilitation process.

Most Comfortable and Uncomfortable Listening Levels

In addition to the measures of the speech-recognition threshold and word-recognition performance, speech stimuli (and pure tones) are used to establish the most-comfortable listening level and the uncomfortable listening level. The most-comfortable level (MCL) is the decibel Hearing Level preferred by the patient for listening to continuous discourse. Listeners with normal hearing or patients with a conductive hearing loss generally have an MCL 40 dB above the speech-recognition threshold. Patients with a sensory hearing loss can have an MCL that is <40 dB above the threshold for speech. In contrast, patients with a neural deficit may have an MCL substantially more than 40 dB above the speech-recognition threshold. The uncomfortable listening level (ULL) is the decibel Hearing Level of continuous discourse that is uncomfortably loud to the patient. Listeners with normal hearing and patients with a conductive or neural hearing loss generally tolerate the maximum decibel Hearing Level available on an audiometer (100-dB HL), whereas patients with a sensory hearing loss may have a reduced tolerance for high level stimuli. Note: Binaural MCLs and especially binaural ULLs may be as much as 5-10 dB lower than monaural MCLs and ULLs.

SITE OF LESION TESTS

Several procedures in the audiologic battery are designed to give an impression about the cause and/or site of damage in the auditory system. Some of these try to differentiate types of peripheral auditory system damage from one another, i.e., conductive vs. cochlear vs. CNVIII lesion. Others give information about the integrity of central auditory pathways and structures in the brainstem and brain.

Behavioral Tonal Tests

Two tonal procedures that require a voluntary, behavioral response from the patient are useful.

Tone Decay Test: This procedure examines the ability of the patient to sustain hearing for a tone over time (Carhart, 1957; Olsen and Noffsinger, 1974). Tones are presented at a fixed level near threshold until the listener no longer hears them or until 60 s elapse. Until then, each loss of perception triggers a 5-dB increase in level without interrupting the tone until the 60-s plateau is reached. Results indicate (in dB) how much it was necessary to increase the level before the 60-s plateau was reached. Tone decay exceeding 30 dB is usually a clue to CNVIII or peripheral brainstem lesion.

Loudness Balance Test: The alternate binaural loudness balance test (ABLB) compares the loudness perceived by a listener when tones are alternated between ears (Dix, Hallpike, and Hood, 1948; Jerger and Harford, 1960). The goal is to define the level of tones to each ear that produces a judgment of equal loudness. Normal listeners judge equally intense tones to the two ears to be equally loud (**Figure 13A**). Patients with cochlear lesions usually do the same at high levels,a phenomenon called recruitment. Recruitment signals a rapid growth of loudness in a cochlear-damaged ear (**Figure 13B**). Patients with hearing loss due to CNVIII or peripheral brainstem lesion usually do not demonstrate this rapid loudness growth, i.e., these patients show no recruitment. (**Figure 13C**).

Non-Behavioral Tonal Tests

Non-behavioral tonal tests are procedures using tonal stimuli that do not require a voluntary response from the patient. The three most important are otoacoustic emissions, auditory evoked potentials, and acoustic-reflex thresholds, all of which are covered in subsequent sections of this primer.

Behavioral Speech Tests

Words and other speech units also can be useful in evaluating auditory function, particularly in testing for central auditory damage. This usually means a search for damage to auditory structures or pathways in the low brainstem or at the level of the temporal lobes or corpus callosum in the brain.

Undistorted Speech Tests: Word-recognition tests discussed in the “Speech Audiometry” section earlier are mostly useful in threshold definition and in examining the effect of cochlear and CNVIII lesions on the ability of a patient to understand speech. The basic word-recognition tests seldom give clues to central auditory problems.

Monotic Distorted Speech Tests: Monotic in this context means one or more signals to one ear. There are many versions of these procedures. They usually feature meaningful monosyllables as stimuli. The monosyllables are made difficult to understand in two ways: by altering the fundamental character of the signal (filtering, time compression, etc.) or by mixing the signal with a masking sound (noise, speech, etc.) presented to the same ear. Such tests are sometimes useful as a screening device for damage within the central auditory system, but offer little clue as to its side or location.

Dichotic Speech Tests: Dichotic means that both ears simultaneously receive different signals. Generally, dichotic procedures can be divided into two categories: crudely controlled tasks and carefully controlled tasks. The crudely constructed tasks are often called competing message tests, and require the listener to repeat speech signals (usually words) delivered to one ear while ignoring another speech message in the other ear. When breakdown in understanding occurs in one ear, it usually means damage at the opposite temporal lobe. The carefully constructed tasks commonly use short words (e.g., digit test) or syllables as the signal. The signals are delivered simultaneously to the two ears and the listener must identify both. Normal listeners, when listening to dichotic nonsense syllables (*pa, ta, ka, ba, da, ga*), get about 75% correct in the right ear and 65% correct in the left ear, scores that reflect the dominance of the left hemisphere/right ear for speech (Wilson and Leigh, 1996). Difficult dichotic speech tests, such as the nonsense syllable task just mentioned, may give indications of temporal lobe damage and also reveal useful information about inter- hemispheric pathways that carry auditory information such as the corpus callosum. Typically, for difficult dichotic tasks, temporal lobe damage produces breakdown in performance in the contralateral ear. Lesions in the posterior portion of the temporal lobe in the dominant (usually left) hemisphere for speech may degrade both ears performance, and damage to the corpus callosum

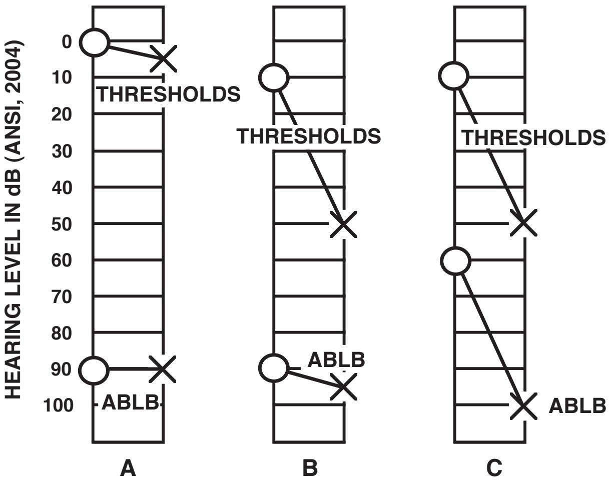

Figure 13. Loudness balance results illustrating three common ABLB findings. In each case, the uppermost right-ear (Os) and left-ear (Xs) symbols represent thresholds in the two ears. The same symbols at the bottom of the graph portray the hearing levels at the two ears necessary to produce a judgment of equal loudness. In panel A, a normal listener judges equally intense signals to be equally loud. In panel B, a patient with a unilateral cochlear hearing loss does the same. This illustrates recruitment of loudness in the left ear. In panel C, a patient with a similar hearing loss due to a CNVIII tumor on the left has no recruitment. The patient continues to need more energy in the left ear, even at high levels, to judge it equal in loudness to the right ear signal.

usually produces left ear breakdown. The latter reflects the fact that the corpus callosum is the final pathway needed by the left-ear signal to achieve processing in the dominant left hemisphere.

Binaural Speech Tests: These tests involve presentation of virtually identical or highly related speech to the two ears in a nearly simultaneous fashion. The object is to examine the ability of the low brainstem to integrate, fuse, or correlate the signals. This can mean tying together fragments of speech alternated between ears, combining filtered parts of a signal into a whole, or enhancing threshold for a signal dependent on phase relations between ears. In short, the procedures probe the integrity of what the auditory brainstem is designed to do, *viz*., take advantage of binaural (two-ear) information. A useful test that deserves special mention is the speech masking-level difference test (speech MLD) (Olsen, Noffsinger, and Carhart, 1976). For normal listeners, speech delivered to both ears is heard better in noise delivered to both ears when either the speech or noise is 180° out-of-phase with itself. Threshold for speech under such antiphasic conditions is usually 6-14 dB better than when the signals and noise are in- phase with themselves, i.e., an MLD of 6-14 dB. Exactly how the brainstem accomplishes this is uncertain, but it is clear that often people with brainstem disease or lesions cannot take advantage of such binaural cues.

AURAL ACOUSTIC-IMMITTANCE MEASURES

Aural acoustic-immittance (acoustic impedance and/or acoustic admittance) measures provide an objective method for evaluating the status of the middle-ear transmission system and the integrity of CNVII and CNVIII. All commercially available electroacoustic-immittance instruments measure acoustic admittance, or the ease with which acoustic energy flows into the middle-ear transmission system. Acoustic admittance is a complex quantity that can be specified in polar format [acoustic admittance (Y_a) and phase angle (φ_a)] or in rectangular format [acoustic susceptance (B_a) and acoustic conductance (G_a)]. Alternatively, some instruments measure only the magnitude of acoustic admittance at 226 Hz and express the value in terms of an equivalent volume of air with units in cm^3. The most commonly used probe frequency is 226 Hz, but many instruments also incorporate an optional high-frequency probe tone (e.g., 678, 800 Hz, or 1000 Hz) or multiple frequency probe tones (200-2000 Hz).

Although instruments vary in the components measured and in the frequency of the probe tone, all instruments work on the same basic principle. A probe device is sealed into the ear canal using various sized ear tips. The probe contains a loudspeaker, a microphone, and a pressure tube. The miniature loudspeaker delivers a 226-Hz tone at a known sound pressure level (e.g., 85-dB SPL) into the ear canal, and the microphone measures the sound pressure level of the tone reflected from the surface of the eardrum. An automatic gain control (AGC) circuit adjusts the voltage to the loudspeaker to maintain a constant probe tone level in the ear canal. The acoustic admittance of the ear, which is displayed on a meter, is proportional to the voltage level to the loudspeaker. In a highly compliant ear with ossicular discontinuity, most of the energy of the probe tone is absorbed into the middle ear and little is reflected at the eardrum. Consequently, the voltage to the loudspeaker must be increased by the AGC circuit to maintain a constant probe tone level in the ear canal, and the ear will measure high admittance. Conversely, in a fluid-filled middle ear, most of the probe tone will be reflected at the surface of the eardrum. Only a small adjustment will be required by the AGC circuit to maintain a constant probe tone level in the ear canal, and the ear will measure low admittance. The third component of the probe device is a pressure tube that allows the pressure in the ear canal to be varied over a range typically not exceeding -600 daPa (dekaPascals) to 400 daPa during tympanometry.

Tympanometry

Tympanometry measures changes in acoustic admittance as a function of changes in ear-canal pressure; a tympanogram is a graphic display of these measures. Tympanometry is useful (1) in identifying negative middle-ear pressure and middle-ear effusion, (2) in identifying tympanic membrane perforations or patent tympanostomy tubes (TT), and (3) to some extent, in the differential diagnosis of middle-ear disease.

The top panel of **Figure 14** illustrates a method of categorizing 220/226-Hz tympanograms that was popularized by Jerger in 1970 and remains in widespread use today. A normal Type A tympanogram peaks near 0 daPa. The tympanogram peak, i.e., the maximum flow of acoustic energy into the middle ear, occurs when the pressure in the ear canal is equal to the middle-ear pressure. If the Eustachian tube is functioning normally, then the pressure in the middle-ear cavity will approximate atmospheric pressure or 0 daPa. As the ear-canal pressure is increased or decreased toward extreme values, the eardrum becomes very stiff. Most of

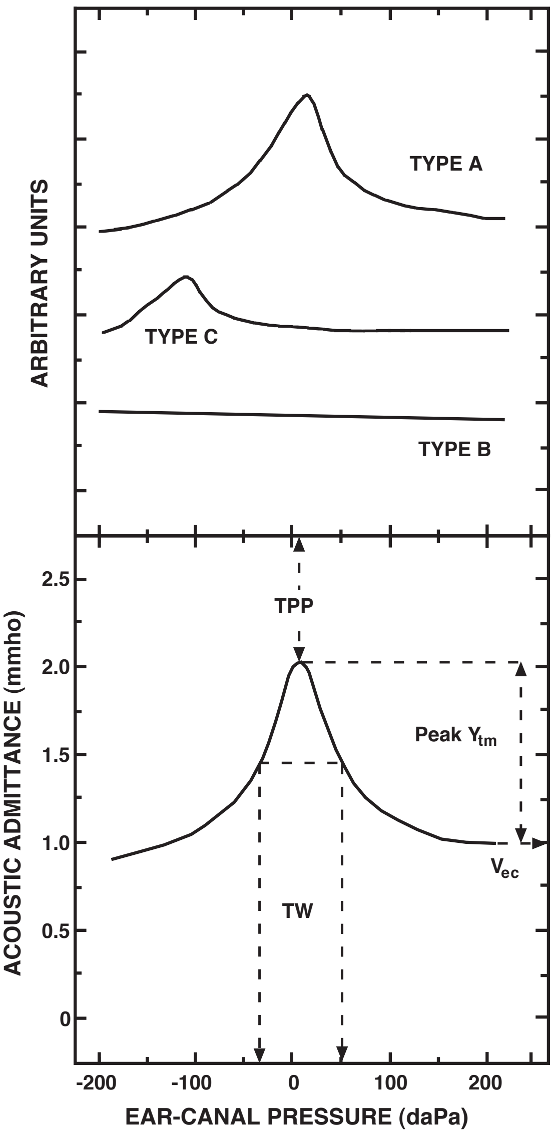

Figure 14. Tympanogram Types A, B, and C popularized by Jerger (1970) (top panel). Four measurements commonly made on normal 226-Hz admittance tympanograms are shown in the bottom panel: tympanogram peak pressure (TPP), equivalent ear-canal volume (Vea), peak compensated static acoustic admittance (peak Ytm), and tympanogram width (TW).

the acoustic energy of the probe tone is reflected from the surface of the eardrum, and admittance decreases to a minimum at extreme positive and negative pressures. Two variations of the Type A tympanogram are recorded in some ears with otosclerosis and ossicular discontinuity. In both cases, peak pressure is normal, but peak admittance is "shallow" (Type A_s) or stiff in otosclerosis, and conversely, peak admittance is "deep" (Type A_d) or high in ossicular discontinuity.

If the Eustachian tube is obstructed, then negative middle-ear pressure can result and the tympanogram will peak at a similar negative ear-canal pressure; the resulting Type C tympanogram also is shown in the left panel of Figure 14. If the Eustachian tube obstruction persists, then middle-ear effusion can develop. As the middle-ear cavity fills with fluid, eardrum movement is restricted, resulting in a flat Type B tympanogram. Flat tympanograms also are recorded in ears with patent TT or eardrum perforations.

The Jerger classification system for describing tympanogram shape was the preferred method when tympanometry came into widespread clinical use in the early 1970s. Clinical instruments available at that time did not incorporate AGC circuits. Tympanogram amplitude, expressed in arbitrary units, was not only dependent on the admittance characteristics of the middle ear transmission system, but also to a large degree, on the volume of the ear canal. Tympanogram amplitude, therefore, could not be quantified meaningfully, and tympanogram shape was broadly categorized as Type A, B, or C.

When the next generation of acoustic immittance instruments was introduced, the devices incorporated AGC circuits; tympanogram amplitude no longer was influenced by the volume of the ear canal and could be meaningfully quantified. The bottom panel of Figure 14 illustrates four calculations commonly used to quantify tympanogram shape. As previously discussed, tympanometric peak pressure (TPP), i.e., the ear-canal pressure corresponding to the tympanogram peak, provides an estimate of middle-ear pressure. Normal TPP typically occurs between ±50 daPa. The clinical relevance of extreme negative TPP has changed over the years. Early screening protocols that used a TPP ≤200 daPa as a criterion for medical referral produced an unacceptably high over-referral rate. In the absence of other abnormal findings, medical referral on the basis of TPP alone is no longer recommended. Ears exhibiting high negative pressure, however, should be monitored more closely for the development of middle ear effusion. Second, the volume of air medial to the probe device also can be estimated from a 226-Hz tympanogram.

The goal of tympanometry is to measure the acoustic-admittance of the middle ear transmission system. The probe device, however, cannot be placed at the eardrum, but instead is sealed in the bony portion of the ear canal. The acoustic admittance measured at the probe device, then, represents the combined effects of the volume of air in the ear canal (V_{ea}) plus the acoustic admittance of the middle ear in the plane of the tympanic membrane (Y_{tm}). When an extreme pressure, typically 200 daPa, is introduced into the ear canal, the eardrum becomes very stiff and the contribution of the middle ear transmission system is minimuized. As depicted in the right panel of Figure 14, the admittance measured at this pressure extreme then is attributed solely to the volume of air in the ear canal (V_{ea}). If the eardrum is intact, then this volume will average 0.6 cm^3 in children less than 7 years to 1.5 cm^3 in adult males. An estimate of V_{ea} is primarily used to help differentiate between an intact and perforated eardrum. With a perforated eardrum or patent TT, V_{ea} will exceed 1.0 cm^3 in children less than 7 years of age and 2.5 cm^3 in adult males. Although volumes in excess of these ranges can reliably identify a perforated eardrum, flat tympanograms with volumes less than these cutoffs does not necessarily rule out a perforated eardrum. If the middle ear space is obliterated by fluid or cholesteatoma, for example, then V_{ea} can fall within the normal range. The value of an otoscopic examination in interpreting tympanometric data cannot be over emphasized.

Similarly, the admittance attributed solely to middle-ear effects can be estimated from the tympanogram. As depicted in Figure 14, peak compensated static acoustic admittance (peak Y_{tm}) is an estimate of the admittance at the lateral surface of the eardrum free of the effects of the ear-canal volume. This is accomplished by subtracting the admittance of the ear canal measured at 200 daPa (V_{ea}) from the peak admittance measured at the probe tip. Static admittance averages 0.5 mmhos (or cm^3) in children less than six years to 0.8 mmhos (or cm^3) in adults (the 90% range is from 0.25 to 1.60 mmhos). The clinical utility of this third measure has been debated in the literature for years. High Y_{tm} is associated with eardrum pathology (e.g., tympanosclerotic plaques or atrophic scarring from a healed eardrum perforation) and ossicular discontinuity if the eardrum is intact. Again, the importance of an otoscopic exam and audiogram in interpreting tympanograms must be emphasized. High Y_{tm} is not a reason for medical referral in the absence of other abnormal findings. Low Y_{tm}, however, typically is associated with middle-ear effusion and is used as a criterion for medical referral. Both ASHA (1997) and AAA (1997) recommend medical referral of children less than eight years if peak Y_{tm} is <0.2 acoustic mmhos.

The fourth, and quite possibly, the most useful calculation in detecting MEE is tympanogram width (TW). As depicted in Figure 14, tympanogram width (TW) is the pressure interval (in daPa) encompassing one half peak Y_{tm}. Shallow, broad 226-Hz tympanograms with TW >250 daPa are associated with middle ear effusion.

Although tympanometry using a 226-Hz probe tone is the most commonly used procedure, significant evidence exists to demonstrate increased sensitivity to some middle ear pathology when a higher frequency probe tone is utilized. A disease process often shows its greatest effect when a probe frequency close to the resonant frequency of the middle-ear transmission system (800-1200 Hz) is used. The magnitude of acoustic admittance depends upon the mass, stiffness, and resistance of the ear canal and middle ear and upon the frequency of the probe tone. Low-frequency probe tones measure primarily the effects of stiffness, whereas high-frequency tones are influenced more by the mass components in the middle-ear transmission system. If a high-frequency probe tone is used, both components of complex acoustic admittance [acoustic susceptance (Ba) and acoustic conductance (Ga)] generally are measured. The shapes of tympanograms recorded at high frequencies such as 678 Hz are markedly different from those recorded at 226 Hz. **Figure 15** shows four normal tympanometric patterns at 678 Hz that were described by Vanhuyse, Creten, and Van Camp (1975). In the 1B1G pattern, susceptance (B_a) and conductance (G_a) are single peaked and static acoustic susceptance is less than or equal to static acoustic conductance; this is a stiffness controlled pattern. In the 3B1G pattern, conductance still is single peaked but susceptance is notched. The center of the notch, however, is above the value at 200 daPa so static acoustic susceptance remains positive or stiffness controlled. Both susceptance and conductance are notched in

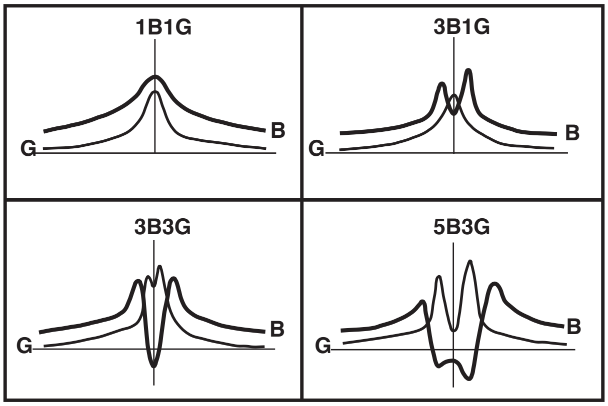

Figure 15. Four normal tympanometric patterns recorded using a 678-Hz probe tone that were described by Vanhuyse et al. (1975). Two stiffness controlled patterns (1B1G and 3B1G) are shown in the top panels whereas two mass controlled patterns (3B3G and 5B3G) are shown in the bottom panels.

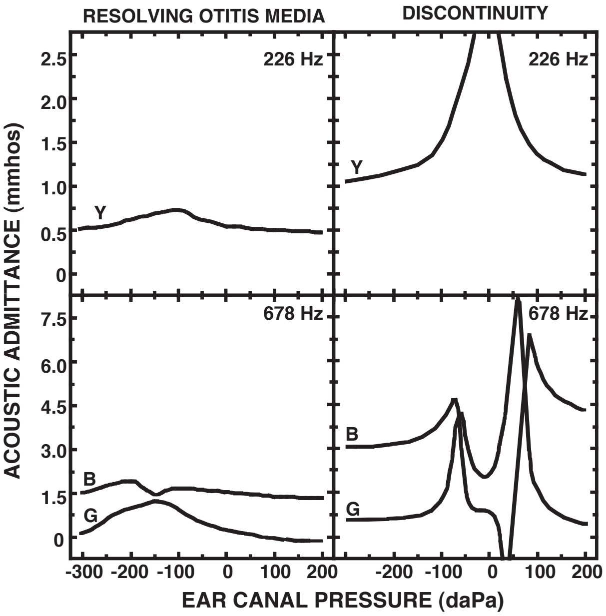

Figure 16. A comparison of tympanometric patterns recorded using a 226-Hz probe tone (upper panels) versus a 678-Hz probe tone (lower panel) in an ear with resolving otitis media and in an ear with ossicular discontinuity.

the 3B3G pattern. The notch in the susceptance tympanogram falls below the value at 200 daPa, and therefore, static susceptance is negative and the ear is described as mass controlled. If the center of the notch is exactly equal to the value at 200 daPa, then static acoustic susceptance is 0 acoustic mmhos and the middle ear is in resonance. In the 5B3G pattern, the static susceptance tympanogram has a double notch and conductance has a single notch; the middle ear again is mass controlled.

Figure 16 shows two examples in which high-frequency tympanometry reveals an abnormality that is not so obvious when a low-frequency probe tone is used. Notching is abnormal when the outermost peaks of the susceptance tympanogram are separated by more than 100 daPa or when susceptance and conductance tympanograms have more complex notches than a 5B or 3G pattern. As shown in the left panels of Figure 16, broad, shallow notching is recorded in ears with low fluid levels in the middle ear or in otitis externa with debris mass loading the eardrum. The right panels show abnormally complex notched tympanograms recorded in ossicular discontinuity. Ears following stapedectomy, and ears with eardrum pathology such as a atrophic scarring or tympanosclerotic plaques also show complex notched tympanograms at 678 Hz. Ossicular discontinuity, however, typically results in broad notching with a maximum conductive hearing loss, whereas eardrum pathology produces tightly peaked notches with little if any conductive hearing loss. This differentiation requires that tympanometry be analyzed in conjunction with an otoscopic examination and pure tone audiogram.

Renewed interest in tympanometry in recent years resulted with the implementation of universal hearing screening of newborns. When a newborn fails the hearing screening, the question that arises is whether the failure occurred because of a sensorineural or a conductive hearing loss. The type of hearing loss identified obviously has a huge impact on the medical/audiological management of the newborn. Conventional 226-Hz tympanometry in newborns yields different tympanogram patterns from infants over four months of age. 226-Hz tympanograms in neonates with normal middle ears frequently are notched, whereas single-peaked tympanograms have been recorded in neonates with otoscopically/surgically confirmed MEE. The ideal probe tone frequency and admittance component to use for neonates currently is being debated, but a measure of admittance magnitude (Y_a) at 1000 Hz is emerging as the procedure of choice. This measure is gaining acceptance because normal neonate ears have predominantly single peaked tympanograms and ears with MEE have flat tympanograms. Research in this area is ongoing.

In addition to the traditional applications for tympanometry, the instrument also can be used to measure changes in acoustic admittance at a single ear-canal pressure over time by utilizing the acoustic reflex mode. One advantage of this application is the increased sensitivity by about a factor of 20 of this mode over standard tympanometry. One such application is confirming a patulous Eustachian tube in patients with intact eardrums. With ear-canal pressure adjusted to produce maximum admittance, the immittance device is switched to the acoustic-reflex decay mode, and the reflex eliciting stimulus is turned off or as low as possible. A baseline trace then is obtained during quiet breathing; if the Eustachian tube is patulous, then cyclical fluctuations in immittance coincide with the patient's breathing (4-5 times during the 12-s time base). Traces are repeated while the patient first holds his breath, and then again during forced breathing. If the Eustachian tube is patulous, then the cyclical fluctuations disappear when the patient holds his breath and are markedly accentuated (in amplitude and frequency) during forced breathing. Vascular perturbations also can be documented in the acoustic reflex mode with the stimulus turned off. In contrast to a patulous Eustachian tube, cyclical fluctuations in acoustic admittance associated with a glomus tumor are high amplitude and much faster, coincident with pulse rate.

Acoustic-Reflex Measures

The acoustic reflex is the contraction of the stapedius muscle in response to acoustic stimulation at high presentation levels. When the stapedius muscle contracts, the middle-ear acoustic admittance of the probe ear decreases. This change in middle-ear admittance is measured with the same probe tone device used to measure tympanograms. The acoustic-reflex arc, a sche-matic of which is depicted in **Figure 17**, involves CNVIII of the stimulus ear, the auditory pathways in the brain stem to the level of the superior olivary complex, the motor nucleus of CNVII, and CNVII of the probe ear. The acoustic reflex is a good clinical measure because it is time locked to the activator signal and because the magnitude of the reflex generally increases with increased presentation level of the activator signal. The acoustic reflex can be monitored either in an ipsilateral (activator signal and probe in the same ear) or contralateral (activator signal and probe in opposite ears) configuration.

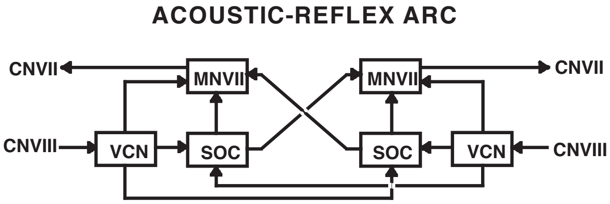

Figure 17. A schematic of the acoustic-reflex arc based on the rabbit (Borg, 1973). The arc involves input through CNVIII to the ventral cochlear nucleus (VCN) from which there are neural pathways through the two superior olivary complexes (SOC) to the motor nuclei of CNVII (MNVII) and the CNVII that innervates the stapedius muscle.

Two parameters of the acoustic reflex, threshold and adaptation, are measured clinically. The acoustic-reflex threshold is the lowest level (in decibels) at which an acoustic-immittance change can be measured in the probe ear concurrent with the presentation of a reflex-activator signal. Acoustic-reflex thresholds usually are measured both ipsilaterally and contralaterally with pure-tone signals. The reflex thresholds are measured in 5-dB increments starting at 80-dB HL. An example of the descending reflex-threshold search is shown in **Figure 18A**. The stimulus used to elicit the acoustic reflex is shown as the solid line above the reflex responses that are depicted as downward deflections. In this example, the acoustic reflex is measured at the first five levels (110-dB HL through 90-dB HL); no reflex is measurable at 85-dB HL. Thus, the acoustic-reflex threshold is 90-dB HL. Normal reflex thresholds for pure tones are frequency dependent and range from 80-dB HL to 100-dB HL. The interpretation of acoustic-reflex thresholds usually can be made with reference to this normal range. In some cases, however, it may be helpful in the interpretation to consider the inter-aural reflex-threshold differences. Data from normal subjects suggest that an inter-aural threshold difference >10 dB is indicative of an abnormality in the auditory system. Trace B in Figure 18 shows a normal measure of reflex adaptation over a 10-s interval, whereas Trace C depicts an abnormal reflex-adaptation function. Acoustic-reflex adaptation (decay) refers to a decrease in the magnitude of the stapedius contraction during sustained acoustic stimulation. This measure generally is made with 500- and 1000-Hz signals presented for 10 s, 10 dB above the reflex threshold. The percent of reflex adaptation is derived from the comparison of the reflex magnitude at onset of the reflex with reflex magnitude at the offset of the tonal activator. A normal reflex-adaptation function is shown in **Figure 18B** in which the onset of the reflex- activator signal occurred at 0 s and the offset was at 10 s. Reflex magnitude at signal onset and at signal offset is the same, indicating no acoustic-reflex adaptation. The reflex-adaptation function in **Figure 18C** is an illustration of abnormal acoustic-reflex adaptation. Even though the reflex-activator signal continued for 10 s, the acoustic admittance of the middle ear returned to its initial

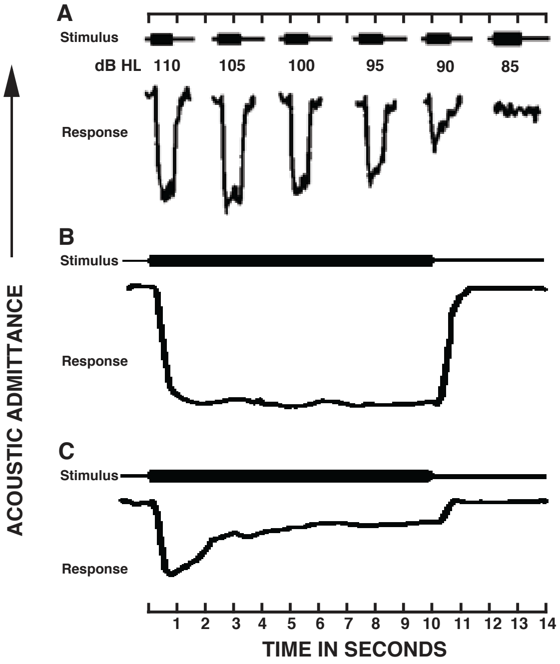

Figure 18. Acoustic-reflex tracings are shown in which the magnitude of the muscle contraction is on the ordinate and time in seconds is on the abscissa. The line above each response depicts the reflex activator signal. Trace A depicts a reflex-threshold search from 110- to 85-dB HL; the reflexes are in the downward deflections of which there are five. Trace B shows a normal reflex-adaptation function.

value after 3 s had elapsed. It should be noted that for reflex-activator signals ≥2000 Hz, more rapid adaptation of the reflex magnitude is observed even in young adults with normal hearing.

The following guidelines for interpreting acoustic-reflex data can be applied:

1. Middle-Ear and CNVII Disorders. Contralateral and ipsilateral reflexes are absent in the probe ear. A slight conductive component (5-10 dB) in the probe ear can preclude the measurement of the acoustic reflex in that ear. The stapedius muscle may contract, but because of the abnormal stiffness or mass in the middle ear, the contraction produces no measurable change in the acoustic immittance of the ear. The exception is with certain ossicular chain discontinuity cases, e.g., a fracture of a stapes cura. If the level of the reflex-activator signal applied to the ear with the conductive loss can be increased enough to overcome the attenuation caused by the middle-ear lesion (up to 30 dB conductive component), then a reflex may be measured with the probe in the contralateral ear. With CNVII disorders central to the innervation of the stapedius muscle, the acoustic reflex either is present at abnormally high levels or is absent whenever the measuring probe is on the affected side. The acoustic-reflex should be present, however, with CNVII lesions peripheral to the innervation of the stapedius muscle.

2. Cochlear and CNVIII Disorders. Contralateral and ipsilateral thresholds are elevated or absent in the ear receiving the reflex-activator signal. In a sensory (cochlear) hearing loss of <40-dB HL, acoustic-reflex thresholds for tonal stimuli are in the normal range. In sensory hearing losses between 40-dB HL and 70-dB HL, acoustic reflexes can be measured in 80% of the patients, although the reflex thresholds may be elevated. In contrast, acoustic reflexes rarely are measurable in patients with CNVIII lesions even when pure-tone thresholds are <40-dB HL. Finally, in those ears with measurable acoustic reflexes and concomitant hearing losses for pure tones, acoustic-reflex adaptation measures should aid in the differentiation of sensory and neural hearing losses. Patients with neural losses should demonstrate abnormal adaptation of the reflex response over time, whereas patients with sensory hearing losses should not have abnormal reflex adaptation at 500 Hz and 1000 Hz.

3. Intra-Axial Brain Stem Disorders. Ipsilateral acoustic reflexes are present in both ears and the contralateral acoustic reflexes are elevated or absent in both ears. This reflex pattern, which occurs only rarely, is attributed to a disruption within the brain stem of the contralateral pathways of the acoustic-reflex arc.

EVOKED OTOACOUSTIC EMISSIONS

First described by Kemp (1978, 1979), evoked otoacoustic emissions (EOAEs) can be defined as the acoustic energy generated by the cochlea in response to auditory stimuli that travel back through the middle ear and into the ear canal where they can be measured with a miniature microphone. While the specific physiological mechanism responsible for EOAEs is unknown, it is believed that the cochlear outer hair cells (OHCs) are an integral component in EOAE generation. EOAEs can be obtained in a relatively brief period of time with limited patient cooperation using a non-invasive recording technique that requires little or no patient preparation. It is well established that EOAEs are detected in nearly all individuals with normal pure-tone thresholds (as well as normal middle-ear function) and are either altered or absent in individuals with pure-tone thresholds greater than 20- to 50-dB HL. Research has focused on the use of EOAEs in hearing screening, differential diagnosis, and the monitoring of cochlear status. The two most widely used types of EOAEs are transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs). Whereas the presence of either TEOAE or DPOAE is compelling evidence of the cochlear integrity of a specific frequency region, the wide range of normal OAE amplitudes and their sensitivity to low levels of insult dictates caution in the interpretation of these measures in differential diagnosis.

Transient Evoked Otoacoustic Emissions (TEOAEs), so-called because they are typically elicited by brief acoustic stimuli, can be recorded in essentially all ears with normal hearing. Although there is some disagreement concerning the specific magnitude of hearing loss above which no TEOAE can be detected, the majority of studies have reported that TEOAEs are absent when the average hearing threshold at 500, 1000, 2000, and 4000 Hz exceeds approximately 20- to 40-dB HL. To record a TEOAE, a probe containing a miniature speaker and microphone is sealed into the ear canal. Following the presentation of a transient stimulus (usually a broadband click), the output of the microphone is amplified and sampled for about 20 ms with time domain signal averaging employed to improve the signal-to-noise ratio. Similar to the recording of auditory evoked potentials, the averaging procedure is time-locked to the presentation of the auditory stimulus.

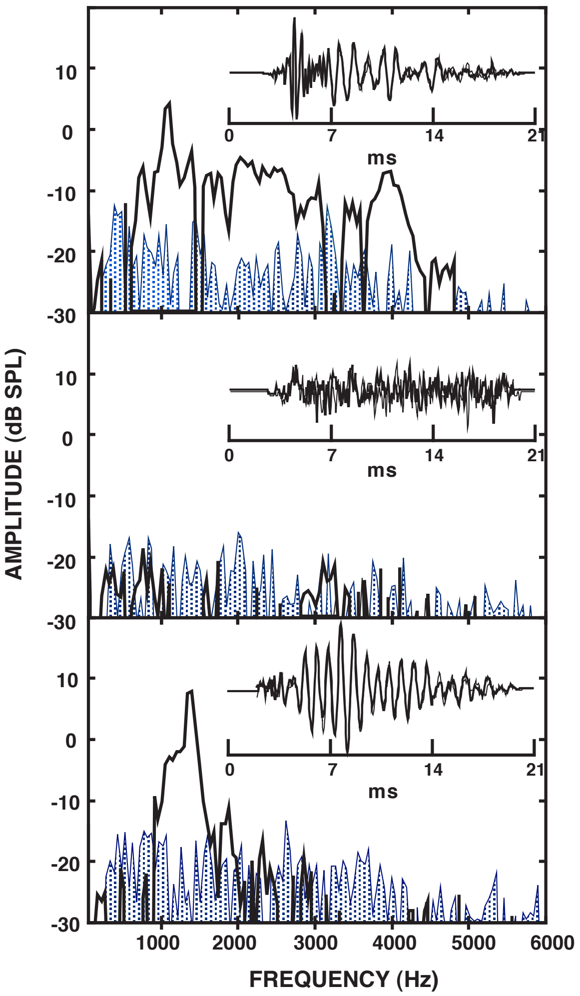

Figure 19. Transient Evoked Otoacoustic Emissions (TEOAEs) obtained from three patients with different hearing losses. The upper, right portion of each panel contains two, superimposed time-domain TEOAE waveforms. The bottom portion of each panel displays the amplitude spectrum of the two emission waveforms (heavy line) and associated noise spectrum (shaded area). The three patients are: a patient with normal hearing (upper), a patient with a moderate-to-severe sensorineural hearing loss (middle), and a patient with a high-frequency hearing loss.

Figure 19 depicts TEOAEs obtained from three patients using a commercially available instrument (Otodynamics Analyzer - ILO92). The tracings displayed in the upper, right of each panel are two, superimposed time-domain TEOAE waveforms, which demonstrate reliability. The lower portion of each panel displays the amplitude spectrum of the two emission waveforms (heavy line) and associated noise spectrum (shaded area). The top panel shows a TEOAE obtained from a patient with normal hearing. The two time-domain waveforms are well replicated and the amplitude spectrum of the response is well above the noise spectrum over a broad frequency range. The middle panel shows the TEOAE obtained from the patient whose audiogram is illustrated in Figure 7. This patient has pure-tone thresholds of at least 40-dB HL from 500-8000 Hz. The response waveforms are poorly replicated and the emission amplitude spectrum overlays the noise spectrum at all frequencies. TEOAEs are usually present in ears having normal or near-normal hearing across some frequency ranges but hearing loss across others. The bottom panel shows the TEOAE obtained from the patient whose audiogram is illustrated in Figure 6. This patient has normal pure-tone thresholds through 1000 Hz with a mild to moderate high-frequency hearing loss. The response waveforms are well replicated, but the amplitude spectrum reveals that the frequency content of the emission is limited to frequencies below 2000 Hz. This corresponds to frequencies at which the audiometric thresholds are better than 20-dB HL.

Distortion Product Otoacoustic Emissions (DPOAEs)

DPOAEs are measured in response to the simultaneous presentation of a pair of pure tones of moderate level (55- to 75-dB SPL) and are present in essentially all ears with normal hearing over a frequency range from 500 to 8000 Hz. The two pure tones are presented through two speakers. The output of these speakers is conducted through sound tubes that are connected to a probe that houses a miniature microphone. The probe is seated in the external ear canal in which the two-tone stimulus is acoustically mixed. Nonlinear processes that are inherent to the normal cochlea produce responses at frequencies not present in the stimulus. The frequency content of the resulting distortion products are algebraically related to the two-tone stimulus. In humans, the DPOAE with the greatest amplitude occurs at the cubic difference frequency 2f1 - f2, in which f1 represents the lower frequency stimulus or primary tone and f2 the higher frequency primary. The largest amplitude 2f1 - f2 DPOAE is obtained when f2/f1 is about 1.2 and the level difference between the primary tones (L1 - L2) is 0-10 dB.

Two protocols are typically used to measure DPOAEs: (1) the DPOAE audiogram and (2) the DPOAE input/output (I/O) function. For the DPOAE audiogram, DPOAE amplitude is measured as a function of either the geometric mean of the two primary frequencies or as a function of f2. Primary tone levels are held constant (e.g., L1 = L2 or L1 - L2 = 10-15 dB) and emission frequency is increased in regular intervals with a fixed number of measurements made per octave. For the I/O protocol, a series of I/O functions are usually obtained at either the geometric mean of f1 and f2 or at f2 frequencies

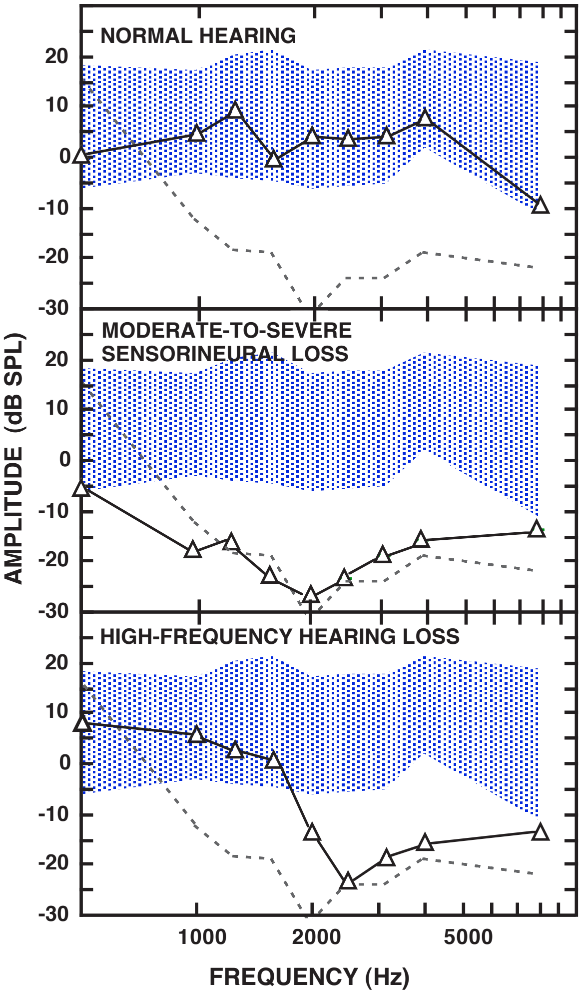

Figure 20. DPOAE audiograms obtained from three patients with different hearing losses. The DPOAE level is plotted as a function of the f2 frequency. The triangles represent the 2 f1 - f2 DPOAE amplitudes obtained at nine f2 frequencies from 500 Hz to 8000 Hz. The thin dashed line represents the associated noise amplitudes. The shaded region represents the 95th percentile for a group of young adults with normal hearing. The three patients are: patient with normal hearing (upper panel), patient with a moderate to severe sensorineural hearing loss (middle panel), and patient with a high-frequency hearing loss.

that are similar to the conventional audiometric frequencies by varying the primary tone levels in 5-dB steps between about 25- and 75-dB SPL. Of the latter two protocols, the DPOAE audiogram has been used more extensively.

Figure 20 shows DPOAE audiograms obtained from three patients using a commercially available instrument (Virtual, Model 330). In each panel DPOAE level is plotted as a function of the f2 frequency. The primary tone levels were held constant (L1 = L2 = 75-dB SPL) and f2/ f1 = 1.21. The triangles represent the 2f1 - f2 DPOAE amplitudes obtained at nine different f2 frequencies from 500 to 8000 Hz. The thin dashed line represents the associated noise amplitudes. The shaded region represents the 95 percent confidence limits for a group of young adults with normal hearing. The top panel shows the DPOAE audiogram obtained from a patient with normal hearing. DPOAE amplitudes are well above the corresponding noise amplitudes and within the 95 percent confidence limits. The middle panel shows the DPOAE audiogram obtained from the patient whose audiogram is illustrated in Figure 7.

This patient has pure-tone thresholds of at least 40-dB HL from 500-8000 Hz. DPOAE amplitudes are below the 95 percent confidence limits over the entire range of f2 frequencies and either below or just above the corresponding noise. The bottom panel shows the DPOAE audiogram obtained from the patient whose pure-tone audiogram is illustrated in Figure 6. DPOAE amplitudes are within the 95 percent confidence limits for f2 frequencies through 1600 Hz and then drop below the normal range at higher frequencies. These findings are consistent with the patient's pure-tone audiogram in Figure 6.

AUDITORY EVOKED POTENTIALS

An auditory evoked response (AER) is activity within the auditory system that is produced or stimulated by acoustic stimuli. Stimuli may range from clicks to tones, even to speech sounds, and are presented to the listener by way of some type of acoustic transducer such as an earphone. Brain (electrical) activity evoked by the sounds is picked up by wire electrodes, which are placed at specific places on the scalp and near the ears. The electrode wires lead this electrical activity to a specially programmed computer that amplifies and averages the resulting AER waveforms before being displayed. Response averaging is possible because the responses are time-locked to the onset of the stimulus. The following are six classes of AERs that are grouped by latency [measured in milliseconds (ms)] relative to the acoustic stimulus:

1. Electrocochleography (ECochG) (1.5 to 2.0 ms),
2. Auditory brainstem response (ABR) (1 to 10 ms),
3. Auditory middle latency response (AMLR) (10 to 100 ms),
4. Auditory late response (ALR) (50-250 ms),
5. Auditory P300 response (»300 ms), and
6. Mismatch negativity response (MMN) (»200 ms).

Electrocochleography (ECochG)

The ECochG was the earliest of the AERs discovered, first identified in 1930 (Wever and Bray) and utilized clinically in the early 1960s. The ECochG consists of three major components that occur within the first 1.5-2.0 ms after an acoustic stimulus. The first component, called the cochlear microphonic (CM), is alternating current (AC) cochlear activity arising from the outer hair cells. The second component, the summating potential (SP), is a direct current potential also arising primarily from the hair cells that probably reflects distortion products in hair cell function. The action potential (AP) is the third component of the ECochG, and reflects activation of auditory nerve fibers as they leave the cochlea. The AP is also the Wave I in the auditory brainstem response. The ECochG has been used clinically in the diagnosis of Ménière's disease and may be used intraoperatively for monitoring of cochlear and CNVIII activity during surgery that puts the auditory system at risk.

Auditory Brainstem Response (ABR)

The ABR was first identified in the early 1970s (Jewett and Williston) and since that time has been the most widely utilized and the most reliable of the AERs. The response is a series of 5-7 major peaks, labeled by Roman numerals, occurring within a 10-ms period following presentation of a brief acoustic stimulus. A normal ABR is shown and labeled in **Figure 21**. Stimulus characteristics are critically important for generating the ABR. The onset of the stimuli must be rapid to produce large, well-synchronized responses. Stimuli can be clicks with instantaneous rise times and broadband frequency compositions, or tone bursts with slower rise times (vs. click stimuli) and narrow band frequency compositions. Either of these classes of stimuli may be used for eliciting the ABR.

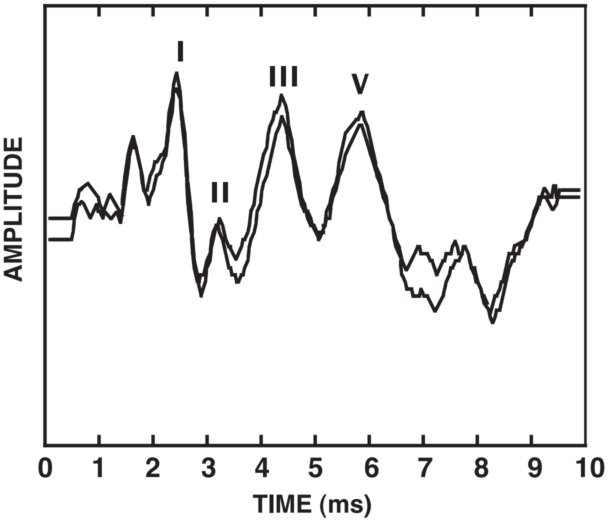

Figure 21. An example of a normal ABR obtained from one ear of an adult female in response to a 90-dB nHL rarefaction click stimulus delivered via insert earphones. The Jewett nomenclature of using Roman numerals for peak labeling (vertex-positive up) is shown. A 0.8 ms delay is included in the 10-ms recording window and represents the acoustic travel time through the earphone tubing.

Despite the complexity of the central auditory nervous system pathways, investigators have been relatively consistent in their descriptions of probable generator sites of the ABR. Wave I originates exclusively from the distal part of CNVIII; wave II originates mainly from the proximal part of CNVIII. Most investigators agree that waves III through V result from contributions of multiple generators including the cochlear nucleus, superior olivary complex, lateral lemniscus, and inferior colliculus.

One of the major applications of the ABR is neurodiagnosis of CNVIII or auditory brainstem dysfunction. Latency and amplitude characteristics of the waveform peaks are used to identify pathology along the auditory brainstem pathway. For example, an absence of some or all of the waves, a delay in their absolute latencies, and/or an increase in the relative latencies between pairs of waves have been associated with lesions of CNVIII and/or brainstem. Such lesions also may reduce the amplitudes of the waves or may alter the amplitude relations among the waves. Generally, if waveforms are present, there are two criterion used in interpretation of the ABR: 1) The I-V interpeak latency should be <4.50 ms; and (2) when comparing wave V latency between ears (the interaural wave V latency difference or ILD_V), the difference should be no greater than 0.4. The effect of hearing loss must also be considered when interpreting ABR waveforms. Conductive hearing loss will generally result in an increase in the latency of all waves of the ABR. The effect of sensorineural hearing loss is more variable, but generally results in the absence of wave I and/or an increase in wave V latency.

Figure 22 shows ABRs obtained from two patients with CNVIII tumors. The lower tracings in each panel are from the ear with the tumor, whereas the upper tracings are from the contralateral ear. The data in the top panel are from a 49-year old who had progressive unilateral hearing loss (AS), unilateral tinnitus (AS), and a 1-cm, intracanicular tumor on the left. The data in the bottom panel are from a 53-year-old male with a progressive bilateral hearing loss, worse AS. The MRI findings of a >2-cm, cerebellopontine angle tumor on the left were confirmed during surgery.

A second major clinical application of the ABR is estimation of auditory sensitivity in very young

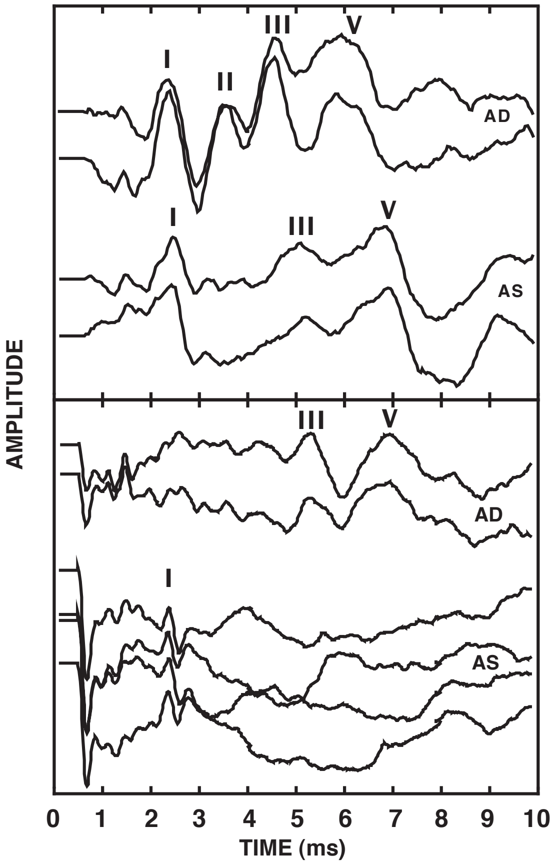

Figure 22. Each panel contains the ABRs obtained from a patient with a CNVIII tumor (AS). The lower tracings in each panel are the ABRs from the ear with the tumor; the upper tracings are from the other ear. Because the 90-dB nHL rarefaction clicks were delivered via insert earphones, the 0.8 ms delay from the earphone tubing is included in the 10 ms recording window. The top panel shows the ABRs obtained from a 49-year-old male who complained of left- sided, progressive hearing loss and unilateral tinnitus on the left side. The left-ear ABR shows that wave V latency (6.12 ms) is significantly prolonged relative to the right (5.48 ms) and the I-V (4.56 ms) and I-III (2.68 ms) interpeak latencies are abnormal. An MRI with contrast revealed a left-sided, 1-cm, intracanicular tumor. The bottom panel shows the ABRs obtained from a 53-year-old male who complained of progressive bilateral hearing loss, worse in the left ear. The ABRs obtained from the left ear show no replicated activity with the possible exception of wave I. An MRI with contrast revealed a left-sided, >2-cm, cerebellopontine angle tumor.

or difficult-to-test patients. Wave V is used in the estimation of auditory thresholds because it is the largest and the most reliable potential, and because it can be traced to levels near the behavioral threshold. Clicks, commonly used as stimuli, are broadband frequency stimuli, and can be used to estimate high-frequency (2000-4000 Hz) hearing sensitivity. Tone bursts can provide more frequency-specific information and are often used for threshold estimation, especially in patients with severe hearing loss for the high frequencies.

The ABR is also widely used as a tool for newborn infant hearing screening. The prevalence of newborn and infant hearing loss is estimated to range from 1.5 to 6.0 per 1000 live births, and it has been shown that reduced hearing acuity during infancy and early childhood interferes with the development of speech and verbal language skills.

In their 1994 Position Statement, the Joint Committee on Infant Hearing endorsed the goal of universal detection of infants with hearing loss and summarized high-risk factors associated with hearing loss in newborns and infants. Today, audiologists in over 150 hospitals in the United States have implemented universal newborn hearing screening programs.

Auditory Middle Latency Response (AMLR)

Clinically, audiologists occasionally rely on responses that arise above the ABR. The auditory middle latency response (AMLR) is probably recorded most often, although still rarely in comparison to the ABR. The AMLR was initially described in 1958 (Geisler, Frishkopf, and Rosenblith) and studied extensively during the late 1960s and early 1970s. The response occurs within the interval of 10-100 ms after presentation of a high-level acoustic stimulus. Major peaks in the waveform are labeled N (negative voltage waves) and P (positive voltage waves), and the sequence of waves is denoted alphabetically (e.g., Na, Pa, Nb, Pb). Although still speculative, research suggests anatomic generators for the Pa component of the AMLR in the auditory thalamus and primary auditory cortex. The primary clinical application of the AMLR is frequency-specific estimation of auditory sensitivity in older children and adults (e.g., pseudohypacusis).

A variation of the AMLR is the 40-Hz response. It is produced by a stimulus repetition rate of 40/s (and thus its name), consists of four positive electrical potentials in the 100 ms period following stimulus presentation, and is thought to represent overlapping events of the AMLR. The 40-Hz response is used primarily to estimate behavioral threshold.

Auditory Late Response (ALR)

The auditory late response (ALR) has been used less often clinically, but results have been reported in a variety of clinical populations. The ALR was first described in 1939 (Davis) and was introduced clinically in the mid 1960s. Major components of the ALR occur within 50-250 ms following stimulus onset. Major peaks in the waveform are labeled N (negative voltage waves) and P (positive voltage waves), and the sequence of waves is denoted numerically (e.g., P1, N1, P2, N2). Although precise anatomic generators are unknown, studies suggest that N1 and P2 components arise from auditory cortex. Although not routinely used for diagnostic purposes, the ALR has been used for electrophysiologic assessment of higher-level CNS functioning and in some cases for frequency-specific estimation of auditory thresholds.

Auditory P300 Response

The P300 response has been used less often clinically, but results have been reported in a variety of clinical populations. The P300 was first described in 1964 (Davis) and has been studied extensively since that time. The response is represented by a large positive voltage wave (5 v or greater) occurring at approximately 300 ms after presentation of an infrequent or rare auditory stimulus embedded within a sequence of standard stimuli. The term “endogenous” is often used to describe the P300 response and other AER components that are highly dependent on subject attention to certain auditory stimuli (as opposed to exogenous responses that are stimulus dependent). Although an exact generator site is unknown, human depth electrode studies provide evidence of medial temporal lobe (hippocampus) contribution to the response. Clinically, the P300 has been used for assessment of higher-level auditory processing in both children and adults.

Mismatch Negativity Response (MMN)

The mismatch negativity (MMN) response is one of the most recently investigated cortical AERs. The MMN was first described by Näätänen, Gaillard, and Mäntysall (1978). The response is a negative voltage trough occurring »200 ms following stimulus presentation. Similar to the P300, the response is obtained by presenting a block of several hundred standard stimuli that are occasionally replaced by rare or deviant stimuli. Once these waveforms have been averaged, the standard waveform is subtracted from the deviant waveform, leaving a difference wave, or the MMN. Research suggests that the origin of the MMN is in the auditory cortex on the superior surface of the temporal lobe. Although still a new area of research, the MMN has been used in the assessment of higher level auditory processing, confirmation of neural dysfunction in clinical populations (e.g., stroke, dementia, cochlear implant patients), and studies of speech perception in persons of all ages and mental states.

Intraoperative Monitoring

Some audiologists are involved in recording auditory evoked responses (particularly ECochG and ABR) and neurophysiologic data of facial nerve function, during surgical procedures. There are two major reasons for the use of intraoperative monitoring AERs in the operating room. First, AERs can provide an early indicator of changes in neurophysiologic status of the peripheral and central nervous system during surgery. These changes may be due to various physiologic or surgical factors such as hypoxia and the compression or retraction of nerves or brain tissue. Second, since AERs provide information on the functional status of the auditory pathway, they have been proven valuable in the preservation of hearing during posterior fossa surgery. Other nonauditory electrophysiologic measures, such as somatosensory and visual evoked responses, are also commonly applied intraoperatively.

TESTS FOR PSEUDOHYPACUSIS

Non-organic hearing loss is referred to by many names. Pseudohypacusis and functional hearing loss are common terms. Whatever the label, this condition describes persons who cannot or will not give accurate estimates of their hearing abilities. The reasons are often obscure, but potential financial gain is one motivating factor. Since psychological need, especially with children, may also play a role, some caution should be exercised before direct confrontation with patients suspected of pseudohypacusis. (see Rintelmann and Schwan, 1999, for a detailed discussion of pseudohypacusis.) There are many clues that a person may be exaggerating the extent of hearing disability. These include behavior observed in the waiting room, in conversation with other people, in responses to “automatic” questions, and in exaggerated attempts to hear.

On standard pure-tone hearing tests, the patient may be unreliable or give responses that are unlikely without masking, i.e., crossover from one ear to the other at high levels may not occur. On standard speech tests, the speech-recognition threshold may be better than the pure-tone thresholds (owing to the patient’s attempt to match the loudness of the speech and pure-tone stimuli), or speech responses may be half-word responses, rhyming responses, or no response in situations that should provoke crossover responses from the other ear.

When a patient is suspected of giving false estimates of hearing in one ear, a test that uses voluntary responses from the patient may be useful. The Stenger Test (Stenger, 1907) takes advantage of the fact that when identical tones or speech signals are delivered to both ears, the recipient is aware of just one signal (binaural fusion) located in the ear in which the signal is louder. If the signals are equally loud, then normal listeners experience the fused experience in the head. Careful control of the relative levels of the signals to the ears can allow the examiner to estimate the actual threshold within 10-15 dB. In essence, a "Stenger audiogram" can be obtained.

Since medico-legal issues may occur in cases where voluntary hearing levels are suspect, the tests of choice are often ones that do not require the patient to respond. Such procedures are called objective tests, and include tasks like acoustic reflex measures, otoacoustic emissions, and auditory evoked response measures.

Acoustic reflex tests determine if stapedial muscle contraction can be elicited by loud sounds presented to the ear. This response is not voluntary. It is a reflexive response triggered by loud sound. The presence of acoustic reflexes is easily detected by standard commercial instrumentation. If acoustic reflexes are present near or below the admitted pure-tone thresholds, then the odds are great that the voluntary responses are not true thresholds.

As evoked otoacoustic emissions (EOAEs) are present in essentially all ears with normal pure-tone thresholds and normal middle-ear function, the measurement of EOAEs in cases of suspected pseudohypacusis may provide valuable clinical information. Although there is some disagreement concerning the specific magnitude of hearing loss above which no EOAE can be detected, the presence of a robust emission is rare in ears with any degree of cochlear hearing loss. It is important to note, however, that retrocochlear lesions involving CNVIII may result in significant hearing loss and normal EOAEs. The most judicious use of EOAEs in the evaluation of cases of suspected pseudohypacusis, therefore, would be as one test in a battery of tests that include pure-tone audiometry, acoustic immittance, and auditory brainstem responses. Evoked response measures are procedures that monitor electrical activity provoked by acoustic signals like clicks. Scalp electrodes allow collection of the data and computer averaging allows definition of repeatable activity. Although these measures are discussed elsewhere in this primer, the important thing to iterate here is that some auditory evoked responses can be triggered and measured at levels near behavioral threshold. Because of this, an estimate of threshold can be obtained from some procedures. Three procedures that allow an estimate of the true behavioral threshold deserve mentioned. The auditory brainstem response (ABR) is the electrical activity that occurs within 10 ms of an acoustic signal like a click or tone burst. In the series of 5-7 vertex-positive potentials that occur, Wave V and the large negative-going slope that follows can be elicited down to 10-15 dB of true behavioral threshold. The middle-latency response (MLR) describes activity that follows in time the auditory brainstem response. These are two positive and two negative waves that also can be seen near threshold. A variant of these, the 40-Hz response, is a characteristic pattern of electrical activity elicited by the rate of the stimulus presentation (40/s). The 40-Hz response is quickly obtained and can be seen near threshold.

The ABR is resistant to influences like attentiveness and medication and thus useful clinically. It is most accurate in estimating high-frequency thresholds. The MLR and 40-Hz responses give better estimates of low-frequency sensitivity, but are more susceptible to factors like arousal state and drugs. Last, ABR is better at giving threshold estimates in infants and children than are most of the other auditory evoked responses.

VESTIBULAR ASSESSMENT

The auditory and vestibular sensory organs occupy the same area within the temporal bone and are both innervated by branches of CNVIII. Because of the proximity of the vestibular system to the auditory system, hearing and balance disorders often coexist. The audiologist, therefore, is often called upon in the evaluation of both the vestibular and auditory systems.

The primary function of the vestibular system is to maintain balance and gaze stability. The vestibular sensory organs (semicircular canals and otolith organs) detect head acceleration and changes in gravity, and disturbances to the vestibular system can cause dizziness, imbalance, and vertigo. The sensory input to the vestibular organs is processed via two primary reflex pathways: the vestibulo-ocular reflex (VOR) and the vestibulo-spinal reflex (VSR). The VOR produces compensatory eye movement to maintain gaze stability, and the VSR produces postural changes to maintain equilibrium. Most clinical tests have assessed vestibular function through the measurement of the VOR with the vestibular sensory organ stimulated by caloric irrigation (via video- or electro-nystagmography) or rotational stimuli.

There are several tests designed to evaluate the dizzy patient, including electronystagmography (ENG), rotary chair testing, and computerized dynamic posturography.

Eye Movement Recording

To measure vestibular function via the vestibulo-ocular reflex, eye movement can be recorded with video-oculography or electro-oculography. Until recently, electro-oculography (EOG) was the standard clinical method to record eye movement following vestibular stimulation. EOG is based on measuring small voltages on the face that vary with movement of the eyes. The eye acts as a battery, with the cornea having a positive charge and the retina having a negative charge. This "battery" is called the corneo-retinal potential. Small surface electrodes measure the potentials which result from eye movement and the corneo-retinal potential. When the eye views straight ahead, the voltage difference under the skin is symmetric. When the eyes rotate, the positively-charged cornea is closer to one electrode, and the negatively-charged retina (in the other eye) is closer to the other electrode. These small voltage differences are amplified by a factor of about 10,000, filtered to eliminate noise and drift artifacts, and recorded by a strip chart or computer. While EOG accurately records horizontal eye movement, recordings of vertical eye movement are less accurate and torsional eye movements are not sensed.

More recently, video-oculography (VOG) has become widely used to record eye movement during vestibular assessment. Video recorded eye movement eliminates the need for electrodes. The patient wears video goggles with infrared cameras mounted to record eye movement. The advantages of VOG include cleaner and more accurate eye movement tracings due to the higher resolution and artifacts from biological noise and electrode drift are eliminated. In addition, torsional components of nystagmus, that are missed on EOG tracings, can be recorded. Finally, with the need for electrodes eliminated, testing may be quicker and easier to administer with minimal patient preparation.

Videonystagmography (VNG)/ Electronystagmography (ENG)

Videonystagmography (VNG) or electronystagmography (ENG) describes a series of tests used to assess vestibular and eye movement disorders while eye movements are recorded with VOG or EOG, respectively. The traditional test battery includes subtests for ocular motility function, pathologic nystagmus, and horizontal semi-circular canal vestibulo-ocular reflex function. Eye movement responses are analyzed to determine the presence of peripheral (vestibular nerve and/or end organ) vestibular or central dysfunction. Tests of ocular motility function in the ENG battery evaluate the saccadic eye movement system, the smooth pursuit system and the optokinetic system. Abnormalities in the ocular motility tests help to localize central nervous system lesions. Unless the lesion is acute, peripheral vestibular lesions do not interfere with ocular motor control. Pathologic nystagmus may be gaze-evoked, spontaneous (present with the patient in a sitting position), or positional (induced by changes in head position). In general, spontaneous and/or positional nystagmus greater than 3°/s that can be suppressed with fixation suggests unlocalized vestibular dysfunction; gaze-evoked nystagmus that persists for more than a week is a central sign.

The bithermal caloric test uses a nonphysiologic stimulus to determine vestibular function in each horizontal semicircular canal. It is the only clinical vestibular test that allows the clinician to selectively assess the function of each labyrinth. Therefore, the caloric test best localizes to the side of lesion. The bithermal caloric test was first described by Fitzgerald and Hallpike (1942), and an adaptation of their original methodology is the most widely used clinical test for vestibular function. Each ear is irrigated twice, once with warm water or air (above body temperature) and once with cool water or air (below body temperature). The temperature change induces movement of the endolymph in the horizontal semicircular canal, which, in turn, deflects the cupula, and thus, alters afferent neural activity from the stimulated vestibular end organ. The patient's nystagmic eye movement is recorded usually with EOG, and the peak slow phase eye velocity is calculated as the index of caloric response strength. The four responses obtained from a caloric test are compared to determine if caloric stimulation with both temperatures produced similar results in both ears. Approximately equal responses suggest normal vestibular function. A weaker caloric response in one ear compared with the other indicates a unilateral weakness and is evidence of a lesion of the labyrinth or vestibular nerve on the side of the weak response. A bilateral weakness is the sum of the peak warm and peak cool responses below 12°/s for each ear (Barber and Stockwell, 1980). A bilateral weakness usually suggests bilateral peripheral vestibular loss. If no response were observed during caloric stimulation, then ice water calorics may be used to distinguish between canal paresis or paralysis. The caloric responses are analyzed to determine directional preponderance. A directional preponderance results when peak intensities of caloric responses are stronger in one direction than in the other (e.g., right beating caloric responses are greater than left beating caloric responses). A directional preponderance is a result of vestibular asymmetry owing to spontaneous nystagmus. Spontaneous nystagmus is superimposed on the caloric nystagmus; thus, if a patient has right beating spontaneous nystagmus, then caloric irrigations inducing left beating nystagmus will be reduced and right beating caloric nystagmus will be enhanced.

Rotary Chair Test

The rotary chair test (or the slow harmonic acceleration test) has become more widely used due to technological advancements in torque-driven motors and computers. In the rotary chair test, the patient is seated in darkness with the head positioned so that the horizontal semi-circular canals are in the plane of rotation. Typically, the patient undergoes sinusoidal rotations at frequencies from 0.01 to 0.64 or 1.0 Hz at peak angular velocities of 50°/s. Eye movements are recorded with EOG or VOG, and slow phase eye movement is compared with chair (or head) movements to determine measures of phase, gain and asymmetry. Patients with unilateral peripheral (CNVIII or labyrinth) lesions typically display a phase lead or abnormal timing of eye velocity relative to stimulus velocity at low frequencies of rotation, 0.05 Hz and lower. In addition, in acute cases, an asymmetry may be present resulting from decreased slow-phase velocity with rotation towards the side of lesion. The asymmetry of the response often disappears as recovery or central compensation occurs. With bilateral peripheral vestibular lesions, gain is decreased or absent. For patients with bilateral vestibular loss, rotary chair testing is particularly useful for determining the presence of residual vestibular function, characterized as normal gain in the higher frequencies.

Computerized Dynamic Posturography

Computerized dynamic posturography is a clinical test that evaluates balance function by measuring postural stability. The test is composed of two areas: the sensory organization test (SOT) and the motor control test (MCT). The SOT assesses the ability of a patient to use visual, vestibular, and somatosensory inputs to maintain balance. Patients are positioned at a platform and a visual surround that are sway referenced in order to disrupt somatosensory and/or visual information. The six conditions of the SOT range from eyes open on a fixed support surface to sway-referencing of both the support surface and the visual surround. The MCT uses platform perturbations to evoke postural responses. A primary use of computerized dynamic posturography is to evaluate how the dizzy patient functions in everyday life. Advantages of posturography include the ability to determine inconsistencies in results due to nonphysiologic factors and it provides pre- and post-treatment information for vestibular rehabilitation.

Vestibular Evoked Myogenic Potentials

Vestibular evoked myogenic potentials (VEMPs) supplement the vestibular test battery by providing diagnostic information about saccular and/or inferior vestibular nerve function. In contrast to traditional clinical vestibular tests, the VEMP is recorded by activating the vestibular system (saccule and inferior vestibular nerve) with a high-level acoustic stimulus. VEMPs are short latency electromyograms (EMG) that are evoked by high-level acoustic stimuli and are recorded from surface electrodes over the tonically contracted sternocleidomastoid (SCM) muscle. Studies using human subjects with well documented peripheral audiovestibular lesions have confirmed the vestibular origin of the response (Colebatch and Halmagyi, 1992). Colebatch and Halmagyi demonstrated that the VEMP is abolished following unilateral vestibular neurectomy. These studies also demonstrated that there is no correlation between the VEMP and the degree of sensorineural hearing loss suggesting that the VEMP is not mediated by the cochlear afferents (Colebatch et al., 1994). Furthermore, the saccule has been implicated as the origin of the VEMP and a response pathway has been suggested that includes the saccular macula, afferent inferior vestibular nerve, brainstem vestibular nuclei, the descending medial vestibulospinal tract, and the motoneurons of the SCM muscle.

VEMPs can be recorded with patients seated upright and heads turned to one side (away from the stimulus ear) to activate unilaterally the SCM muscle. A two-channel recording of the VEMP can be obtained using a commercially-available evoked potential unit. Non-inverting electrodes are placed at the midpoint of the SCM muscle on each side of the neck, the inverting electrodes are placed at the sternoclavicular junctions, and the ground electrode is placed on the forehead. Click or tone burst stimuli are presented monaurally at

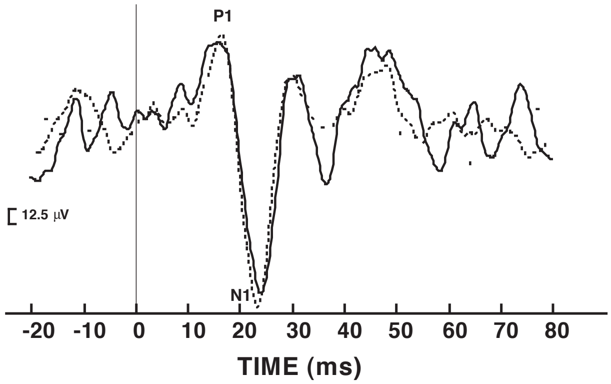

Figure 23. Two-channel VEMP recordings obtained from a normal hearing subject with 100 dB nHL click stimuli delivered to the right ear during activation of the right SCM muscle. The vertical line at 0 ms indicates the onset of the stimulus.

a repetition rate of 5/s.

Representative VEMP waveforms obtained from one subject are shown in **Figure 23**. The VEMP waveform is characterized by a positive peak (P1) at 11 ms, and a negative peak (N1) at 18 ms. The presence of a VEMP in subjects with normal vestibular function is dependent upon adequate acoustic stimulation and ipsilateral activation of the SCM muscle. Side-to-side differences are expressed as an asymmetry ratio (AR) calculated as:

$$AR = 100\,|(A_L - A_R)/(A_L + A_R)|.$$

The VEMP amplitude is influenced by the stimulus level, stimulus frequency, and tonic EMG level, whereas VEMP latency is independent of these variables (Colebatch et al., 1994; Robertson and Ireland, 1995; Lim et al., 1995; Bath et al., 1998; Li et al., 1999; De Waele et al., 1999; Murofushi et al., 1999; Todd et al., 2000; Ochi et al., 2001; Welgampola and Colebatch, 2001; Akin et al., 2003; Akin et al., 2004). Click-evoked VEMP thresholds ranged from 80 to 100 dB nHL in subjects with normal audiovestibular function (Akin et al., 2003; Colebatch et al., 1994; Welgampola and Colebatch, 2001). For tone burst-evoked VEMPs, thresholds range from 100 to 120 dB $_{\text{peak}}$SPL across frequency with the lowest thresholds obtained at 500 and 750 Hz and the highest thresholds obtained at 2000 Hz (Akin et al., 2003).

VEMP abnormalities vary across pathologies; however, in general, interaural amplitude differences and an absent response are the most common abnormalities in vestibular-related disorders. The main exception to this rule is abnormally low VEMP thresholds that primarily occur in patients with superior semicircular canal dehiscence and Tullio phenomenon. Prolonged latency is most common in patients with central pathologies such as multiple sclerosis.

AMPLIFICATION

HEARING AIDS

Hearing aids are a common treatment when hearing loss cannot be medically remediated. Hearing aids are regulated by the FDA, which mandates a 30-day trial period. At the end of the 30-day trial, the hearing aids may be returned for a refund minus fitting fees. Although in most states hearing aid dispensers must be licensed to sell hearing aids, only audiologists (those with a graduate degree in Audiology) are licensed to perform diagnostic auditory tests and to prescribe and dispense hearing aids.

History

The earliest forms of hearing aids consisted of raising a hand to the ear, ear trumpets, and hearing horns (Berger, 1988). The first electric hearing aid was developed in the early 1900s. Technology advanced rapidly with the invention of vacuum tubes that were incorporated into hearing aids. The hearing aid, however, was about the size of a table. The first wearable hearing aid was introduced in the United States in 1937. The next technological advancement to affect the hearing industry was the invention of the transistor (1947). With this new technology, hybrid circuits were developed that led to the miniaturization of hearing instruments. The first ear-level hearing aid was marketed in 1955. Integrated circuits for hearing aids were developed in 1964 eventually leading to the first all-in-the-ear style of hearing aids (1984). Since the mid-1980s, the quality of integrated analog circuits has improved tremendously allowing for a clearer, less distorted signal to be delivered to the listener. Hearing aids with digital signal processors became commercially available in the mid-1990s.

Digital technology has advanced the hearing aid fitting process by providing audiologists with greater flexibility to shape the frequency response to more accurately compensate for a patient's hearing loss. Additionally, digital instruments allow for advanced algorithms designed to reduce feedback and noise while enhancing speech recognition. Digital technology has allowed the directional microphone to also become more adaptive and automatic affording the patient better signal-to-noise ratios and greater ease of use.

Some of the newer technologies that have emerged from the hearing aid industry include receiver-in-the-canal hearing aids and behind-the-ear hearing aids with open earmolds or slim tube fittings relative to traditional custom hearing aids or earmolds. These new models are often referred to as 'free forms' and are changing how professionals and patients think of traditional hearing aids. Patient evaluations of these new devices indicate they are more cosmetically appealing than traditional hearing aids. Other direct patient benefits of these more open ear canal fittings include improvement to how a patient's own voice sounds, i.e., a reduction of the occlusion effect. Additionally, these more open ear canal fittings provide a new amplification option for patients with up to a mild sloping to moderately-severe high frequency hearing loss above 2000 Hz. High frequency gain that is typically prescribed by prescriptive targets is theoretically achievable with open canal fittings due to effective acoustic feedback management systems. By preserving gain in the higher frequencies, speech intelligibility is better maintained. Moreover, effective acoustic feedback management has promulgated the use of extended high-frequency bandwidth beyond the traditional high-pass cutoff frequency of 5.5-6 kHz with extensions commonly in the range of 7-9 kHz. Twenty years of digital development in the area of hearing aid design are, now, beginning to evidence favorable synergistic product features and components. To date, these developments have marginally demonstrated improvements in subjective and objective patient outcomes beyond those obtained with analog hearing aids of the past.

Candidacy and Expectations for Hearing Aids

In the early years, hearing aids were only recommended for patients with conductive hearing loss. These patients generally had good word-recognition abilities and high tolerances for loud sounds. Patients with sensorineural hearing losses and diminished word-recognition abilities were not considered good candidates for amplification. With the advancement of middle-ear surgical techniques, many conductive hearing losses can be medically or surgically remediated, thereby reducing the need for hearing aids in that population. As the number of hearing aid fittings for conductive losses decreased, fittings for sensorineural losses increased. Sensorineural hearing impairment presents several unique challenges for selecting and fitting hearing aids. Because reduced word-recognition ability and reduced dynamic ranges (particularly in the high frequencies) are common for patients with sensorineural hearing impairment, the audiologist must take care in selecting the appropriate hearing aid parameters and counseling patients on realistic expectations of hearing aid use. Due to technological advancements and miniaturization, even patients with normal hearing through 2000 Hz can be provided beneficial amplification. The general criteria for a hearing aid candidacy are an individual whose hearing function is not normal and whose hearing loss cannot be remediated with medical/surgical intervention. In addition, the individual must be motivated to wear hearing aids.

The recommendation for binaural amplification for bilateral hearing loss is preferred because the advantages of binaural listening are restored or maintained, including improved speech under-standing in noise and improved sound localization. When binaural amplification appears to be indicated, there are several circumstances that preclude the prescription of two hearing aids, including an ear with chronic ear disease, a substantial disparity in word-recognition scores between ears, or evidence of difficulty fusing binaural information (Chmiel et al., 1997). The most significant predictor of successful hearing aid use is realistic expectations. Ideally, educating about hearing aid expectations begins with the referral source. The following guidelines can serve to shape such expectations:

1. A hearing aid should help one hear sounds that are difficult without amplification (i.e., women's and children's voices, birds chirping, etc.).

2. Hearing aids may improve speech understanding in noisy listening environments; however, hearing aids, particularly digital noise reduction algorithms, will not filter background sound especially when the background noise is speech.

3. Hearing aids should be comfortable in terms of physical fit in the ear and sound quality. Sounds that are uncomfortable for normal hearing individuals are similarly uncomfortable with hearing aids.

4. Hearing aids do not restore hearing. One cannot expect to understand what someone is saying from the next room.

5. One cannot expect to hear speech clearly if the ear distorts sound (as evidenced by very poor word recognition scores). In such cases, amplification may provide speech (syllable and intonation) cues and signal-warning capabilities. Benefit may be more evident to friends and family who no longer have to raise their voices to be heard.

Styles of Hearing Aids

Hearing aids are available in a variety of styles from large hearing aids that are worn on the body

Figure 24. Different styles of hearing aids with the controls labeled on each instrument.

to very small hearing aids that fit within the external ear canal. All hearing aid styles are currently available to veterans through contracts awarded to manufacturers by the Department of Veterans Affairs. The upper and middle panels in the left column of **Figure 24** display two of the oldest styles of hearing aids (a) body hearing aids and (b) eyeglass hearing aids. These hearing aids are coupled either to an earmold that is worn in the concha of the ear, or to a bone transducer that is placed on the mastoid area behind the pinna. Both of these hearing aids are used with sensorineural and conductive hearing losses. Body hearing aids are usually recommended for profound hearing losses or for patients who cannot manipulate smaller hearing aids. Eyeglass hearing aids are less common than body aids and are generally only found in VA Medical Centers, because they were among the first hearing aids on government contract.

The other four hearing aids in Figure 24 represent the majority of hearing aids prescribed by government facilities and by private practices. The behind-the-ear (BTE) hearing aid also couples with an earmold and is worn over the anterior edge of the pinna. This hearing aid style is often fitted on infants and children with hearing loss; the earmolds are easily changed as the pinnae mature, thus reducing numerous and expensive replacements of the actual hearing aid due to fit problems. Adults are fitted with BTE aids for a variety of reasons including severe-to-profound sensorineural loss, outer and middle ear effusions, poor dexterity that may preclude the use of smaller instruments, and personal choice. The hearing aids displayed in the right column of Figure 24 are basically hearing aids contained within the earmold. The in-the-ear (ITE) hearing aid and the in-the-canal (ITC) hearing aid fit in the concha of the ear and can provide enough amplification for a mild (ITE and ITC), moderate (ITE and ITC), and severe (ITE) hearing loss. The ITE fills the concha, while the faceplate (portion of instrument that is seen in the ear) of the ITC is positioned at the opening of the external auditory canal. Completely-in-the-canal (CIC) hearing aids are the smallest hearing aids available today. The CIC hearing aids fit deep into the external auditory canal making contact with the bony portion of the ear canal. CICs provide additional cues for localization due to microphone placement and additional high frequency cues provided by the pinnae. CIC hearing aids are appropriate for various degrees of sensorineural hearing losses, particularly high-frequency losses and are more cosmetically acceptable to most patients.

In cases in which only one ear would benefit from a hearing aid, CROS or BiCROS arrangements may be used. CROS stands for Contralateral Routing of Signals. These hearing aids require a patient to wear a unit on each ear. The unit on the unaidable ear transmits the signal to a receiver on the normal-hearing ear via a wire or a mini-FM (or AM) transmitter. Because the ear with normal hearing does not require amplification, that ear is kept as open as possible with a non-occluding earmold. BiCROS (bilateral CROS) hearing aids are similar to the CROS except that there is a hearing loss in the better ear that requires amplification. In the BiCROS arrangement, the receiver (worn on the better ear) also acts as a hearing aid. Thus, with the BiCROS, the better ear receives amplified sound from microphones located on both ears. A third option for this patients in a Transcranial CROS (TCROS) hearing aid. This type of fitting places a power hearing aid in the unaidable ear and stimulates the ear through bone conduction. This is accomplished through both acoustic and mechanical stimulation of the temporal bone.

Due to the miniaturization of hearing aids, behind-the-ear hearing aids are now only slightly larger than full shell in-the-ear hearing aids. **Figure 25** shows the relationship in size among a family of hearing aids. The left-most hearing aid is a receiver

Figure 25. A family of hearing aids including the behind-the-ear style through the completely-in-the-ear style.

in the ear instrument. These hearing aids allow for a separation of the receiver from the rest of the chassis of the instrument. The receiver is coupled to a dome or non-occluding earmold and sits in the ear canal, while the microphone a digital processor are located either in the concha or over the ear. These hearing aids provided a broader frequency response and are ideal for listeners with hearing loss above 2000 Hz. Similar to the receiver in the canal instruments are open fit behind-the-ear hearing aids that have the receiver, microphone and processor in the same chassis, but are coupled with a non-occluding earmold. To the right of this instrument is a standard behind-the-ear model followed by the instruments that fit all in the ear: full shell, half shell, canal, and completely-in-the-canal instruments.

Hearing Aid Components and Signal Processing

All styles of hearing aids just discussed have common components. A modern electric hearing aid is an amplifier designed to increase the level of sound energy and deliver the energy to the ear with minimal distortion to the signal (Madaffari and Stanley, 1996). **Figure 26** displays a block diagram of a simple hearing aid. Basic components include:

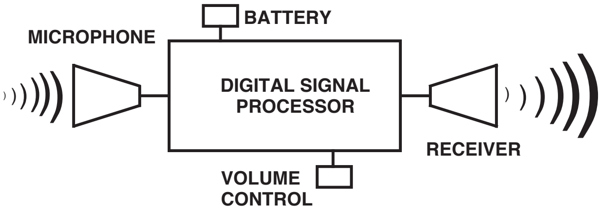

Figure 26. The main five components of a hearing aid.

1. **microphone**--converts acoustic energy to a weak electric (analog) signal,

2. **digital signal processor**--shapes the digital representation of the acoustic signal and controls the algorithms for feedback management, noise reduction, speech processing, etc.,

3. **receiver**--converts the amplified electric signal back to an acoustic signal and transmits to the ear,

4. **power supply**--a 1.3 to 1.5 volt battery, and

5. **volume control**--a dial or serrated wheel that adjusts the amount of amplification of the input signal.

Currently most hearing aids utilize digital signal processing instead of analog signal processing. The digital signal processor converts an analog signal into binary digits through a process referred to as sigma delta conversion. To obtain accurate representation of input signals, sampling and bit rates should be high, e.g., compact-disc quality has a sampling rate of 44.1 kHz and 16-bit resolution. Sampled bits are then processed by a series of algorithms that determine the type of sound processing to be delivered by the hearing aid. Digital processing allows for more precise manipulation of amplitude, frequency, and phase characteristics of signals.

Hearing Aid Selection

The patient with hearing loss should be involved in the selection of the hearing aid. Dexterity, visual acuity, motivation, and family support should all be considered when selecting a hearing aid. These factors will help determine the size of the hearing aid, hearing aid technologies, and or special modifications that need to be made to facilitate an easier transition to hearing aid use. Once hearing aids have been recommended, appropriate parameters of the hearing aid must be chosen. The goal of any hearing aid selection procedure is to maximize word recognition, provide good sound quality, and provide comfortable amplification. To accomplish these goals, the frequency response of the hearing aid must be shaped to compensate for the loss of loudness resulting from the hearing impairment. Several approaches to prescribing appropriate amplification have been developed over the years.

Calculations based on auditory thresholds, most comfortable listening levels, uncomfortable listening levels, and loudness growth provide desired guidelines for selecting specific electroacoustic characteristics (i.e., gain and output). Appropriate dynamic and static characteristics of compression circuits (i.e., attack and release time, compression ratio) can also be estimated from some prescriptive formulas. About 90% of all hearing aids presently ordered in the United States involve some type of prescriptive calculation. Prescriptions provide a target gain appropriate for the user (Tecca, 1996). The programming software used to shape the frequency response of the instrument allows the audiologist to change hearing aid parameters such as gain, output, and compression. In addition, the software allows the audiologist to modify features such as noise reduction, directional microphones, feedback management, and speech enhancement. All of these changes will result in an individualized hearing aid fitting for the patient.

Verification and Validation of Hearing Aid Use

Verification of the hearing aid fitting is essential for successful hearing aid use. The theoretical basis for fitting protocols is broad enough to allow fitting without relying solely on subjective reports from the patient. Thus difficult to test patients (i.e., infants, aphasic patients, etc.) can be fit as soon as the degree of hearing loss is documented. A combination of the following procedures can be incorporated into the hearing aid fitting:

Output SPL: This type of verification procedure includes the use of a probe microphone system (real-ear system) to measure the output of a hearing aid in response to pure tone or speech weighted signals. A real-ear procedure is a non-invasive and requires a thin, pliable probe tube to be placed in the ear canal between the hearing aid and the tympanic membrane. The tube is coupled to a microphone that measures the output of the hearing aid in sound-pressure level. Fitting hearing aids in SPL mode has became the most popular method of fitting hearing aids in recent years when probe microphone measures are used. Prescriptive targets are expressed as real ear aid response (REAR) targets and such targets are usually generated for multiple input levels representing soft, average, and loud speech (e.g., 50, 65, and 80 dB SPL). Additionally, the maximum possible output of a hearing aid is measured, usually with a 90 dB swept pure tone input signal, to ensure that output levels do not exceed a patient's loudness discomfort levels LDLs) or uncomfortable listening levels (ULLs).

Insertion Gain: This type of verification procedure also uses a probe microphone system to measure objectively the gain of the hearing aid in response to pure-tone signals or speech weighted noise. The gain of the hearing aid, termed real ear insertion gain (REIG) can then be directly compared to the REIG target derived from a selected prescriptive technique. Again, prescriptive REIG targets are generated for multiple input levels (e.g., 50, 65, and 80 dB SPL) as hearing aids now predominantly utilize compression processing as opposed to linear processing. Accordingly, prescriptive REIG targets decrease as input level increases for hearing aids utilizing compression, whereas gain remains the same across input levels for a hearing aid utilizing linear processing.

Functional Gain: When probe microphone instrumentation is not available another option is measuring the functional gain of the hearing aid(s). During functional gain testing, patients are tested in the sound field. Behavioral aided and unaided responses (threshold and word recognition) are compared to determine the amount of gain provided by the hearing aids. The gain is then compared to the prescribed gain to determine if the hearing aid fit is successful. Care must be taken to reduce or eliminate ambient room noise and internal hearing aid noise that may reduce the validity of the measures. More information regarding strategies for hearing aid selection and verification can be found in de Jonge (1996).

Following the fitting, the hearing aid user undergoes a period of acclimatization. Adjustment entails learning the non-trivial details of use and care of the hearing aids as well as learning to use new sound. Some research indicates that hearing aid benefit increases over time, at least for some listeners (Turner et al., 1996). Several subjective instruments are available to validate hearing aid performance and benefit. These instruments are interview or survey formats that ask specific questions about hearing aid performance in real environments. Some examples of these measures include the Hearing Aid Performance Inventory (Walden et al., 1984), Communication Profile for the Hearing Impaired (Demorest and Erdman, 1987), Profile of Hearing Aid Benefit, (Cox et al., 1991), the Client Oriented Scale of Improvement (Dillon et al., 1997), and the International Outcomes Inventory for Hearing Aids (Cox and Alexander, 2002). A successful hearing aid fitting culminates in the patient wearing the instrument and perceiving benefit from the hearing aid.

COCHLEAR IMPLANT

A cochlear implant is an electronic device that is designed to provide useful sound information by directly stimulating the surviving CNVIII fibers in the cochlea. A cochlear implant is an option for adults and children who have a sensory hearing loss and receive limited benefit from traditional hearing aids. There are six general criteria for consideration of cochlear implantation in adults (18^+ years of age):

1. bilateral, severe to profound sensorineural hearing loss for pure tones;

2. less than 50% aided open-set sentence recognition for the ear to be implanted or less than 60% open-set sentence recognition under the best aided listening condition;

3. post-linguistic hearing loss;

4. limited benefit from the most appropriate hearing aids;

5. no medical contraindications; and

6. strong desire to be a part of the hearing world.

The internal portion of the cochlear implant system consists of a receiver/stimulator and an electrode array. The cochlear implant surgically is placed using a posterior-tympanotomy approach. The internal device is placed in a shallow bed made in the mastoid bone behind the pinna and secured in place. The electrode array is inserted into the scala tympani via a cochleostomy. Approximate insertion depth of the electrode array is 25 mm or one and a half turns. The external components are fit and programming of the cochlear implant system is completed approximately 3-5 weeks after surgery. The external portion of the cochlear implant system consists of a microphone, transmitting cords, speech processor, and transmitting coil; the implanted receiver/stimulator and electrode array. The microphone receives the auditory signal and transmits it to the speech processor. The signal received by the speech processor is then encoded into electrical signals and sent to the transmitting coil. The transmitting coil, which is held in place over the internal device by a magnet, receives the encoded electrical signal and sends this signal to the internal receiver/stimulator that activates the appropriate electrodes in the electrode array. The electrodes stimulate the corresponding CNVIII nerve fibers. This information then is passed along CNVIII for final auditory processing by the brain.

Success of the cochlear implant cannot be predicted and is quite varied. Length of deafness, status of the cochlea and CNVIII, motivation to hear by the individual as well as the support of family members, and post surgical rehabilitation, play a key role in the final outcome. On average, adults with post-lingual deafness achieve 50% open-set word recognition and 80% open-set sentence recognition with their cochlear implants after one-year of implant use. Many cochlear implant users are even able to use the telephone.

Bone Anchored Hearing Aid

For individuals with conductive or mixed hearing losses, traditional air conduction hearing aids frequently are contraindicated. These patients often resort to using a traditional bone-conduction hearing aid, which is not appealing cosmetically or is uncomfortable to wear. In these cases, a bone anchored hearing aid, or BAHA, may be a viable option. With a BAHA, a titanium fixture is inserted into the mastoid bone surgically. Three to five months later, the bone osseointegrates around the fixture. A BAHA processor, then is attached to this fixture via an abutment. The BAHA processor has a microphone that picks up the sound, which is converted into mechanical vibrations so that the abutment vibrates the skull and the patient hears directly through bone conduction. In order to be a candidate for a BAHA, the patient must meet the following general criteria:

1. age 5 years or older,

2. pure-tone average < 45 dB HL for bone-conduction thresholds at 500, 1000, 2000, and 3000 Hz,

3. unaided word recognition scores ≥ 60%,

4. can not or will not use air-conduction or bone-condition hearing aids.

An additional application of a BAHA may be indicated for individuals with a unilateral deafness. In these cases, one ear has normal hearing and the other ear has a profound sensorineural hearing loss. Traditionally, these cases have been fit with CROS or transcranial CROS hearing aids, but the use of a BAHA to treat patients with this type of loss is becoming increasingly popular. In order to be a candidate for a BAHA for unilateral deafness, the patient must meet the following general criteria:

1. age 5 years or older,

2. pure-tone average < 20 dB HL for air-conduction thresholds at 500, 1000, 2000, and 3000 Hz,

3. can not or will not use CROS or transcranial CROS hearing aids.

ASSISTIVE LISTENING TECHNOLOGY

A variety of assistive technologies are available for individuals with hearing loss. Several of these devices can be coupled to hearing aids or cochlear implants, whereas others are independent of the amplification. These technologies are intended to enhance listening in noisy environments, improve telephone communication, and alert listeners to environmental sounds.

Assistive Listening Devices (ALD)

Assistive listening devices (ALDs) are amplification systems designed to improve the signal-to-noise ratio. Enhancement of the signal-to-noise ratio is accomplished by delivering the signal of interest to the listener without added background noise. Some listening situations in which ALDs may be the most beneficial include classrooms, lecture halls, movie houses, theaters, business meetings, automobiles, restaurants and telephones. The majority of ALDs can be used with and without hearing aids, thus making these systems available for many individuals with hearing loss. Many of the systems can be used individually or in group settings (Compton, 1989).

Most ALDs have the same basic components including a microphone, transmitter, and a receiver. The microphone is placed near the sound source and transduces an acoustic signal to an electric signal. The transmitter sends the signal either directly to the ALD receiver (a headphone) or indirectly to the receiver in a hearing aid (via a neckloop or direct audio input). Several tech-nologies are used in assistive devices including induction loop, frequency modulation (FM) and infrared, (Ross, 1994).

Induction Loop Systems: Induction loop systems are based on the principle of electromagnetic induction, which occurs when an electrical current is amplified and passed through a loop of coiled wire, generating an electromagnetic field in the vicinity of the loop. When another coil of wire (such as a telecoil in a hearing aid) is introduced into the vicinity of the electromagnetic field surrounding the loop, an electric current is induced in the coil. When used in ALD technology, the electromagnetic loop is placed around the perimeter of the room or listening area. Another example of an induction loop is an individually worn neckloop. The major limitation to induction loop technology is spillover, which occurs when adjacent rooms are equipped with loops and the auditory signal from one loop bleeds into the adjacent loop. A new technology has recently been applied to induction loop systems that may improve coupling to hearing aid telecoils and reduce spillover from room to room. This three-dimensional system consists of a pre-fabricated configuration of three audio loops (embedded in a mat) that vary the output of the signal in amplitude and phase, creating a three-dimensional electromagnetic signal directly over the mat (Gilmore, 1995). In addition to looping large areas for groups, smaller areas (i.e., a car, a chair, or an individual's room) can be looped for individual use.

FM Assistive Devices: FM assistive devices use frequency modulated sound waves to transmit signals and are similar to a miniature FM radio station. FM systems have been used in schools by children with hearing impairment since the 1960s. The Federal Communications Commission (FCC) originally allocated frequencies in the 72 mHz to 76 mHz band to be used specifically for assistive listening devices by individuals with hearing impairment. FM systems are the most flexible and durable of all large groups assistive listening devices and therefore are very popular in school systems. Because 72-76 mHz is no longer reserved for the hearing-impaired population, interference from other FM transmissions, such as pagers, taxis, and monitoring systems can occur. This problem can usually be alleviated by changing the carrier frequency of the system. Another potential disadvantage to the FM systems is that they will transmit through obstructions and over long distances; thus, the signal can be picked up by unauthorized listeners (Lewis, 1995). FM systems are commonly found in theaters and lecture halls, however, individual systems are also available. Personal FM systems can be used in restaurants, automobiles, crowded rooms, and elsewhere to enhance the signal-to-noise ratio, thus providing more advantageous listening environments.

Infrared Systems: Infrared systems provide excellent fidelity and are becoming increasingly popular in theaters and concert halls. These devices transmit signals via harmless light waves using an infrared light carrier frequency of 95 kHz. Infrared signals are confined to the listening area, as the light cannot penetrate walls; thus, spillover and unauthorized listening are not concerns. Limitations of infrared technology include interference from other light sources (e.g., fluorescent light and sunlight), the need for the listener to be in the "line-of-sight" of the emitters to obtain the strongest signal, and the lack of directionality of the signal owing to light reflecting off of walls, ceiling, furnishings, and clothing (Ross, 1994). In addition to theaters, infrared systems can also be found courtrooms, in which confidentiality is important. Individual use of this technology includes a device for the television that provides excellent sound quality and a separate volume control.

Telecommunication Devices

Telecommunication devices are used to improve telephone communication. Difficulty using telephones is one of the most common complaints of hearing aid users. Several devices are available to consumers now; other, more advanced technologies are still in development. Telecommunication technologies provide assistance for a wide range of hearing loss, with some routinely used by members of the deaf community.

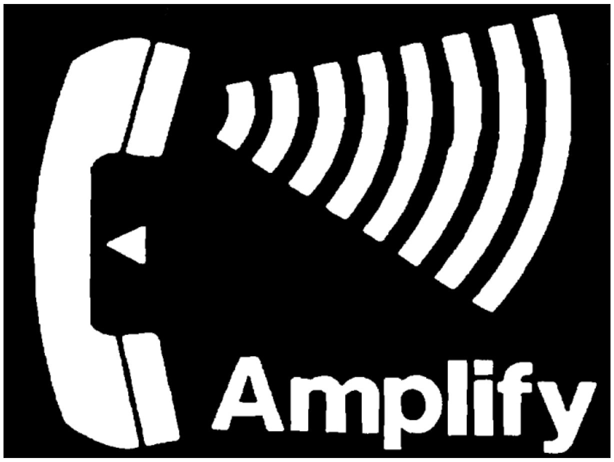

Figure 27. Amplified telephone sign.

Amplified Phones: Several telephone manufacturers offer telephones with amplifiers that increase the level of the speaker's voice. Telephones that have amplifiers are identified in public by the symbol shown in **Figure 27**. Typically a volume control is placed on the handset, allowing the user to adjust the volume of the speaker to a comfortable level. Some amplifiers are portable and can be attached to the receiver of almost any telephone. After the Americans with Disability Act was passed, many public telephones were equipped with amplifiers. These phones are usually identified by a light blue band placed around the cord at the receiver. Amplified ringers for telephones also are available.

Text Telephones: Text telephones are telephones equipped with a special modem (acoustic coupler) and keyboard that enable individuals who are deaf or very hard-of-hearing to communicate using the telephone system. Text telephones (TT) also are known as Telephone Devices for the Deaf (TDD) and teletypewriters (TTY). The devices provide immediate telephone interaction between two individuals with compatible text telephones. Relay services are mandated by the Americans with Disabilities Act (1992) to facilitate communication between a text telephone and a standard telephone. This service is accessed through a 1-800 telephone number and requires the participation of an operator (communication assistant) with a text telephone to mediate the conversation. Thus, the communication assistant converts all TTY messages to voice and all voice messages to TTY. Relay numbers are listed in the front section of most telephone books. Public text telephones are available in airports, conference halls, hotels, etc. **Figure 28** depicts the international symbol for the TDD, TT, and TTY.

Figure 28. The international symbol for TDD, TT, and TTY.

Video and Multimedia Telephones: The use of personal computers and fiber optics over the past several years may provide new options for communication with individuals with hearing impairment. This technology is rapidly becoming available and may become the option of choice for these individuals. Videophones include a small monitor with the phone, whereas multimedia applications involve the use of telephones, televisions, and computers. These devices provide facial cues, lip movements, and signing to ease communication.

Alerting Devices

There are also several devices available that alert individuals with hearing loss that something important is happening. Many of these devices can be purchased at local electronic stores and are used with or without hearing aids (Garstecki, 1995).

Smoke Detectors: Several different types of smoke detectors are available for individuals with hearing loss. Some models use a visual strobe light (100 candela) or an auditory output of 85-dB SPL to warn the individual of a possible fire. These devices typically operate on 115-volt house current and use a back-up battery system. Other devices have a transmitter in a regular smoke detector that sends a signal to a receiver unit placed near the hearing-impaired individual. The receiver unit has a strobe light or a vibrating unit that is placed near or on the individual with hearing loss.

Visual Signaling Devices: Different types of signaling devices are available to alert an individual to a ringing telephone, doorbell, or crying baby. A door or phone can be equipped with a transmitter, which sends a signal to the receiver.

The receiver can be coupled to a household lamp, thus causing the light to flash when the signal is received. This same principle can be used with motion and sound sensors to alert the individual about changes in their environment. Another example of a visual system is a baby crying signaler. These devices are essentially amplified baby monitors equipped with a light source that flashes when sound is detected.

AUDIOLOGIC REHABILITATION

After a hearing loss has been diagnosed and medically treated (when possible) the next course of treatment typically is audiologic rehabilitation and amplification. Audiologic rehabilitation focuses on the individual and the environment whereas amplification (hearing aids, assistive technologies, and cochlear implants) focuses on maximizing residual hearing. Legislation formulated in the early 1990s provided greater accessibility to amplification and assistive technologies for individuals with hearing impairment. The Americans with Disabilities Act (ADA) (1992) mandates communication access for individuals with hearing impairment. Title III of the ADA (January 26, 1993) prohibits discrimination on the basis of disability in places of public accommodation. Places of public accommodation include hotels/motels, restaurants, theaters, convention centers, doctors' offices, public transportation stations, parks, zoos, libraries, and universities. Many public facilities have made special provisions (i.e., assistive technologies) for individuals with hearing loss. Individuals should ask the management of movie theaters, stage theaters, hotels/motels, banks, etc., for information on what types of provisions have been made for people with hearing loss. One impact of the ADA is the incorporation of closed captioning on all televisions made after July 1, 1993. The international symbol for hearing impairment is shown in **Figure 29**.

Figure 29. The international symbol for hearing impairment.

Audiologic rehabilitation or habilitation "is an ecological, interactive process that facilitates one's ability to minimize or prevent the limitations and restrictions that auditory dysfunctions can impose on well-being and communication, including interpersonal, psychosocial, educational, and vocational functioning" (ASHA, 2001). Habilitation refers to intervention procedures with children who have pre- or peri-lingual hearing impairment or deafness. Rehabilitation refers to intervention procedures with children and adults with post-lingual hearing loss. Individuals with hearing loss must learn to integrate visual and auditory cues as well as communication strategies to compensate for the auditory deficit. During audiologic rehabilitation, an audiologist can work alone or lead a team of professionals that may include vocational counselors, social workers, psychologists, speech pathologists, and teachers. The professionals help the child or adult with hearing impairment overcome the communicative, social and psychological effects of the hearing loss (Schow and Nerbonne, 1996).

The history of audiologic rehabilitation dates to the 16th century when instruction was limited to children with hearing impairment and the course content was restricted to speech production. By the latter part of the 19th century, instruction was offered to adults, and the course content was expanded to include speechreading (lipreading), visual cues, and contextual cues. During the past century, communication strategies training, auditory training, assertiveness training, and informational counseling on hearing aids and assistive listening devices have been added to the course content, creating a multisensory approach to audiologic rehabilitation. Because the age of the patient and the severity of the hearing loss influence the communication impairment, the emphasis in audiologic rehabilitation programs differs according to the needs of the individual.

Pediatric Habilitation

Children require intensive audiologic habilitation programs that require input from several different disciplines. Infant and preschool programs give equal emphasis to speechreading, speech production, amplification, and auditory discrimination to maximize the use of residual hearing. The use of sign language or other methods of manual communication varies according to the philosophy of the teaching institution and the degree of hearing loss. Early identification of and intervention with children with hearing impairment is necessary to realize full potential for language development. Family support is imperative to the success of the program. Beginning with preschool, audiologic habilitation programs incorporate academic subjects to increase the possibility of mainstreaming into regular classrooms.

Adult Rehabilitation

Speechreading (Lipreading)

Historically, audiologic rehabilitation has emphasized speechreading. Various methods are used to teach the participants to recognize the facial and or lip formations that correspond to particular speech sounds. Speechreading alone, however, cannot provide sufficient linguistic information to allow for adequate comprehension of the spoken words. Over 40% of the speech sounds in the English language are homophenous (i.e., visually identical). Speechreading, therefore, is at best a series of educated guesses. For example, the initial consonant sounds of the words my, pie, and by require the upper and lower lips to join together and then release. Because no visual difference exists among the words, the listeners cannot distinguish the words without the acoustic information. If a contextual cue is provided (e.g., the conversation concerns food), then the listener can deduce that the word is pie, instead of my or by (Hipskind, 1996).

In addition to the problems of the homophenous sounds, speechreading is limited by speaker differences, the normal rapidity of speech, modification of sounds by adjacent sounds, and environmental limitations. For example, beards, mustaches, and poor lighting can obscure essential visual input. A successful audiologic rehabilitation program consists of good patient motivation and a multimodality approach to improving communication skills. Familial support is a significant factor in the success of the program (Preminger, 2003).

Communication Strategies Training

In the adult audiologic rehabilitation program, the primary focus is maximizing communication and reducing the psychosocial implication of the hearing loss on the individual and the family. Most often, communication strategies are taught and involve manipulation of environmental cues, visual cues, and auditory cues to enhance communication. Rehabilitation may be conducted on an individual or group basis and covers topics such as better understanding of hearing loss and hearing aids, trouble shooting hearing aids, assistive listening technologies, the effects of hearing loss on daily experiences, and other specific tasks. In group settings, role playing often is beneficial in demonstrating good communication strategies and encourages group participation (Alpiner and Garstecki, 1996). Family members should be involved whenever possible to facilitate a better understanding of what hearing impairment involves and to develop an extensive support network for the individual. This support network can further diminish feelings of frustration, anxiety, or inadequacy resulting from the hearing loss.

Examples of good communication strategies for individuals with hearing loss include:

1. make it a habit always to watch the speaker,

2. eliminate background noise when possible,

3. concentrate on the topic of the discussion, instead of individual words,

4. stay aware of current events, and

5. ask the speaker to repeat/rephrase a sentence if the sentence was not understood.

Examples of good communication strategies when speaking to someone with a hearing loss include:

1. speak clearly and slowly,

2. do not shout (shouting distorts speech),

3. do not obscure your mouth while speaking,

4. look directly at the listener,

5. stand in clear lighting to avoid casting shadows on your face, and

6. make sure you have the listener’s attention before you begin speaking.

Auditory Training

In recent years, auditory training has re-emerged as a treatment for adult hearing-aid users. Traditionally with auditory training, the patient and therapist have an individual training session in which the patient performs discrimination exercises between two phonemes in nonsense syllables and words (i.e., analytic, bottom-up approach) or tries to comprehend the overall meaning of a sentence or paragraph that contained the target phoneme (i.e., synthetic, top-down approach). Recently, computerized auditory training programs have gained popularity. Many of these computerized auditory training programs are commercially available and are targeted for home use. There are home-based, computerized auditory training programs available for both the hearing aid user and for cochlear implant users. Although auditory training typically is performed on an individual basis, it is not uncommon for auditory training to be a part of a group audiologic rehabilitation program.

Assertiveness Training

Individuals with hearing loss often need to ask others for assistance during conversation. Some individuals are passive and do not ask for assistance from their communication partner. These passive individuals often bluff or pretend to understand the conversation when they really do not. Other individuals are aggressive when asking for assistance and blame their communication partner for the communication breakdown or ask for assistance in a demanding or hostile fashion. Neither the passive or aggressive conversational styles are effective, but are often a defense mechanism for individuals with hearing loss. In audiologic rehabilitation, a goal is to train individuals how to adopt an assertive conversational style, which is an effect method of gaining assistance from a communication partner. An assertive conversational style incorporates the following techniques:

1. inform the communication partner that you have a hearing loss and that you need assistance,

2. be specific in the request for assistance (e.g, “Because of my hearing loss it would help me if you looked at me when you spoke”),

3. be polite with your request, and

4. provide the communication partner with feedback on how his/her assistance worked.

Informational Counseling on Hearing Aids and Assistive/Alerting Devices

A significant component of audiologic rehabilitation is the provision of informational counseling on hearing aids, assistive listening devices, or altering devices. Contemporary hearing aids have several unique features for typical use and require daily care. Audiologists spend approximately 30-45 minutes instructing new hearing-aid users on hearing-aid care and use, and practicing hearing-aid skills such as cleaning and battery insertion (Reese and Smith, 2006). Individuals, particularly older individuals, may only remember ~50% of the information provided (Margolis, 2004). In order to maximize informational counseling sessions for patients, clinicians can adopt the following strategies:

1. divide the information in logical sections,

2. practice with easier skills first before moving to harder skills,

3. lots of repetition,

4. use of role play,

5. include a family member in the session to help the patient remember the information, and

6. use pedagogic materials as supplements for the counseling session (Smith and West, 2006)

HEARING CONSERVATION

Hearing Conservation is the prevention or minimizing of noise induced hearing loss through the use of hearing protective devices and the control of noise by engineering methods or administrative procedures. The Occupational Safety and Health Administration (OSHA) is the federal agency that regulates hearing conservation programs. Hearing Conservationists receive certification through the Council for Accreditation in Occupational Hearing Conservation (CAOHC). Noise induced hearing loss is the most prevalent occupational health impairment. It is almost always preventable. The prevention is generally simple, safe, and reasonably economical, especially when compared to the millions of dollars paid annually for compensable work-related hearing loss.

Overexposure to noise affects the entire body. In addition to the physiologic damage to structures in the Organ of Corti and associated sensorineural hearing loss and tinnitus, many other effects are reported. These include increased pulse rate, hypertension, increased secretion of certain hormones, tiredness, nervousness, sleeplessness and other symptoms of stress. Early symptoms of noise induced hearing loss are temporary hearing loss, tinnitus, aural fullness and reports of speech sounding muffled. Over time the temporary hearing loss becomes permanent. Typically noise induced hearing loss begins as a mild sensorineural dip in the frequency range 3000- 6000 Hz. Later the loss becomes more severe at these frequencies and also affects both lower and higher frequencies.

Hearing Conservation programs include the five following elements:

1. **Noise Hazard Evaluation**. Noise surveys confirm the presence of hazardous noise (85 dBA for continuous noise and 140 dBP for impulse noise) and monitor any changes in equipment or procedures that might affect noise levels.

2. **Engineering Controls**. The most desirable method of controlling noise is to reduce the sound levels at the source. Noise control measures are often expensive and impractical. Any procedure that reduces the total noise exposure for an individual, including adjusting work schedules, will be effective to conserve hearing.

3. **Monitoring Audiometry**. OSHA requires that monitoring audiometry be conducted by audiologists, physicians or CAOHC certified technicians. Periodic tests are compared to baseline audiograms to monitor hearing levels during employment. If a “standard threshold shift” (shift in baseline of an average of 10 dB at 2000, 3000, and 4000 Hz) is noted, then the employee is re-tested, notified in writing and referred for further medical and audiologic evaluation. Note: The OSHA regulation specifies hearing-loss correction factors for age and gender that are included in the calculations of standard threshold shift.

4. **Hearing Protection**. Hearing protection devices are usually in the form of earplugs or earmuffs and serve as a barrier between the noise and the cochlea. There are many types on the market; compliance with requirements to use hearing protection often depends on whether or not the person finds them comfortable, so proper fit is essential. Extremely high level noise exposures indicate the need for double protection, earplugs and earmuffs worn together.

5. **Health Education**. OSHA requires training sessions annually for all employees exposed to any hazardous noise. When educated on the effects of noise on hearing and prevention measures, many employees become motivated to protect their own hearing. Good programs include supervisors and top management, as well as all noise exposed employees.

ORGANIZATIONS

The following is a list of organizations that are involved with the effects of hearing loss on individuals:

American Academy of Audiology (AAA)
Suite 300
11730 Plaza America Drive
Reston, VA 20190
(703) 790-8466; (800) 222-2336
website: http://www.audiology.org

American Speech-Language-Hearing Association (ASHA)
2200 Research Boulevard
Rockville, MD 20850-3289
(800) 498-2071 (Members); (800) 638-8255 (Non-members)
(301) 296-8580 (FAX)
website: www.asha.org

Academy of Dispensing Audiologists
3008 Millwood Avenue
Columbia, SC 29205
(803) 252-5646 (803) 765-0860 (FAX)
website: www.hear4u.com

Academy of Rehabilitative Audiology
Box 952
DeSoto, TX 75123
(972) 534-1281 (FAX)
website: www.audrehab.org

Alexander Graham Bell Association for the Deaf
3417 Volta Place Northwest
Washington, DC 20007
(202) 337-5220
website: www.agbell.org

American Auditory Society
352 Sundial Ridge Circle
Dammeron Valley, UT 84783
(435) 574-0062; (435) 574-0063 (FAX)
website: www.amauditorysoc.org

Audiology Foundation of America (AFA)
Suite 406
8 North Third Street
West Lafayette, IN 47901
(765) 743-6283
website: www.audfound.org

Better Hearing Institute, BHI
Suite 700
1444 I Street, NW
Washington, DC 20005
(202) 449-1100; (800) EAR-WELL
e-mail: mail@betterhearing.org
website: www.betterhearing.org

International Hearing Society
Suite 4
16880 Middlebelt Road
Livonia, MI 48154
(734) 522-7200; (734) 522-0200 (FAX)
website: www.ihsinfo.org

League for the Hard of Hearing
6th Floor.
50 Broadway.
71 W. 23rd St.
New York, NY 10004
(917) 305-7700; (917) 305-7999 (TTY)
(917) 305-7888 (FAX)
website: www.lhh.org

Hearing Loss Association of America (HLAA)
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website: www.sertoma.org

EXAMPLE CASES

The following pages contain typical audiograms and other audiologic data that are from 12 representative patients. Accompanying each example case is a narrative that explains the audiologic findings and the treatment plans that were formulated for the respective patients.

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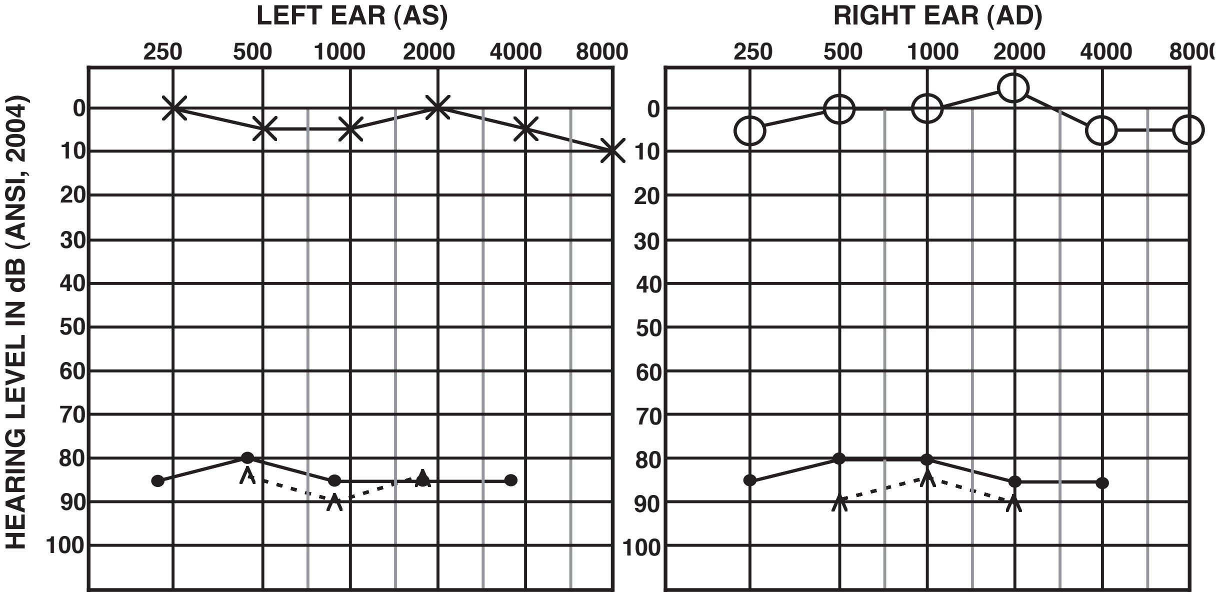
AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING											
A/C											
B/C											

EFFECTIVE MASKING											
A/C											
B/C											

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	P	P	P	P
DPOAE						

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	P	P	P	P
DPOAE						

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION					MCL	UCL
				QUIET				WIN		
	2 FREQ.	3 FREQ.	[✓ SRT]	50 dB HL	dB HL	dB HL	90 dB HL	50% dB S/N	dB HL	dB HL
AD	-3	-2	3	92%			100%	6.0	45	90
MASKING AS				20			60			
AS	3	3	4	96%			100%	6.0	50	90
MASKING AD				20			60			

[✓ Compact Disc]
MLV
[✓ N.U. No. 6]
MARYLAND CNC
W-22
PICTURE IDENTIFICATION

RELIABILITY
[✓ GOOD]
FAIR
POOR

	AS	AD
A/C UNMASKED	×	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

ACOUSTIC REFLEXES
CONTRA ●——●
IPSI ʌ— —ʌ

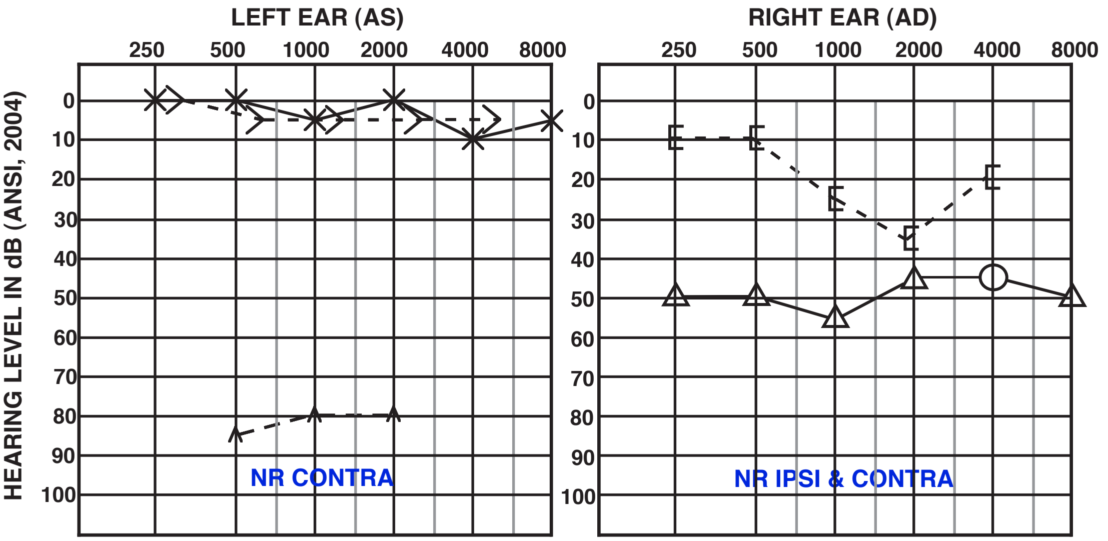
REMARKS: Tympanograms normal AU

Case #1. This is a 23-year old male with no complaints of hearing loss, dizziness, or tinnitus, and no history of otologic disease. The results of his audiologic evaluation are shown on the accompanying audiogram.

Pure-tone air-conduction thresholds for the left ear are shown with Xs on the left graph and thresholds for the right ear are shown with Os on the right graph. Air-conduction thresholds for both ears were -5 to 10-dB HL from 250-8000 Hz, which are within normal limits. Bone-conduction thresholds were not obtained because the air-conduction thresholds were normal. The two-frequency pure-tone average (500 and 1000 Hz) for the left ear was 3-dB HL and the three-frequency pure-tone average (500, 1000, and 2000 Hz) was 3-dB HL. Similarly, for the right ear, the two-frequency average was -3-dB HL and the three-frequency average was -2-dB HL. The speech-recognition thresholds (SRT) for the left and right ears were 3-dB HL and 4-dB HL, respectively, which are within the 6-dB range of agreement with the two- and three-frequency pure-tone averages, indicating good inter-test reliability. Transient-evoked otoacoustic emissions were present at least 3-dB above the level of the noise floor across the frequency range. This finding was in agreement with pure-tone findings, indicating normal cochlear function in both ears.

Word-recognition performance in quiet at conversational level (50-dB HL) was 96% for the left ear and 92% for the right ear. During the speech test, 20 dB of effective masking was applied to the opposite ear to mask the 10 dB of cross hearing expected from the 50-dB HL air-conducted speech signal. The word-recognition performance in quiet at a high level (90-dB HL) with 60 dB of masking in the opposite ear also was good in both ears, indicating that the ability of the auditory system to transmit signals at high levels was intact. The 50% points on the words-in-noise test (WIN) were 6.0-dB S/N in both ears, which is on the upper limit of the normal range. The most comfortable listening level (MCL), 45-dB HL and 50-dB HL respectively in the right and left ears, was normal. The uncomfortable listening level (ULL), 90-dB HL in both ears, also was normal. Tympanograms in both ears were normal, meaning that a single peak of maximum admittance occurred at atmospheric pressure in the acoustic susceptance and the acoustic conductance measures. Acoustic reflex thresholds are shown on the lower portion of the pure-tone graphs. The reflex thresholds are plotted for the stimulus ear. Thus, for contralateral measures, the activator signal and the probe (recording) device are in opposite ears; the contralateral thresholds are plotted with dots on the graph for the stimulus ear. For ipsilateral measures, the stimulus and probe are in the same ear; the ipsilateral thresholds are plotted with carets on the graph for the stimulus ear. All of the reflex thresholds were normal (85- to 100-dB HL) and no contralateral reflex adaptation was measured at 500 Hz and 1000 Hz. In summary, all test results were consistent with normal hearing.

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING

A/C										
B/C										

A/C	30	30		35		30				45
B/C	40	40		55		70		50		

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION						
				QUIET				WIN	MCL	UCL
	2 FREQ.	3 FREQ.	[✓ SRT]	60 dB HL	70 dB HL	90 dB HL	dB HL	50% dB S/N	dB HL	dB HL
AD	47	50	48	36%	84%	100%		--	85	100+
MASKING AS			30	20	30	50				
AS	0	2	0	100%		100%		4.4	50	90
MASKING AD				60		90				

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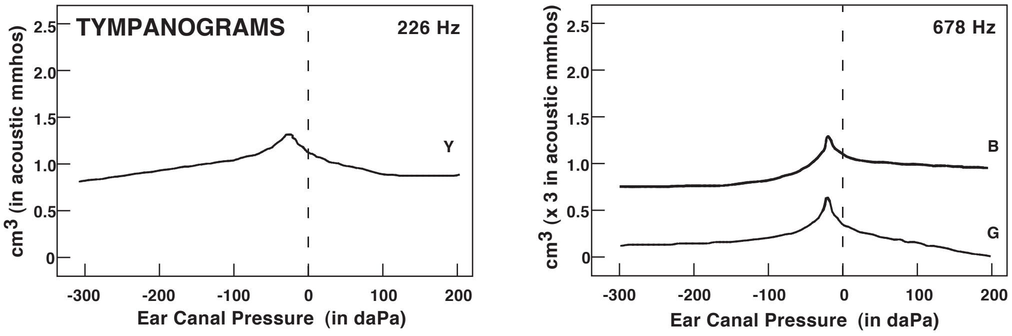
MLV
[✓ N.U. No. 6]
MARYLAND CNC
W-22
PICTURE IDENTIFICATION

RELIABILITY
[✓ GOOD]
FAIR
POOR

	AS	AD
A/C UNMASKED	×	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ʌ– – ʌ

REMARKS: Weber lateralized right ; Bing was negative in the right ear and positive in the left ear.



Case #2. This case is a 45-year old female who complained of a progressive, unilateral hearing loss. She reported difficulty hearing people on her right side, localizing sounds, and understanding conversations in noisy environments. The patient reports only being able to use the telephone on her left ear. The patient denied a history of ear infection, but reported a family history of hearing loss. Subsequent to audiometric testing, surgical findings confirmed otosclerosis in the right ear. The pure-tone air-conduction thresholds were normal in the left ear. The SRT of 9-dB HL agreed with the pure-tone averages. Word-recognition performance at 60-dB HL and at 90-dB HL was good.

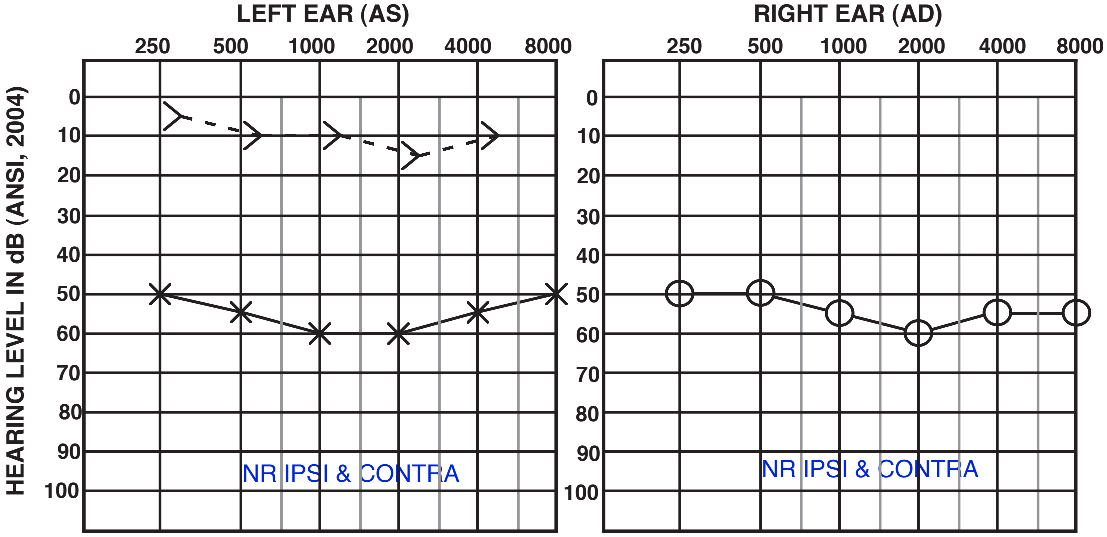
The pure-tone air-conduction thresholds in the right ear demonstrated a moderate, flat hearing loss. Because symmetrical hearing is imperative in localizing sounds and in understanding speech in noise, a unilateral hearing loss of this degree accounts for the communicative difficulties of the patient.

The masked bone-conduction thresholds in the right ear (brackets) were normal except at 2000 Hz. The hearing loss, therefore, is predominantly conductive. The decrease in bone-conduction sensitivity at 2000 Hz, the *Carhart notch*, has been attributed to a change in the resonance properties of the ossicular chain because of the bony growth around the stapes footplate. The Carhart notch generally is absent following a stapedectomy. This post-surgical finding indicates that bone-conduction testing does not bypass completely the middle-ear transmission system.

Word-recognition performance in quiet in the right ear at a slightly above normal conversational level (60-dB HL) was poor. This result is expected because the words were only 10 dB above the air-conduction thresholds at 500-2000 Hz. When the presentation level of the words was increased to 70-dB HL, word-recognition performance improved to good. This 48% improvement in performance for a 10 dB increase in signal level is consistent with the slope of the psychometric function in normal listeners and in listeners with conductive hearing losses. Word-recognition performance was 100% at 90-dB HL. Because of the severity of the air-conduction loss in the right ear, the words-in-noise test (WIN) was not administered. The 50% point for the WIN administered to the left ear was 4.4-dB S/N, which is well within the normal range (0- to 6-dB S/N). The level of the signal reaching the cochlea is attenuated by the magnitude of the air-bone gap. This attenuation, about 30 dB in this case, is responsible for the elevated MCL in the right ear.

Tympanograms for both ears were normal (1B1G); tympanometric shape generally is not altered by stapedial fixation. Acoustic reflexes were present only when the stimulus and the probe were in the normal, left ear (ipsilateral). Acoustic reflexes were absent when the probe was in the ear with the conductive pathology (right ipsi and left contra). Because the stapes is fixed, contraction of the stapedial muscle does not move the stapes, and therefore, the acoustic admittance does not change. The acoustic reflexes also were absent when the stimulus was presented to the right, conductive ear, because the level of the tone at the limits of the equipment is not high enough to overcome the conductive component. The audiologic results are consistent with a unilateral conductive hearing loss in the right ear.

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING

A/C										
B/C										

A/C										
B/C										

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION					MCL	UCL
				QUIET				WIN		
	2 FREQ.	3 FREQ.	[✓ SRT]	dB HL	dB HL	dB HL	90 dB HL	50% dB S/N	dB HL	dB HL
AD	52	55	58				92%	--	90	100+
MASKING AS										
AS	58	58	60				100%	--	95	100+
MASKING AD										

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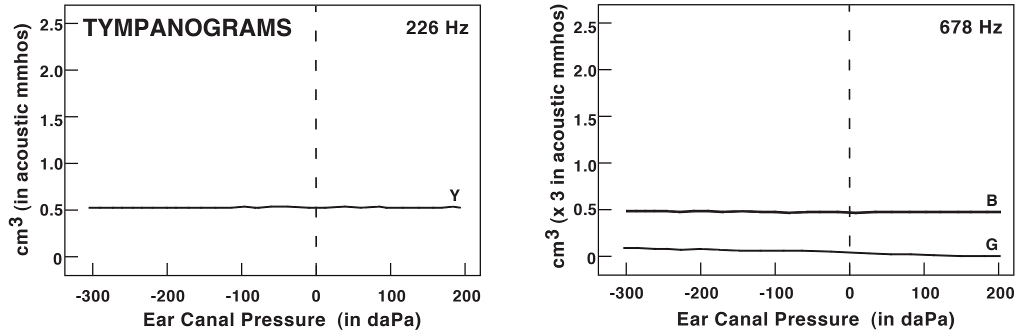
[✓ PICTURE IDENTIFICATION]

	AS	AD
A/C UNMASKED	×	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

RELIABILITY
[✓ GOOD]
FAIR
POOR

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ⋀— — ⋀

REMARKS: Weber was midline and Bing was negative AU at 250 & 500 Hz



Case #3. This case is a 4-year old male with a history of ear infections bilaterally since infancy. The results of the audiologic evaluation are shown on the audiogram. Unmasked pure-tone air-conduction thresholds showed a moderate, flat hearing loss bilaterally. Unmasked pure-tone bone-conduction thresholds were normal. This case presents a masking dilemma. Although air-conduction and bone-conduction thresholds in both ears must be masked to prevent a cross-over response from the opposite ear, over-masking occurs before sufficient masking can be delivered to the non-test ear. It is not possible, therefore, to test the two ears independently. [Note: the masking dilemma presented in this case potentially could have been avoided with the use of insert earphones.]

In the absence of sufficient masking in the non-test ear, the only conclusion that can be drawn from the pure-tone thresholds is that there is a maximum conductive hearing loss in at least one ear (either the right ear, the left ear, or both ears). True air-conduction thresholds in the other ear could be anywhere between a moderate hearing loss and the output limits of the audiometer. Similarly, true bone-conduction thresholds could range from normal to no response at the output limits of the equipment.

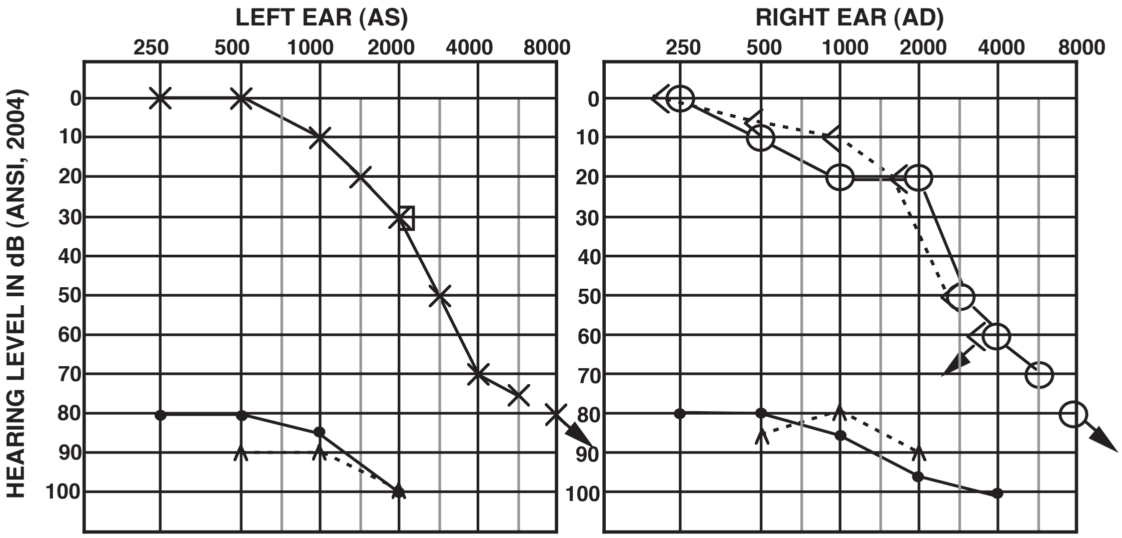
The speech-recognition thresholds agreed with the pure-tone averages. Word-recognition performance was good at 90-dB HL. Again, sufficient masking cannot be presented to the non-test ear; therefore, it cannot be determined which ear responded to the stimuli. Because of the lack of norms on the WIN on young children and the severity of the air-conduction hearing loss in both ears, the WIN was not administered.

Flat tympanograms with normal ear-canal volumes were obtained from both ears. This pattern is consistent with a middle-ear cavity completely filled with fluid. Contralateral and ipsilateral acoustic reflexes were absent. These findings support the presence of a bilateral conductive hearing loss, but do not preclude the presence of a mixed hearing loss in one ear or even a “dead” ear. Midline audiometric Webers at all frequencies, however, support symmetrical bone-conduction thresholds.

With the degree of hearing loss shown on the audiogram, this child will have difficulty hearing normal conversational speech. Although a conductive hearing loss generally can be improved with medical or surgical treatment, a hearing aid must be considered for patients with long-standing hearing losses. If a hearing loss persists for a long time, then the child’s speech and language development could be affected adversely.

Myringotomies were performed on both ears of this child. Thick fluid was found in both middle-ear cavities. Two months following the surgery, pure-tone sensitivity had returned to normal in both ears.

AUDIOLOGICAL CONSULTATION


LEFT EAR (AS)

RIGHT EAR (AD)

EFFECTIVE MASKING										
A/C										
B/C						70				

A/C											
B/C	UNMASKED, UNOCCLUDED										

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION						
				QUIET				WIN	MCL	UCL
	2 FREQ.	3 FREQ.	[✓ SRT]	50 dB HL	dB HL	dB HL	90 dB HL	50% dB S/N	dB HL	dB HL
AD	15	17	20	84%			90%	9.2	65	100
MASKING AS				20			60			
AS	5	13	10	76%			90%	11.6	60	90
MASKING AD				20			60			

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W-22
PICTURE IDENTIFICATION

RELIABILITY
[✓ GOOD]
FAIR
POOR

	AS	AD
A/C UNMASKED	×	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ʌ– –ʌ

REMARKS: Tympanograms normal AU; Weber lateralized AD; Bing positive AU

↘ = no response at limits of equipment

Case #4. This case is a 58-year old male whose chief complaint was bilateral tinnitus, worse in the left ear. The patient reported some difficulty understanding conversational speech mostly in noisy places, however denied having significant hearing problems. The patient expressed only occasional difficulty using his cell phone. The patient reported that he has been a heavy equipment operator for over 30 years. With the exception of diet-controlled diabetes, the medical history was negative.

Pure-tone air-conduction thresholds were within normal limits from 250-1000 Hz in the left ear and 250-2000 Hz in the right ear. For both ears, the thresholds indicated a steeply sloping moderate-to-severe hearing loss in the high frequencies through 6000 Hz. No response was obtained at 8000 Hz in either ear. The unmasked bone-conduction thresholds were equivalent to the air-conduction thresholds in the right ear, indicating a hearing loss of probable cochlear origin. The SRTs were in good agreement with the pure-tone averages in both ears. Word-recognition performance was good at 50-dB HL and 90-dB HL in the right ear and was fair at 50-dB HL improving to good at 90-dB HL in the left ear. The poorer air-conduction threshold at 2000 Hz in the left ear can account for the slightly poorer word-recognition performance in comparison with the right ear. Errors in the words presented to the left ear occurred primarily for phonemes containing high-frequency energy such as *f*, *th*, *v*, *s*, and *t*. The results of the WIN indicated 50% points at 9.2- and 11.6-dB S/N in the right and left ears, respectively, which indicate mild and moderate hearing losses, respectively, in terms of signal-to-noise ratio (SNR). The most comfortable loudness levels suggest that the patient preferred to listen to speech at slightly louder than normal levels. Tympanograms were normal for both ears. Acoustic reflexes were present at normal levels with no reflex adaptation at 500 Hz and 1000 Hz.

All of the audiologic test results were consistent with a high-frequency sensory hearing loss, probably associated with noise exposure over a long period of time. The following recommendations were made for this patient:

1. The patient was counseled regarding the effects of excessive noise exposure and the use of ear protection to prevent further deterioration of his hearing.
2. The patient was counseled regarding the implications of tinnitus in an attempt to alleviate the patient's concern for its severity.
3. A trial use of binaural in-the-ear hearing aids was recommended. The hearing aids should improve the patient's ability to understand speech in quiet and may mask the tinnitus. It is questionable whether or not the hearing aids will provide improved understanding of speech in background noise.

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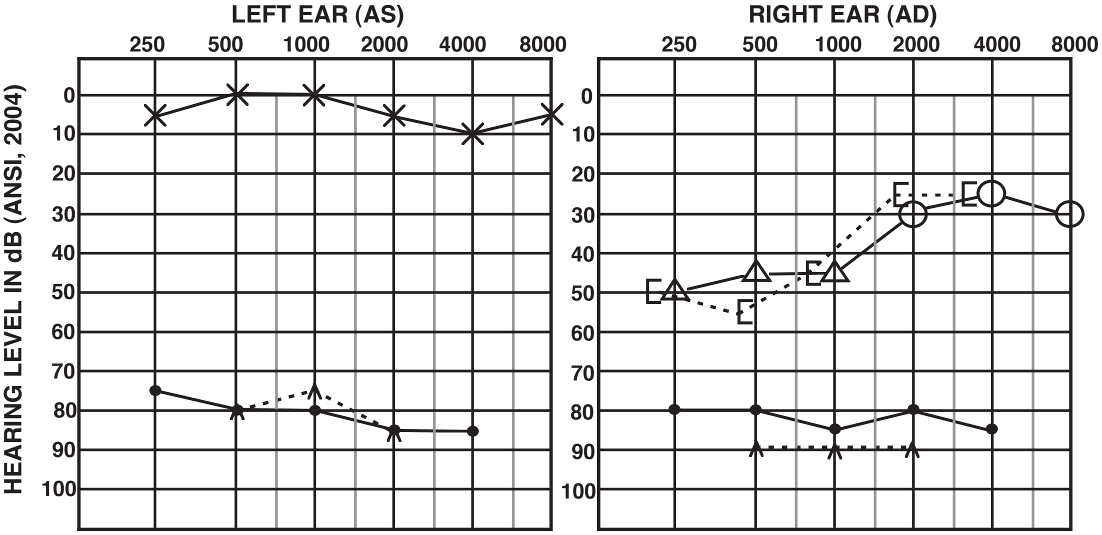
AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING										
A/C										
B/C										

A/C	35	30		30						
B/C	75	70		70		55				

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	P	P	P	P
DPOAE						

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Absent	A	A	P	P	P
DPOAE						

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION					MCL	UCL
				QUIET				WIN		
	2 FREQ.	3 FREQ.	[✓ SRT]	50 dB HL	dB HL	70 dB HL	90 dB HL	50% dB S/N	dB HL	dB HL
AD	38	40	38			52%	60%	19.6	65	95
MASKING AS						40	60			
AS	0	3	0	96%			100%	3.6	45	100+
MASKING AD							60			

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MLV
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MARYLAND CNC
W-22
PICTURE IDENTIFICATION

	AS	AD
A/C UNMASKED	×	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

RELIABILITY
[✓ GOOD]
FAIR
POOR

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ʌ— —ʌ

REMARKS: Stenger negative @ 1000 Hz; tympanograms normal AU;
Weber lateralized left; Bing was positive AU

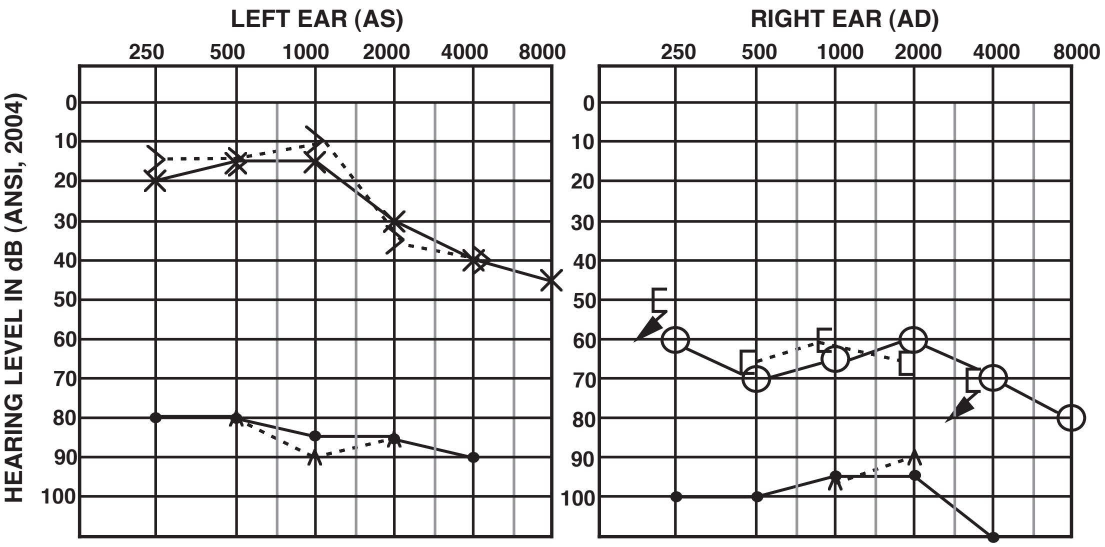
Case #5. This case is a 33-year old female who presented with a recent history of fluctuating hearing loss in the right ear, vertigo accompanied with vomiting, a constant buzzing tinnitus in the right ear, and a sensation of fullness in the right ear. The patient also reported severe earaches and ear infections when she was a child. The patient indicated that she did not use the telephone on her right ear. There was a 10-year history of hearing loss. On the day of the audiologic evaluation, the patient reported that her hearing in the right ear was relatively poor.

Consider first the audiologic results from the left ear. The pure-tone air-conduction thresholds (250-8000 Hz) were within normal limits; bone-conduction thresholds were not obtained because the air-conduction thresholds were normal. Transient-evoked otoacoustic emissions were present at least 3 dB above the level of the noise floor for all frequencies. The SRT and the pure-tone averages were in good agreement. The patient had good word- recognition performance at a normal conversational level (50-dB HL) and at a high level (90-dB HL). The 50% point on the WIN was 3.6-dB S/N, which is well within the normal range. The tympanogram was within normal limits. The contralateral and ipsilateral acoustic-reflex thresholds were present at normal levels; no reflex adaptation was measured. These audiologic test results indicated that the left ear of the patient is normal.

In contrast, the audiologic results from the right ear indicated a moderate hearing deficit. The air-conduction and the bone-conduction pure-tone thresholds, which are essentially equivalent, indicated a moderate low- to mid-frequency (250-1000 Hz) hearing loss with a mild high-frequency (2000-8000 Hz) hearing loss. Transient-evoked otoacoustic emissions were present only in the higher frequencies, consistent with the degree of pure-tone loss. The SRT and the pure-tone averages were in good agreement. The Stenger at 1000 Hz was negative and the Weber lateralized to the left ear (the ear with the better cochlea). At 70-dB HL and at 90-dB HL, word-recognition performance was fair. The ability of the patient to understand the WIN materials was poor with a 50% point of 19.6-dB S/N. The most-comfortable listening level (MCL), although elevated with reference to the MCL in the left ear, was only 27 dB above the speech-recognition threshold. The 95-dB HL uncomfortable listening level (ULL) indicated a tolerance problem for high level stimuli. The tympanogram was normal and acoustic-reflex thresholds were present at normal hearing levels; no reflex adaptation was measured at 500 Hz and 1000 Hz.

The audiologic results obtained on the right ear indicate a moderate-to-mild sensorineural hearing loss. The medical diagnosis in this case was early Ménière's disease. A hearing aid for the right ear was not considered at the time of the evaluation, but will be considered following the medical treatment. The patient (1) was scheduled to have a follow-up evaluation in three months, and (2) was instructed to return if her hearing changed before the scheduled return appointment.

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING

A/C										
B/C										

A/C	50	45		45						
B/C	50	85		85		80		70		

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	Absent	A	A	A
DPOAE						

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Absent	A	A	A	A	A
DPOAE						

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION						
				QUIET				WIN	MCL	UCL
	2 FREQ.	3 FREQ.	[✓ SRT]	50 dB HL	dB HL	dB HL	90 dB HL	50% dB S/N	dB HL	dB HL
AD	63	65	65				24%	--	80	100+
MASKING AS			45				60			
AS	15	20	15	88%			88%	7.6	50	100+
MASKING AD										

[✓ Compact Disc]
MLV
[✓ N.U. No. 6]
MARYLAND CNC
W-22
PICTURE IDENTIFICATION

	AS	AD
A/C UNMASKED	×	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

RELIABILITY
[✓ GOOD]
FAIR
POOR

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ʌ— —ʌ

REMARKS: Stenger negative @ 1000 Hz; tympanograms normal AU;
Weber lateralized AS; Bing was positive AU

↘ = no response at limits of equipment

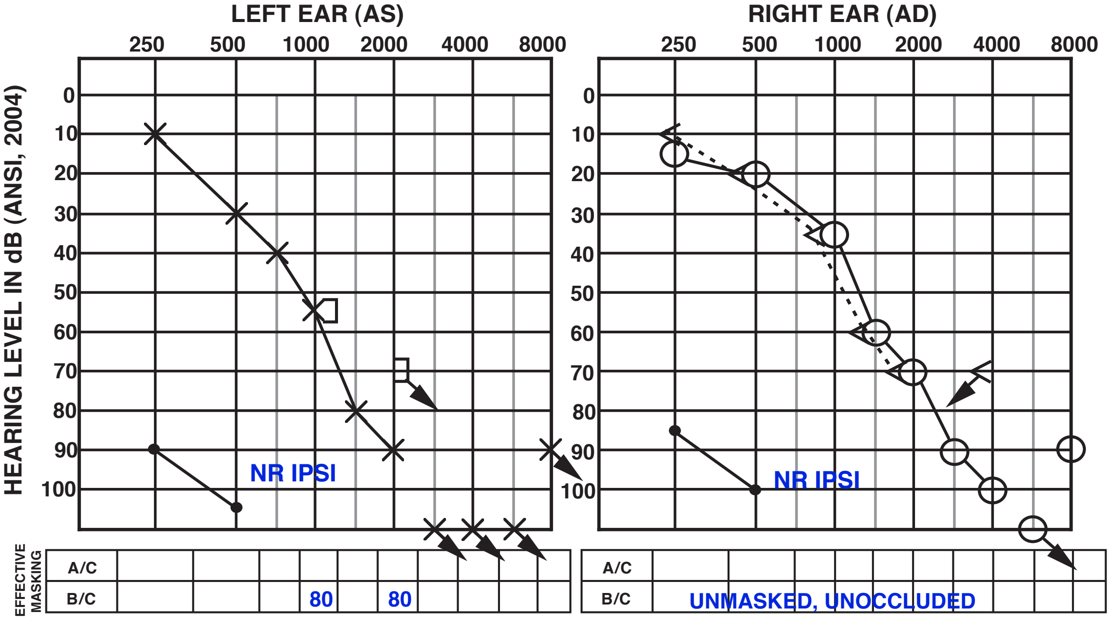
Case #6. This case is a 47-year old male who reported a sudden hearing loss in the right ear that was noticed upon awakening in the morning. Since the hearing loss onset, he reported difficulty localizing sounds and indicated he could not use the telephone on his right ear. The patient also reported nausea, disequilibrium, roaring tinnitus and a feeling of fullness in the right ear. He had no previous history of decreased hearing.

The pure-tone air-conduction thresholds in the left ear were normal from 250-1000 Hz with a mild-to-moderate hearing loss from 2000-8000 Hz. Transient-evoked otoacoustic emissions were present at 500-1000 Hz only, consistent with the degree of pure-tone hearing loss. The SRT agreed with the pure-tone averages. Word-recognition performance in quiet was good at normal conversational levels and at high levels. The WIN indicated a 50% point at 7.6-dB S/N, which demonstrates a mild loss in terms of SNR. The tympanogram is normal. Ipsilateral and contralateral acoustic reflex thresholds are present at normal levels.

The pure-tone air-conduction thresholds in the right ear demonstrated a moderate-to-severe hearing loss at all frequencies. The bone-conduction thresholds were equivalent to the air-conduction thresholds. Transient-evoked otoacoustic emissions were absent across all frequencies. The Stenger at 1000 Hz was negative. Additionally, the SRT agreed with the pure-tone averages. The results of the Stenger, otoacoustic emission results, and the agreement between the SRT and the pure-tone averages suggest that there is an organic hearing loss in the right ear, i.e., it is not a functional loss. The word-recognition performance assessed in quiet at 90-dB HL was poor even though the words were presented 25 dB above the speech-recognition threshold. Because of the severity of the hearing loss, the WIN was not administered. The tympanogram was normal. The acoustic-reflex thresholds with stimulation to the right ear were present but are depressed by 10-20 dB in comparison with the reflex thresholds in the left ear.

In summary, the left ear demonstrated a mild high-frequency sensorineural hearing loss. The test results from the right ear suggested a moderate-to-severe hearing loss of cochlear origin. The patient was referred for an ABR to rule out retrocochlear involvement in the right ear, and results were within normal limits. For follow-up, he was tested weekly over a two month interval, during which time his hearing improved by about 30 dB in the right ear. [Note: etiology in cases like this one, which usually are difficult to establish, may include viral, vascular, or auto- immune problems.]

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING

A/C								
B/C				80		80		

A/C	
B/C	UNMASKED, UNOCCLUDED

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION						
				QUIET				WIN	MCL	UCL
	2 FREQ.	3 FREQ.	[✓ SRT]	dB HL	70 dB HL	dB HL	90 dB HL	50% dB S/N	dB HL	dB HL
AD	28	42	35		24%		16%	--	75	90
MASKING AS				20			60			
AS	43	58	55		20%		20%	--	80	95
MASKING AD				20			60			

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RELIABILITY
[✓ GOOD]
FAIR
POOR

	AS	AD
A/C UNMASKED	×	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

ACOUSTIC REFLEXES

CONTRA	●—●
IPSI	ʌ— —ʌ

REMARKS: tympanograms normal AU

↘ = no response at limits of equipment

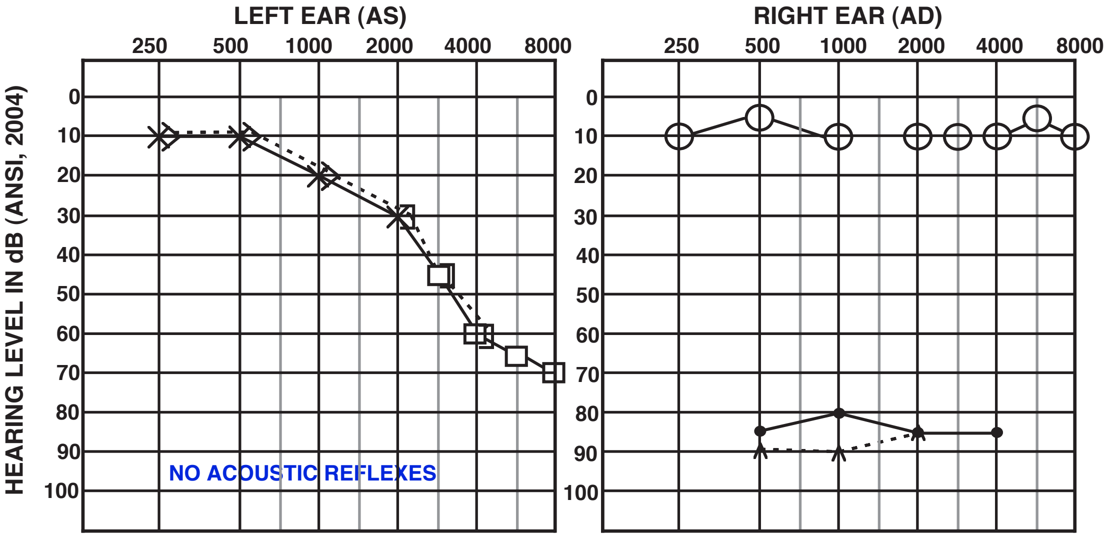
Case #7. This case is a 107-year old man who served in World War I. The veteran's chief complaint was that he could hear people talking but had difficulty understanding what they were saying. He further stated that men were easier to understand than were women. He reported that he could use the telephone with his right ear but not with his left ear. The veteran reported a history of 40 years of noise exposure in the shipyards, but no other positive history. The patient indicated that he had tried hearing aids 15 years ago but that the hearing aids did not help.

The results of the audiologic evaluation for the right ear indicated normal hearing at 250-500 Hz with a sloping moderate-to-profound loss from 1000-8000 Hz. The bone-conduction thresholds (unmasked) were interwoven with the air-conduction thresholds. The pure-tone thresholds for the left ear were similar in configuration to the thresholds for the right ear, but with 10-20 dB more hearing loss. The threshold at 250 Hz was normal in the left ear with a mild-to-severe loss at 500-2000 Hz. No responses were obtained at the output limits of the audiometer at 3000-8000 Hz; hence, there was a profound hearing loss. The masked bone-conduction thresholds agreed with the air-conduction thresholds.

The SRTs and the word-recognition performance of both ears were similar. The SRTs were in fair agreement with the pure-tone averages, especially considering the precipitous drop in the pure-tone sensitivity in the mid to high frequencies. Word-recognition performance was poor, even at high levels. Because of the poor word recognition in quiet, the WIN was not administered. The MCLs were elevated 40 dB above the SRTs and the ULLs were lower than normal ULLs. Viewed from a different perspective, the MCL-ULL relations indicate that the patient had only a 15 dB range in which to listen comfortably to speech. The tympanograms were both normal. Only contralateral acoustic reflex thresholds were present in both ears at 250 Hz and 500 Hz. Ipsilateral reflexes, which are usually measured at 500-2000 Hz, were not measurable; this absence was attributed to the output limits of the reflex-activator signals in the ipsilateral test mode (90-dB HL at 500 Hz; 110-dB HL at 1000 Hz; and 100-dB HL at 2000 Hz).

The results of the audiologic evaluation for both ears indicated normal hearing in the low-frequency range with a mild-to-profound hearing loss in the mid- to high-frequency range. The results are consistent with a sensorineural hearing loss in both ears, typical of presbycusis, and are consistent with the patient's age and history of noise exposure. Subsequent to the audiologic evaluation, the patient was fit with binaural hearing aids and enrolled in audiologic rehabilitation classes.

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING

A/C							40	40	50	50
B/C						40	45	70		

A/C										
B/C										

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	P		Absent	
DPOAE	P	P	P		A	

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	P	P	P		P	
DPOAE	P	P	P		P	

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION						
				QUIET				WIN	MCL	UCL
	2 FREQ.	3 FREQ.	[✓ SRT]	50 dB HL	dB HL	80 dB HL	90 dB HL	50% dB S/N	dB HL	dB HL
AD	8	8	5	96%			100%	2.8	48	100
MASKING AS				20			60			
AS	15	20	30	16%		26%	20%	24.4	70	100+
MASKING AD				20		50	60			

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PICTURE IDENTIFICATION

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A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

RELIABILITY
[✓ GOOD]
FAIR
POOR

ACOUSTIC REFLEXES

CONTRA	●—●
IPSI	ʌ— —ʌ

REMARKS: tympanograms normal AU

Case #8. This case is a 35-ear old female who reported decreased hearing and tinnitus in her left ear for the past 5 months. The patient indicated that she now used the telephone strictly with her right ear as it was difficult to understand what people were saying when she used the telephone on her left ear. She also complained of feeling lightheaded for the past 8 months. Her history was otherwise unremarkable, and the tympanic membranes looked normal on otologic exam.

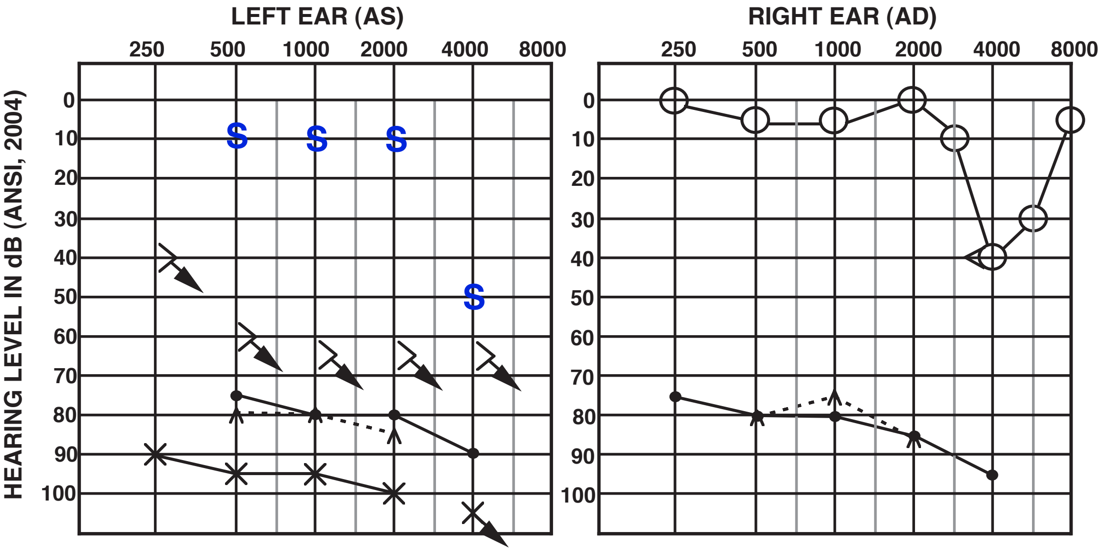
For the right ear, hearing sensitivity was normal and understanding for speech was excellent. All diagnostic tests using tonal speech in quiet and speech in noise were also consistent with normal function. For the left ear, the audiogram illustrated a hearing loss that began at 2000 Hz and gradually worsened to severe levels by 8000 Hz. There was no conductive component by either bone-conduction evaluation or tympanometry. Speech understanding in quiet was poor and did not improve at high levels. The WIN revealed a 50% point of 24.4-dB S/N, which is a profound SNR hearing loss.

Although otoacoustic emissions, an indicator of hair cell function, were present, acoustic reflexes were absent when the left ear was stimulated. These two results indicated good cochlear function, but interruption of the pathways that mediate the acoustic reflex. This suggested that the auditory branch of CNVIII might be damaged. Further clues that this could be true were found: tone decay was excessive and loudness growth in this ear on loudness balancing procedures showed no recruitment.

Auditory brainstem responses (ABR) were obtained from each ear. The right ear findings showed a normal pattern of electric potentials with normal latencies. Brainstem potentials in the left ear were abnormal or missing. Since waves I and II of the ABR arise from the peripheral and central portions of CNVIII, the abnormal result supported the suspicion of CNVIII damage as derived from earlier tests.

All results from the left ear pointed to a CNVIII/extra-axial (peripheral) brainstem lesion. An MRI with contrast revealed the presence of a space-occupying mass in the internal auditory meatus.

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING										
A/C										
B/C	UNMASKED, UNOCCLUDED									

EFFECTIVE MASKING										
A/C										
B/C										

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	P		P	
DPOAE	P	P	P		P	

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	P	P	P	
DPOAE	P	P	P	P	P	

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION						
				QUIET				WIN	MCL	UCL
	2 FREQ.	3 FREQ.	[✓ SRT]	40 dB HL	dB HL	dB HL	80 dB HL	50% dB S/N	dB HL	dB HL
AD	3	3	2	100%			100%	6.0	45	
MASKING AS							60			
AS	95	98	70*				100%	--	70	
MASKING AD			60				60			

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PICTURE IDENTIFICATION

RELIABILITY
GOOD
FAIR
[✓ POOR]

	AS	AD
A/C UNMASKED	✕	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ʌ– –ʌ

REMARKS: **S** = Stenger Threshold Estimates

*half-word responses

↘ = no response at limits of equipment

Case #9. This case is a 29-year old male who reported a severe hearing loss in the left ear following a work-related head injury (blow to head). He had no complaints about the right ear, but indicated that he did not hear anything on his left side. The history was negative for otologic problems or prior hearing loss. ENT exam of his eardrums was unremarkable. He did report significant noise exposure during a 2-year army stint and in his job as a construction worker. The patient repeatedly expressed hearing problems during the interview, despite having no complaints of hearing loss in the right ear.

Results of the standard hearing evaluation are shown on the audiograms. For the right ear, there was a notch of mild hearing loss centered at 4000 Hz, with normal hearing at higher and lower frequencies. Speech understanding in quiet was excellent as was speech understanding in noise (50% point at 6-dB S/N). The tympanogram was normal and acoustic reflexes were triggered at normal stimulus levels and did not show decay over time. Otoacoustic emissions were present at expected levels. The results were consistent with the patient's history of noise exposure.

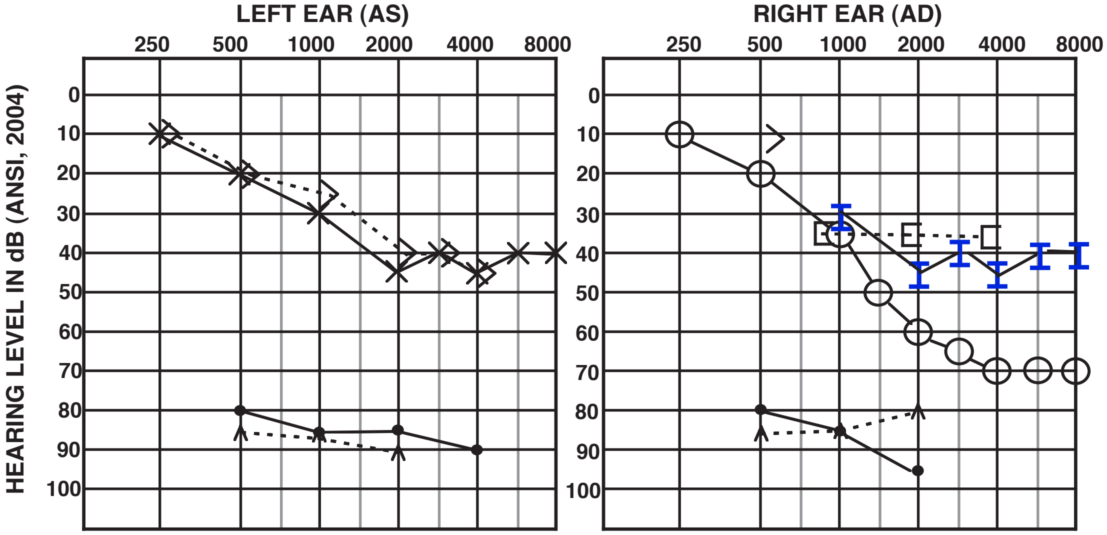
For the left ear, voluntary thresholds for both air-conduction and bone- conduction tones were near or beyond the equipment limits, suggesting a profound hearing loss. Since these thresholds were obtained with no masking to the right ear, they were physiologically unlikely. When using standard earphones, pure-tone signals may cross the head to the other ear at levels as low as 40 dB. Bone-conduction signals cross the head to the better cochlea with virtually no attenuation between ears. This patient, therefore, should have heard the signals delivered to the left ear at far better levels than he volunteered due to cross hearing by the right ear.

The patient recognized parts of speech signals presented in quiet at 70 dB HL, which is below his admitted pure-tone sensitivity in the speech frequency range, and had excellent speech understanding at levels lower than any admitted pure-tone threshold. Because it was obvious that the patient was exaggerating his hearing loss in his left ear, the WIN was not administered and the evaluation focused on the exaggeration. This is impossible. In addition, acoustic reflexes were elicited via the left ear at normal levels, indicating an intact CNVIII-low brainstem-CNVII reflex pathway. Otoacoustic emissions were elicited normally, suggesting good cochlear function.

A pure-tone Stenger test was then administered. (See discussion of the Stenger in the section on diagnostic procedures). The Stenger procedure estimated pure-tone thresholds in the left ear very much like those found for the right ear. In addition, the patient preferred speech "most comfortable" (MCL on the audiogram) at 70-dB HL, a level equal to his speech-recognition level and below any voluntary pure-tone threshold. Finally, an auditory brainstem response was measured to click stimuli for both ears. The responses had normal latencies and morphology, and were virtually identical for the two ears.

In summary, both behavioral and objective tests suggest that the severe- profound hearing loss in the left ear is not real. The best estimate of true hearing in the left ear is that it has pure-tone sensitivity much like that found in the right ear. Given the findings, the patient was counseled on the importance of using hearing protection at work and given information about ear protectors that would be useful.

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING										
A/C										
B/C										

A/C										
B/C				60		75		75		

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	?		?	
DPOAE	P	P	?		?	

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	P	P	?		Absent	
DPOAE	P	P	?		A	

EAR	PURE-TONE AVERAGE 2 FREQ.	PURE-TONE AVERAGE 3 FREQ.	SDT [✓ SRT]	WORD-RECOGNITION QUIET 50 dB HL	dB HL	dB HL	90 dB HL	WIN 50% dB S/N	MCL dB HL	UCL dB HL
AD	25	28	26	62%			90%	13.2	72	105
MASKING AS							60			
AS	25	32	26	58%			92%	11.6	68	100
MASKING AD							60			

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A/C UNMASKED	×	○
A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

RELIABILITY
[✓ GOOD]
FAIR
POOR

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ∧– – ∧

REMARKS: tympanograms normal AU

I = Insert Earphone Thresholds

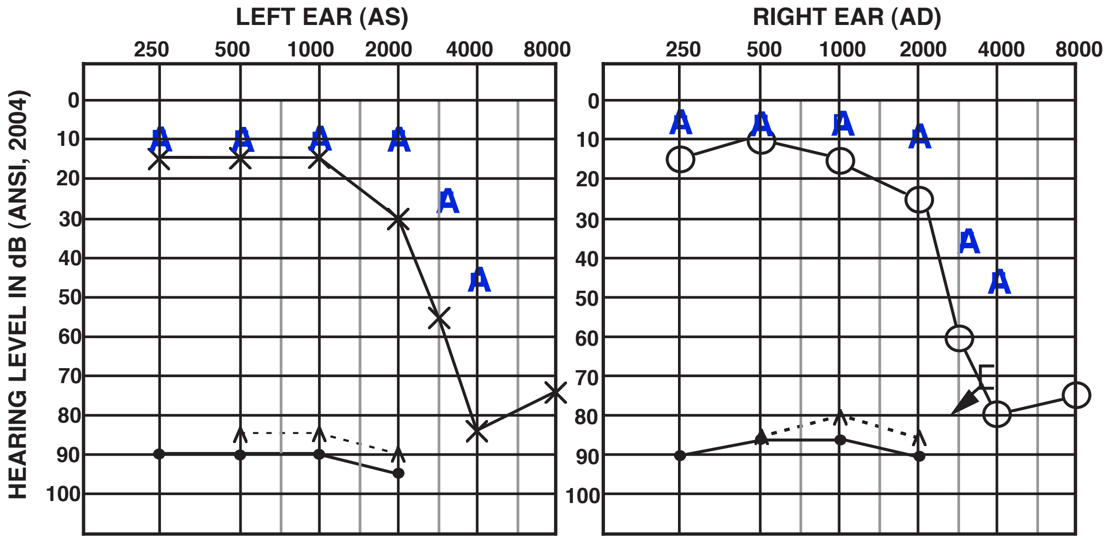
Case #10. This case is a 68-year old male who complained of a gradual decrease in his hearing for several years and difficulty understanding speech in background noise, which were facts that were testified to at length by his wife. He reported occasional tinnitus. The patient that he did not think he had difficulty hearing on the telephone but he indicated that he "did not like to talk on the phone". He had some noise exposure in the armed services, but little since that time. There was no other relevant otologic or hearing history, and the examination of his ears was remarkable only for their size. Tympanic membranes were normal.

The left ear had normal hearing in the low frequencies, with a mild hearing loss at 2000-8000 Hz. There was no conductive component to the hearing loss, tympanograms were normal and acoustic reflexes were elicited at normal levels. Speech understanding in quiet was fair at conversational levels and excellent at higher levels. The result of the WIN was a 50% point at 11.6-dB S/N, which is a moderate SNR hearing loss. An auditory brainstem response was measured using a 2000-Hz tone burst as the stimulus. The resultant electric potentials had latencies consistent with the measured hearing loss.

Pure-tone tests gave similar results in the low frequencies in the right ear. At 1000 Hz and higher frequencies, however, there appeared to be a mild-moderate hearing loss with a conductive component that increased in size as the test frequency increased. Since conductive components that are limited to high frequencies are often caused by ear canals that closed owing to pressure from the earphone cushion, the air-conduction testing was repeated using insert earphones (calibrated ear plug inserts). These devices fit in the ear canal and do not put pressure on the pinna of the ear. The thresholds obtained using this new approach were similar to thresholds in the left ear, i.e., the conductive component disappeared. Consequently, insert earphones were used for testing.

Test results obtained with insert earphones for the right ear mirrored those in the left ear. All diagnostic procedures pointed to cochlear damage. The overall picture of a gradual onset of symmetrical hearing loss in each ear, worse in the higher frequencies, is consistent with the presbycusis (age-related hearing loss) typical for males in industrial societies. The patient was counseled about the possible benefits of amplification devices like hearing aids, counsel that he accepted and his wife embraced. A hearing aid evaluation was scheduled to investigate this avenue of audiologic rehabilitation.

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING										
A/C										
B/C										

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	Present	P	P		Absent	
DPOAE	P	P	P		A	

A/C										
B/C										

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE	P	P	P		A	
DPOAE	P	P	P		A	

EAR	PURE-TONE AVERAGE		SDT	WORD-RECOGNITION						
				QUIET				WIN	MCL	UCL
	2 FREQ.	3 FREQ.	[✓ SRT]	50 dB HL	dB HL	dB HL	80 dB HL	50% dB S/N	dB HL	dB HL
AD	13	17	20	80%			100%	14.0	65	100
MASKING AS							60			
AS	15	20	20	84%			100%	14.8	65	100
MASKING AD							60			

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A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

RELIABILITY
[✓ GOOD]
FAIR
POOR

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ⋀— —⋀

REMARKS: Tympanograms normal AU

A = thresholds through CIC hearing aid;
binaural word recognition through CIC was 96%

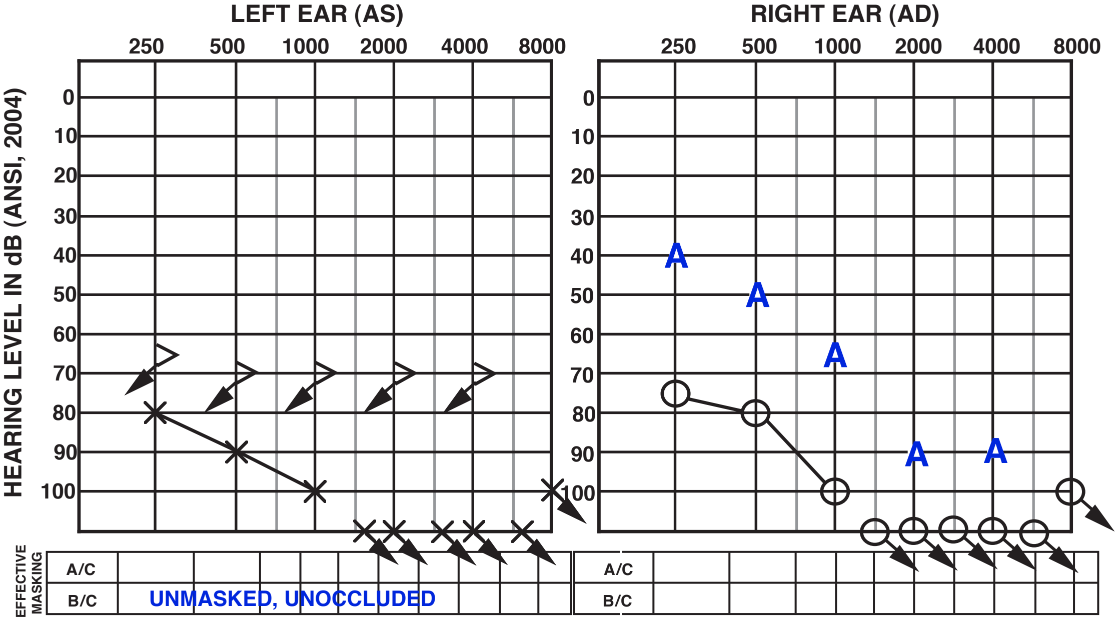
Case #11. This case is a 49-year old male whose chief complaints are hearing loss and understanding conversational speech, especially in the presence of background noise. The patient complains of mild periodic tinnitus. He has no complaints of dizziness or vertigo. He reports difficulty understanding the speech of women and children, however, he feels this is due to the speakers mumbling. He also reports difficulty hearing on the telephone. History of military noise exposure is positive, including exposure to artillery. Civilian noise exposure includes recreational hunting and attending concerts (the veteran stated that he wears hearing protection). The medical history was negative.

Pure-tone air-conduction thresholds were within normal limits 250-2000 Hz, falling to a moderately-severe high-frequency hearing loss, bilaterally. The unmasked bone-conduction thresholds were equivalent to the air- conduction thresholds. Word-recognition performance in quiet was good bilaterally at 50-dB HL and 80-dB HL. Word recognition in background noise indicated a moderate SNR hearing loss (50% points of 14.0- and 14.8-dB S/N for the right and left ears, respectively). Tympanometry indicated normal 226 Hz tympanograms. Ipsilateral and contralateral acoustic reflexes were present. Reflex decay at 1000 Hz was negative bilaterally.

All of the audiologic test results are consistent with a high-frequency sensorineural hearing loss, most likely associated with noise exposure. Deep canal impressions were made and completely-in-the-canal (CICs) hearing aids were ordered.

Sound field testing with the CICs (plotted on the audiogram as “A”) indicated the patient received appropriate gain in the high frequencies (3000 to 4000 Hz), which would not be obtained with the larger in-the-ear hearing aids. Binaural word-recognition testing was good. Unfortunately, the WIN was not administered bilaterally through the hearing aids. Testing with high input levels indicated the hearing aids were never uncomfortably loud. The patient was counseled on the use and care of hearing aids. A two-week follow-up appointment will be scheduled to assess the patients benefit from the hearing aids, which included functional gain of the hearing aids assessed under earphones.

AUDIOLOGICAL CONSULTATION



EFFECTIVE MASKING												
A/C							A/C					
B/C	UNMASKED, UNOCCLUDED						B/C					

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

	.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
TEOAE						
DPOAE						

EAR	PURE-TONE AVERAGE 2 FREQ.	PURE-TONE AVERAGE 3 FREQ.	[✓ SDT] SRT	WORD-RECOGNITION QUIET dB HL	dB HL	dB HL	100 dB HL	WIN 50% dB S/N	MCL dB HL	UCL dB HL
AD	90	--	85				4%	--	>100	
MASKING AS							60			
AS	95	--	90				0%	--	>100	
MASKING AD							60			

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A/C MASKED	□	△
B/C UNMASKED	>	<
B/C MASKED	]	[

RELIABILITY
[✓ GOOD]
FAIR
POOR

ACOUSTIC REFLEXES
CONTRA ●—●
IPSI ʌ— —ʌ

REMARKS: Tympanograms normal AU; Word recognition with hearing aid was 12%.

A = thresholds with hearing aid

↘ = no response at limits of equipment

Case #12. This case is a 76-year old male with a long-standing history of sensorineural hearing loss. The onset of the hearing loss was 50 years ago. The patient complains of constant bilateral tinnitus; he considers the tinnitus severe. He has no complaints of dizziness or vertigo. He reports difficulty hearing and understanding in all listening situations, especially in background noise and relies on speech reading in all situations. The patient indicated that he was not able to talk on the telephone. The veteran has used behind-the-ear hearing aids with little success and can not use any telephone, including those equipped with amplifiers. The patient is in good medical condition.

The results of the audiologic evaluation indicated a severe (250 to 1000 Hz) to profound (no response for 2000 to 8000 Hz) hearing loss, bilaterally. This configuration is known as a corner audiogram. No responses were obtained for bone-conduction stimuli at the limits of the audiometer. Tympanometry indicated normal middle-ear function and acoustic reflexes were absent at all frequencies.

Speech detection thresholds were obtained at 85-dB HL for the right ear and 90-dB HL for the left ear. These results were in good agreement with the two-frequency (500 and 1000 Hz) pure-tone averages. Word-recognition ability was poor (AD--4%; AS--0%) at the limits of the audiometer. Because of the severity of the hearing loss the WIN was not administered.

The patient was fit with a power body aid. Sound field testing (plotted on the audiogram as “A”) indicated the patient was only receiving an average gain of 30 dB across frequencies. Word-recognition ability did not substantially improve. Testing at high levels indicted the hearing aids were never uncomfortably loud. The patient was also given the following assistive devices:

1. Text Telephone. A teletype device that allows him to communicate with others who have a similar device or use the relay system.

2. Smoke detector. A standard smoke detector equipped with a transmitter which signals the receiver placed near the listener. The receiver is equipped with a strobe light to alert the individual to the fire.

3. Alerting system. A signaling system was set up to alert him when the phone rings, someone rings the door bell, or when someone opens the front door. The system is plugged into a lamp. The lamp flashes once for the phone, twice for the doorbell, and three times for the door opening.

The patient is currently under consideration for a cochlear implant. He does receive minimal benefit from amplification; however, he still cannot use the telephone and his word-recognition ability did not improve with amplification.

ABBREVIATIONS

AAA	American Academy of Audiology
ABR	auditory brainstem response
AC	air-conduction testing through earphones
Acuity	auditory measures made at supra-threshold levels
AD	auris dextra (right ear)
ALR	auditory late response
AMLR	auditory middle latency response
ANSI	American National Standards Institute
AS	auris sinistra (left ear)
ASHA	American Speech-Language-Hearing Association
ART	acoustic-reflex threshold
AU	aures unitas (both ears together); auris uterque (each ear)
B_a	Acoustic susceptance
BBN	broadband noise, also white noise
BC	bone-conduction testing through a vibrator
dB	decibel
dB HL	decibel Hearing Level
dB SL	decibel Sensation Level, i.e., above threshold
dB SPL	decibel sound-pressure level
G_a	acoustic conductance
HAE	hearing aid evaluation
Hz	Hertz (cycles/second, cps) unit of measure for frequency
MLV	monitored live voice
NR	no response at the output limits of the audiometer
PB Max	maximum word-recognition score in quiet
% Hearing Loss (per AAO-HNS)	unilateral % = (PTA @ 500, 1000, 2000)-(26) (1.5%) bilateral % = [(5) better ear PTA - poorer ear PTA]/6
PTA	pure-tone average (usually 500, 1000, and 2000 Hz)
Sensitivity	auditory measures made at threshold
Sound Field	the acoustic environment within a sound-treated room
SDT	speech-detection threshold
SRT	speech-recognition threshold
TDD	a telecommunication device
TEOAE	transient-evoked otoacoustic emissions
TT	text telephone
TTY	teletypewriter
VA	Department of Veterans Affairs
VU meter	volume unit meter
WIN	Words-in-Noise Test
Y_a	acoustic admittance

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International Journal of Audiology

Journal of Speech Language and Hearing Research

Journal of the Acoustical Society of America

Journal of the American Academy of Audiology

EXAMPLE LISTS OF THE VARIOUS MATERIALS USED IN SPEECH AUDIOMETRY

Central Institute for the Deaf (CID) W-1

(Spondaic Words)

1. AIRPLANE
2. ARMCHAIR
3. BASEBALL
4. BIRTHDAY
5. COWBOY
6. DAYBREAK
7. DOORMAT
8. DRAWBRIDGE
9. DUCKPOND
10. EARDRUM
11. FAREWELL
12. GRANDSON
13. GREYHOUND
14. HARDWARE
15. HEADLIGHT
16. HORSESHOE
17. HOTDOG
18. HOTHOUSE
19. ICEBERG
20. INKWELL
21. MOUSETRAP
22. MUSHROOM
23. NORTHWEST
24. OATMEAL
25. PADLOCK
26. PANCAKE
27. PLAYGROUND
28. RAILROAD
29. SCHOOLBOY
30. SIDEWALK
31. STAIRWAY
32. SUNSET
33. TOOTHBRUSH
34. WHITEWASH
35. WOODWORK
36. WORKSHOP

Maryland CNC Lists (used by the VA)

	List 1	List 2	List 6	List 7	List 9	List 10
1.	JAR	JAIL	WHIP	NOTE	LACK	SUB
2.	BOIL	RAT	BUD	DOOM	WATCH	LOT
3.	TOUGH	TOSS	SHONE	COKE	POWER	DIN
4.	TOOTH	SOON	RUG	HOLE	MIRE	DEATH
5.	GOOSE	FAITH	CHEESE	JOIN	NAIL	CHILL
6.	TOAD	SUNG	CHAIN	THIRD	THINE	COIN
7.	ROUT	KEG	LOOK	MOUTH	WORD	CAUSE
8.	MESS	VOTE	DULL	SURE	TOOL	BURN
9.	KITE	SIZE	POPE	VAGUE	MOB	LOOSE
10.	JUG	NUMB	CALF	BIG	HEN	PALM
11.	PAD	DAB	FIRE	FAR	GOT	JUDGE
12.	SALVE	WHAT	TURN	GUN	SANE	WASH
13.	VAN	ROOM	RAISE	PEARL	SHOUT	ROB
14.	HOME	KID	SOUR	LOOT	PILL	FINE
15.	CAPE	DIKE	BED	SAVE	BOTH	WHILE
16.	SHORE	MATE	LAWN	SIDE	SHADE	CHAT
17.	WRECK	WELL	SIT	HEAT	JAZZ	BIT
18.	SHIRT	RIG	TUBE	BUN	LATHE	NICK
19.	KNIFE	FOUR	VEAL	FISH	CATCH	NEAT
20.	HULL	BUSH	GET	HAVE	WHITE	HAIR
21.	YEARN	DIP	PACE	MOLE	CHAIR	SAFE
22.	SUN	GAP	NIGHT	PINE	LOAF	HIT
23.	WHEEL	PERCH	HISS	NAP	PUN	JADE
24.	FIT	SHEEP	SHOCK	MINE	HAM	HURT
25.	PATCH	HOUSE	WING	WAS	LIP	PILE
26.	MAKE	FADE	DOOR	REACH	WRONG	SHACK
27.	DIME	LAKE	NIECE	FACE	YES	CONE
28.	BEAN	GULL	CAT	BET	SIN	SELL
29.	THIN	ROUGE	MOVE	CAUGHT	CURVE	YOUR
30.	SEIZE	BAR	COOL	LAUGH	HAZE	TERM
31.	HATE	TONE	WEB	SHALL	GIRL	MOOD
32.	WOOD	CHIN	KNOCK	GEESE	TIME	DEEP
33.	CHECK	PIECE	JOT	TAPE	BOOK	MEEK
34.	DITCH	PURGE	CAGE	SACK	REAP	ROPE
35.	ROSE	BELL	MODE	RIDGE	FUDGE	WITCH
36.	MERGE	WORK	SEARCH	CHEEK	VOICE	RIDE
37.	LEASE	LIFE	GONE	DUMB	RAG	BAKE
38.	LOOP	POD	RUSH	TOP	MUD	GORE
39.	KING	SHINE	POLE	YOUNG	BALL	FOOL
40.	DEAD	TOLL	DIG	LED	DECK	GUESS
41.	CHORE	JOKE	BAD	RIB	CUT	MOUSE
42.	BOAT	HEAD	LIVE	PASS	NEED	LUNG
43.	WISH	WITH	MAP	WIT	CHEER	LOAD
44.	NAME	KEEN	WIFE	DID	SOAP	PATH
45.	PICK	MORE	FAN	CALL	FEET	PEAK
46.	RIPE	LEAVE	BIRTH	NECK	TICK	RUN
47.	FALL	HUT	TEAM	SUCH	ROOF	SAG
48.	LAG	NOISE	HOWL	LOSE	DOG	CAVE
49.	GALE	MAN	HIKE	GEM	BEAT	THATCH
50.	SOB	YAM	JAM	TAR	DISH	TOWEL

Central Institute for the Deaf (CID) W-22

	List 1	List 2	List 3	List 4
1.	AN	YORE	BILL	ALL
2.	YARD	BIN	ADD	WOOD
3.	CARVE	WAY	WEST	AT
4.	US	CHEST	CUTE	WHERE
5.	DAY	THEN	START	CHIN
6.	TOE	EASE	EARS	THEY
7.	FELT	SMART	TAN	DOLLS
8.	STOVE	GAVE	NEST	SO
9.	HUNT	PEW	SAY	NUTS
10.	RAN	ICE	IS	OUGHT
11.	KNEES	ODD	OUT	IN
12.	NOT	KNEE	LIE	NET
13.	MEW	MOVE	THREE	MY
14.	LOW	NOW	OIL	LEAVE
15.	OWL	JAW	KING	OF
16.	IT	ONE	PIE	HANG
17.	SHE	HIT	HE	SAVE
18.	HIGH	SEND	SMOOTH	EAR
19.	THERE	ELSE	FARM	TEA
20.	EARN	TARE	THIS	COOK
21.	TWINS	DOES	DONE	TIN
22.	COULD	TOO	USE	BREAD
23.	WHAT	CAP	CAMP	WHY
24.	BATHE	WITH	WOOL	ARM
25.	ACE	AIR	ARE	YET
26.	YOU	AND	AIM	DARN (dawn)
27.	AS	YOUNG	WHEN	ART
28.	WET	CARS	BOOK	WILL
29.	CHEW	TREE	TIE	DUST
30.	SEE	DUMB	DO	TOY
31.	DEAF	THAT	HAND	AID
32.	THEM	DIE	END	THAN
33.	GIVE	SHOW	SHOVE	EYES
34.	TRUE	HURT	HAVE	SHOE
35.	ISLE	OWN	OWES	HIS
36.	OR	KEY	JAR	OUR
37.	LAW	OAK	NO	MEN
38.	ME	NEW	MAY	NEAR
39.	NONE	LIVE	KNIT	FEW
40.	JAM	OFF	ON	JUMP
41.	POOR	ILL	IF	PALE
42.	HIM	ROOMS	RAW	GO
43.	SKIN	HAM	GLOVE	STIFF
44.	EAST	STAR	TEN	CAN
45.	THING	EAT	DULL	THROUGH
46.	DAD	THIN	THOUGH	CLOTHES
47.	UP	FLAT	CHAIR	WHO
48.	BELLS	WELL	WE	BEE
49.	WIRE	BY	ATE	YES
50.	ACHE	AIL	YEAR	AM

Northwestern University Auditory Test No. 6

	List 1	List 2	List 3	List 4
1.	LAUD	PICK	BASE	PASS
2.	BOAT	ROOM	MESS	DOLL
3.	POOL	NICE	CAUSE	BACK
4.	NAG	SAID	MOP	RED
5.	LIMB	FAIL	GOOD	WASH
6.	SHOUT	SOUTH	LUCK	SOUR
7.	SUB	WHITE	WALK	BONE
8.	VINE	KEEP	YOUTH	GET
9.	DIME	DEAD	PAIN	WHEAT
10.	GOOSE	LOAF	DATE	THUMB
11.	WHIP	DAB	PEARL	SALE
12.	TOUGH	NUMB	SEARCH	YEARN
13.	PUFF	JUICE	DITCH	WIFE
14.	KEEN	CHIEF	TALK	SUCH
15.	DEATH	MERGE	RING	NEAT
16.	SELL	WAG	GERM	PEG
17.	TAKE	RAIN	LIFE	MOB
18.	FALL	WITCH	TEAM	GAS
19.	RAISE	SOAP	LID	CHECK
20.	THIRD	YOUNG	POLE	JOIN
21.	GAP	TON	RODE	LEASE
22.	FAT	KEG	SHALL	LONG
23.	MET	CALM	LATE	CHAIN
24.	JAR	TOOL	CHEEK	KILL
25.	DOOR	PIKE	BEG	HOLE
26.	LOVE	MILL	GUN	LEAN
27.	SURE	HUSH	JUG	TAPE
28.	KNOCK	SHACK	SHEEP	TIRE
29.	CHOICE	READ	FIVE	DIP
30.	HASH	ROT	RUSH	ROSE
31.	LOT	HATE	RAT	CAME
32.	RAID	LIVE	VOID	FIT
33.	HURL	BOOK	WIRE	MAKE
34.	MOON	VOICE	HALF	VOTE
35.	PAGE	GAZE	NOTE	JUDGE
36.	YES	PAD	WHEN	FOOD
37.	REACH	THOUGHT	NAME	RIPE
38.	KING	BOUGHT	THIN	HAVE
39.	HOME	TURN	TELL	ROUGH
40.	RAG	CHAIR	BAR	KICK
41.	WHICH	LORE	MOUSE	LOSE
42.	WEEK	BITE	HIRE	NEAR
43.	SIZE	HAZE	CAB	PERCH
44.	MODE	MATCH	HIT	SHIRT
45.	BEAN	LEARN	CHAT	BATH
46.	TIP	SHAWL	PHONE	TIME
47.	CHALK	DEEP	SOUP	HALL
48.	JAIL	GIN	DODGE	MOOD
49.	BURN	GOAL	SEIZE	DOG
50.	KITE	FAR	COOL	SHOULD

Speech Recognition in Noise Test (SPRINT)

(Northwestern University Auditory Test No. 6, Randomization B)

	List 1	**List 2**	**List 3**	**List 4**
	List 1	List 2	List 3	List 4
1.	RAISE	DEAD	MOP	PERCH
2.	DOOR	JUICE	TELL	BATH
3.	TIP	MERGE	GERM	BACK
4.	SURE	YOUNG	SEIZE	BONE
5.	HURL	CALM	GOOD	WIFE
6.	MET	BITE	BASE	FIT
7.	BURN	RAIN	SEARCH	SHIRT
8.	SELL	MATCH	RING	WASH
9.	REACH	BOOK	HALF	NEAT
10.	DIME	LOAF	MESS	TIRE
11.	JAR	NICE	LATE	MAKE
12.	DEATH	BOUGHT	WHEN	MOB
13.	WHICH	TON	GUN	DOLL
14.	THIRD	SHAWL	NAME	PASS
15.	POOL	WHITE	PAIN	SOUR
16.	MOON	HATE	DITCH	DOG
17.	FAT	SHACK	RAT	VOTE
18.	KING	PIKE	HIRE	TIME
19.	CHALK	FAIL	SHALL	NEAR
20.	YES	ROT	CHEEK	LEASE
21.	WEEK	GIN	POLE	ROSE
22.	WHIP	PAD	LIFE	KILL
23.	BEAN	GAZE	DATE	CAME
24.	CHOICE	LIVE	ROAD	FOOD
25.	RAG	ROOM	TALK	LOSE
26.	FALL	SOUTH	CAUSE	SHOULD
27.	VINE	MILL	YOUTH	CHECK
28.	JAIL	WHICH	BAR	KICK
29.	HOME	TOOL	LID	LONG
30.	BOAT	NUMB	HIT	TAPE
31.	MODE	HAZE	COOL	YEARN
32.	TOUGH	PICK	FIVE	LEAN
33.	LOT	TURN	RUSH	GAS
34.	RAID	GOAL	PHONE	SAIL
35.	TAKE	VOICE	MOUSE	RED
36.	PAGE	KEEP	THIN	WHEAT
37.	KEEN	THOUGHT	PEARL	HAVE
38.	LAUD	FAR	BEG	MOOD
39.	LIMB	READ	WALK	DIP
40.	GOOSE	HUSH	LUCK	SUCH
41.	GAP	CHAIR	TEAM	HALL
42.	SUB	CHIEF	SOUP	ROUGH
43.	NAG	KEG	DODGE	PEG
44.	SIZE	SOAP	CHAT	GET
45.	HASH	SAID	SHEEP	CHAIN
46.	LOVE	DAB	NOTE	JOIN
47.	KNOCK	WAG	VOID	RIPE
48.	PUFF	DEEP	JUG	JUDGE
49.	SHOUT	LEARN	WIRE	HOLE
50.	KITE	LORE	CAB	THUMB

Speech Perception In Noise (SPIN)
List 1

	Predictability	Sentence	Target Word
1.	H	His plan meant taking a big RISK.	RISK
2.	H	Stir your coffee with a SPOON.	SPOON
3.	L	Miss White Won't think about the CRACK.	CRACK
4.	L	He would think about the RAG.	RAG
5.	H	The plow was pulled by an OX.	OX
6.	H	The old train was powered by STEAM.	STEAM
7.	L	The old man talked about the LUNGS.	LUNGS
8.	L	I was considering the CROOK.	CROOK
9.	H	Let's decide by tossing a COIN.	COIN
10.	H	The doctor prescribed the DRUG.	DRUG
11.	L	Bill might discuss the FOAM.	FOAM
12.	L	Nancy didn't discuss the SKIRT.	SKIRT
13.	H	Hold the baby on your LAP.	LAP
14.	L	Bob has discussed the SPLASH.	SPLASH
15.	H	The dog chewed on a BONE.	BONE
16.	L	Ruth hopes he heard abou the HIPS.	HIPS
17.	H	The war was fought with armored TANKS.	TANKS
18.	L	She wants to talk about the CREW.	CREW
19.	L	They had a problem with the CLIFF.	CLIFF
20.	H	They drank a whole bottle of GIN.	GIN
21.	L	You heard Jane called about the VAN.	VAN
22.	H	The witness took a solemn OATH.	OATH
23.	L	We could consider the FEAST.	FEAST
24.	L	Bill heard we asked about the HOST.	HOST
25.	H	They tracked the lion to his DEN.	DEN
26.	H	The cow gave birth to a CALF.	CALF
27.	L	I had not thought about the GROWL.	GROWL
28.	H	The scarf was made of shiny SILK.	SILK
29.	H	The super highway has six LANES.	LANES
30.	L	He should know about the HUT.	HUT
31.	H	For dessert he had apple PIE.	PIE
32.	H	The beer drinkers raised their MUGS.	MUGS
33.	L	I'm glad you heard about the BEND.	BEND
34.	L	You're talking about the POND.	POND
35.	H	The rude remark made her BLUSH.	BLUSH
36.	L	Nancy had considered the SLEEVES.	SLEEVES
37.	H	We heard the ticking of the CLOCK.	CLOCK
38.	L	He can't consider the CRIB.	CRIB
39.	H	He killed the dragon with his SWORD.	SWORD
40.	L	Tom discussed the HAY.	HAY
41.	H	Mary wore her hair in BRAIDS.	BRAIDS
42.	L	She's glad Jane asked about the DRAIN.	DRAIN
43.	L	Bill hopes Paul heard about the MIST.	MIST
44.	H	We're lost so let's look at the MAP.	MAP
45.	H	No one was injured in the CRASH.	CRASH
46.	L	We're speaking about the TOLL.	TOLL
47.	H	My son has a dog for a PET.	PET
48.	H	He was scared out of his WITS.	WITS
49.	L	We spoke about the KNOB.	KNOB
50.	L	I've spoken about the PILE.	PILE

Speech Perception In Noise (SPIN)
List 2

	Predictability	Sentence	Target Word
1.	L	Miss Black thought about the LAP.	LAP
2.	H	The baby slept in his CRIB.	CRIB
3.	H	The watchdog gave a warning GROWL.	GROWL
4.	L	Miss Black would consider the BONE.	BONE
5.	H	The natives built a wooden HUT.	HUT
6.	L	Bob could have known about the SPOON.	SPOON
7.	H	Unlock the door and turn the KNOB.	KNOB
8.	L	He wants to talk about the RISK.	RISK
9.	L	He heard they called about the LANES.	LANES
10.	H	Wipe your greasy hands on that RAG.	RAG
11.	L	She has known about the DRUG.	DRUG
12.	L	I want to speak about the CRASH.	CRASH
13.	H	The wedding banquet was a FEAST.	FEAST
14.	L	I should have considered the MAP.	MAP
15.	H	Paul hit the water with a SPLASH.	SPLASH
16.	H	The ducks swam around on the POND.	POND
17.	L	Ruth must have known about the PIE.	PIE
18.	L	The man should discuss the OX.	OX
19.	H	Bob stood with his hands on his HIPS.	HIPS
20.	H	The cigarette smoke filled his LUNGS.	LUNGS
21.	L	They heard I called about the PET.	PET
22.	H	The cushion was filled with FOAM.	FOAM
23.	H	Ruth poured the water down the DRAIN.	DRAIN
24.	L	Bill cannot consider the DEN.	DEN
25.	H	This nozzle sprays a fine MIST.	MIST
26.	H	The sport shirt has short SLEEVES.	SLEEVES
27.	L	She hopes Jane called about the CALF.	CALF
28.	L	Jane has a problem with the COIN.	COIN
29.	H	She shortened the hem of her SKIRT.	SKIRT
30.	L	Paul hopes she called about the TANKS.	TANKS
31.	L	The girl talked about the GIN.	GIN
32.	H	The guests were welcomed by the HOST.	HOST
33.	L	Mary should think about the SWORD.	SWORD
34.	L	Ruth could have discussed the WITS.	WITS
35.	H	The ship's Captain summoned his CREW.	CREW
36.	L	You had a problem with the BLUSH.	BLUSH
37.	H	The flood took a heavy TOLL.	TOLL
38.	H	The car drove off the steep CLIFF.	CLIFF
39.	L	We have not discussed the STEAM.	STEAM
40.	H	The policemen captured the CROOK.	CROOK
41.	H	The door was opened just a CRACK.	CRACK
42.	L	Tom is considering the CLOCK.	CLOCK
43.	H	The sand was heaped in a PILE.	PILE
44.	L	You should not speak about the BRAIDS.	BRAIDS
45.	L	Peter should speak about the MUGS.	MUGS
46.	H	Household goods are moved in a VAN.	VAN
47.	L	He has a problem with the OATH.	OATH
48.	H	Follow this road around the BEND.	BEND
49.	L	Tom won't consider the SILK.	SILK
50.	H	The farmer baled the HAY.	HAY

Speech Perception In Noise (SPIN)
List 3

	Predictability	Sentence	Target Word
1.	H	Kill the bugs with this SPRAY.	SPRAY
2.	L	Mr. White discussed the CRUISE.	CRUISE
3.	H	How much can I buy for a DIME?	DIME
4.	L	Miss White thinks about the TEA.	TEA
5.	H	We shipped the furniture by TRUCK.	TRUCK
6.	L	He is thinking about the ROAR.	ROAR
7.	L	She's spoken about the BOMB.	BOMB
8.	H	My T.V. has a twelve-inch SCREEN.	SCREEN
9.	H	That accident gave me a SCARE.	SCARE
10.	L	You want to talk about the DITCH.	DITCH
11.	H	The king wore a golden CROWN.	CROWN
12.	H	The girl swept the floor with a BROOM.	BROOM
13.	L	We're discussing the SHEETS.	SHEETS
14.	H	The nurse gave him first AID.	AID
15.	H	She faced them with a foolish GRIN.	GRIN
16.	L	Betty has considered the BARK.	BARK
17.	H	Watermelons have lots of SEEDS.	SEEDS
18.	H	Use this spray to kills the BUGS.	BUGS
19.	L	Tom will discuss the SWAN.	SWAN
20.	H	The teacher sat on a sharp TACK.	TACK
21.	L	You'd been considering the GEESE.	GEESE
22.	H	The sailor swabbed the DECK.	DECK
23.	L	They were interested in the STRAP.	STRAP
24.	L	He could discuss the BREAD.	BREAD
25.	H	He tossed the drowning man a ROPE.	ROPE
26.	L	Jane hopes Ruth asked about the STRIPES.	STRIPES
27.	L	Paul spoke about the PORK.	PORK
28.	H	The boy gave the football a KICK.	KICK
29.	H	The storm broke the sailboat's MAST.	MAST
30.	L	Mr. Smith thinks about the CAP.	CAP
31.	L	We are speaking about the PRIZE.	PRIZE
32.	H	Mr. Brown carved the roast BEEF.	BEEF
33.	H	The glass had a chip on the RIM.	RIM
34.	L	Harry had thought about the LOGS.	LOGS
35.	L	Bob could consider the POLE.	POLE
36.	H	Her cigarette had a long ASH.	ASH
37.	L	Ruth has a problem with the JOINTS.	JOINTS
38.	L	He is considering the THROAT.	THROAT
39.	H	The soup was served in a BOWL.	BOWL
40.	L	We can't consider the WHEAT.	WHEAT
41.	L	The man spoke about the CLUE.	CLUE
42.	H	The lonely bird searched for its MATE.	MATE
43.	H	Plese wipe your feet on the MAT.	MAT
44.	L	David has discussed the DENT.	DENT
45.	H	The pond was full of croaking FROGS.	FROGS
46.	H	He hit me with a clenched FIST.	FIST
47.	L	Bill heard Tom called about the COACH.	COACH
48.	H	A bicycle has two WHEELS.	WHEELS
49.	L	Jane has spoken about the CHEST.	CHEST
50.	L	Mr. White spoke about the FIRM.	FIRM

Speech Perception In Noise (SPIN)

List 4

	Predictability	Sentence	Target Word
1.	H	The doctor X-rayed his CHEST.	CHEST
2.	L	Mary had considered the SPRAY.	SPRAY
3.	L	The woman talked about the FROGS.	FROGS
4.	H	The workers are digging a DITCH.	DITCH
5.	L	Miss Brown will speak about the GRIN.	GRIN
6.	L	Bill can't have considered the WHEELS.	WHEELS
7.	H	The duck swam with the white SWAN.	SWAN
8.	H	Your knees and your elbows are JOINTS.	JOINTS
9.	L	Mr. Smith spoke about the AID.	AID
10.	L	He hears she asked about the DECK.	DECK
11.	H	Raise the flag up the POLE.	POLE
12.	L	You want to think about the DIME.	DIME
13.	L	You've considered the SEEDS.	SEEDS
14.	H	The detectives searched for a CLUE.	CLUE
15.	L	Ruth's grandmother discussed the BROOM.	BROOM
16.	H	The steamship left on a CRUISE.	CRUISE
17.	L	Miss Smith considered the SCARE.	SCARE
18.	L	Peter has considered the MAT.	MAT
19.	H	Tree trunks are covered with BARK.	BARK
20.	H	The meat from a pig is called PORK.	PORK
21.	L	The old man considered the KICK.	KICK
22.	H	Ruth poured herself a cup of TEA.	TEA
23.	H	We saw a flock of wild GEESE.	GEESE
24.	L	Paul could not consider the RIM.	RIM
25.	H	How did your car get that DENT?	DENT
26.	H	She made the bed with clean SHEETS.	SHEETS
27.	L	I've been considering the CROWN.	CROWN
28.	H	The team was trained by their COACH.	COACH
29.	H	I've got a cold and a sore THROAT.	THROAT
30.	L	We've spoken about the TRUCK.	TRUCK
31.	H	She wore a feather in her CAP.	CAP
32.	H	The bread was made from whole WHEAT.	WHEAT
33.	L	Mary could not discuss the TACK.	TACK
34.	H	Spread some butter on your BREAD.	BREAD
35.	H	The cabin was made of LOGS.	LOGS
36.	L	Harry might consider the BEEF.	BEEF
37.	L	We're glad Bill heard about the ASH.	ASH
38.	H	The lion gave an angry ROAR.	ROAR
39.	H	The sandal has a broken STRAP.	STRAP
40.	L	Nancy should consider the FIST.	FIST
41.	H	He's employed by a larg FIRM.	FIRM
42.	L	They did not discuss the SCREEN.	SCREEN
43.	H	Her entry should win first PRIZE.	PRIZE
44.	L	The old man thinks about the MAST.	MAST
45.	L	Paul wants to speak about the BUGS.	BUGS
46.	H	The airplane dropped a BOMB.	BOMB
47.	L	You're glad she called about the BOWL.	BOWL
48.	H	A zebra has black and white STRIPES.	STRIPES
49.	L	Miss Black could have discussed the ROPE.	ROPE
50.	L	I hope Paul asked about the MATE.	MATE

Speech Perception In Noise (SPIN)
List 5

	Predictability	Sentence	Target Word
1.	L	Betty knew about the NAP.	NAP
2.	L	The girl should consider the FLAME.	FLAME
3.	H	It's getting dark, so light the LAMP.	LAMP
4.	H	To store his wood he built a SHED.	SHED
5.	L	They heard I asked about the BET.	BET
6.	H	The mouse was caught in the TRAP.	TRAP
7.	L	Mary knows about the RUG.	RUG
8.	H	The airplane went into a DIVE.	DIVE
9.	H	The firemen heard her frightened SCREAM.	SCREAM
10.	L	He was interested in the HEDGE.	HEDGE
11.	H	He wiped the sink with a SPONGE.	SPONGE
12.	L	Jane did not speak about the SLICE.	SLICE
13.	L	Mr. Brown can't discuss the SLOT.	SLOT
14.	H	The papers were held by a CLIP.	CLIP
15.	L	Paul can't discuss the WAX.	WAX
16.	L	Miss Brown shouldn't discuss the SAND.	SAND
17.	H	The chicks followed the mother HEN.	HEN
18.	L	David might consider the FUN.	FUN
19.	L	She wants to speak about the ANT.	ANT
20.	H	The fur coat was made of MINK.	MINK
21.	H	The boy took shelter in a CAVE.	CAVE
22.	L	He hasn't considered the DART.	DART
23.	H	Eve was made from Adam's RIB.	RIB
24.	H	The boat sailed along the COAST.	COAST
25.	L	We've been discussing the CRATES.	CRATES
26.	H	The judge is sitting on the BENCH.	BENCH
27.	L	We've been thinking about the FAN.	FAN
28.	L	Jane didn't think about the BROOK.	BROOK
29.	H	Cut a piece of meat from the ROAST.	ROAST
30.	L	Betty can't consider the GRIEF.	GRIEF
31.	H	The heavy rains caused a FLOOD.	FLOOD
32.	H	The swimmer dove into the POOL.	POOL
33.	L	Harry will consider the TRAIL.	TRAIL
34.	H	Let's invite the whole GANG.	GANG
35.	H	The house was robbed by a THIEF.	THIEF
36.	L	Tom is talking about the FEE.	FEE
37.	H	Bob wore a watch on his WRIST.	WRIST
38.	L	Tom had spoken about the PILL.	PILL
39.	L	Tom has been discussing the BEADS.	BEADS
40.	H	The secret agent was a SPY.	SPY
41.	H	The rancher rounded up his HERD.	HERD
42.	L	Tom could have thought about the SPORT.	SPORT
43.	L	Mary can't consider the TIDE.	TIDE
44.	H	Ann works in the bank as a CLERK.	CLERK
45.	H	A chimpanzee is an APE.	APE
46.	L	He hopes Tom asked about the BAR.	BAR
47.	L	We could discuss the DUST.	DUST
48.	H	The bandits escaped from JAIL.	JAIL
49.	L	Paul hopes we heard about the LOOT.	LOOT
50.	H	The landlord raised the RENT.	RENT

Speech Perception In Noise (SPIN)
List 7

	Predictability	Sentence	Target Word
1.	L	We're considering the BROW.	BROW
2.	H	You cut the wood against the GRAIN.	GRAIN
3.	L	I am thinking about the KNIFE.	KNIFE
4.	L	They've considered the SHEEP.	SHEEP
5.	H	The cop wore a bullet-proof VEST.	VEST
6.	L	He's glad we heard about the SKUNK.	SKUNK
7.	H	His pants were held up by a BELT.	BELT
8.	H	Paul took a bath in the TUB.	TUB
9.	L	The girl should not discuss the GOWN.	GOWN
10.	H	Maple syrup is made from SAP.	SAP
11.	L	Mr. Smith knew about the BAY.	BAY
12.	H	They played a game of cat and MOUSE.	MOUSE
13.	H	The thread was wound on a SPOOL.	SPOOL
14.	L	We did not discuss the SHOCK.	SHOCK
15.	H	The crook entered a guilty PLEA.	PLEA
16.	L	Mr. Black has discussed the CARDS.	CARDS
17.	H	A bear has a thick coat of FUR.	FUR
18.	L	Mr. Black consided the FLEET.	FLEET
19.	H	To open the jar, twist the LID.	LID
20.	L	We are considering the CHEERS.	CHEERS
21.	L	Sue was interested in the BRUISE.	BRUISE
22.	H	Tighten the belt by a NOTCH.	NOTCH
23.	H	The cookies were kept in a JAR.	JAR
24.	L	Miss Smith couldn't discuss the ROW.	ROW
25.	L	I am discussing the TASK.	TASK
26.	H	The marksman took careful AIM.	AIM
27.	H	I ate a piece of chocolate FUDGE.	FUDGE
28.	L	Paul should know about the NET.	NET
29.	L	Miss Smith might consider the SHELL.	SHELL
30.	H	John's front tooth had a CHIP.	CHIP
31.	H	At breakfast he drank some JUICE.	JUICE
32.	L	You cannnot have discussed the GREASE.	GREASE
33.	L	I did not know about the CHUNKS.	CHUNKS
34.	H	Our cat is good at catching MICE.	MICE
35.	L	I should have known about the GUM.	GUM
36.	L	Mary hasn't discussed the BLADE.	BLADE
37.	H	The stale bread was covered with MOLD.	MOLD
38.	L	Ruth has discussed the PEG.	PEG
39.	H	How long can you hold your BREATH?	BREATH
40.	H	His boss made him work like a SLAVE.	SLAVE
41.	L	We have not thought about the HINT.	HINT
42.	H	Air mail requires a special STAMP.	STAMP
43.	H	The bottle was sealed with a CORK.	CORK
44.	L	The old man discussed the YELL.	YELL
45.	L	They're glad we heard about the TRACK.	TRACK
46.	H	Cut the bacon into STRIPS.	STRIPS
47.	H	Throw out all this useless JUNK.	JUNK
48.	L	The boy can't talk about the THORNS.	THORNS
49.	L	Bill won't consider the BRAT.	BRAT
50.	H	The shipwrecked sailors built a RAFT.	RAFT

Speech Perception In Noise (SPIN)

List 8

	Predictability	Sentence	Target Word
1.	L	Bob heard Paul called about the STRIPS.	STRIPS
2.	H	My turtle went into its SHELL.	SHELL
3.	L	Paul has a problem with the BELT.	BELT
4.	H	I cut my finger with a KNIFE.	KNIFE
5.	L	They knew about the FUR.	FUR
6.	L	We're glad Anna asked about the FUDGE.	FUDGE
7.	H	Greet the heroes with loud CHEERS.	CHEERS
8.	L	Jane was interested in the STAMP.	STAMP
9.	H	That animal stinks like a SKUNK.	SKUNK
10.	H	A round hole won't take a square PEG.	PEG
11.	L	Miss White would consider the MOLD.	MOLD
12.	L	They want to know about the AIM.	AIM
13.	H	The Admiral commands the FLEET.	FLEET
14.	H	The bride wore a white GOWN.	GOWN
15.	L	The woman discussed the GRAIN.	GRAIN
16.	L	You hope they asked about the VEST.	VEST
17.	H	I can't guess so give me a HINT.	HINT
18.	H	Our seats were in the second ROW.	ROW
19.	L	We should have considered the JUICE.	JUICE
20.	H	The boat sailed across the BAY.	BAY
21.	L	The woman considered the NOTCH.	NOTCH
22.	H	That job was an easy TASK.	TASK
23.	L	The woman knew about the LID.	LID
24.	L	Jane wants to speak about the CHIP.	CHIP
25.	H	The shepherd watched his flock of SHEEP.	SHEEP
26.	L	Bob should not consider the MICE.	MICE
27.	H	David wiped the sweat from his BROW.	BROW
28.	L	Ruth hopes she called about the JUNK.	JUNK
29.	L	I can't consider the PLEA.	PLEA
30.	H	The bad news came as a SHOCK.	SHOCK
31.	H	A spoiled child is a BRAT.	BRAT
32.	L	Paul was interested in the SAP.	SAP
33.	H	The drowning man let out a YELL.	YELL
34.	H	A rose bush as prickly THORNS.	THORNS
35.	L	He's glad you called about the JAR.	JAR
36.	H	The dealer shuffled the CARDS.	CARDS
37.	L	Miss Smith knows about the TUB.	TUB
38.	L	The man could not discuss the MOUSE.	MOUSE
39.	H	The railroad train ran off the TRACK.	TRACK
40.	H	My jaw aches when I chew GUM.	GUM
41.	L	Ann was interested in the BREATH.	BREATH
42.	L	You're glad they heard about the SLAVE.	SLAVE
43.	H	He caught the fish in his NET.	NET
44.	H	Bob was cut by the jacknife's BLADE.	BLADE
45.	L	The man could consider the SPOOL.	SPOOL
46.	H	Tom fell down and got a bad BRUISE.	BRUISE
47.	H	Lubricate the car with GREASE.	GREASE
48.	L	Peter knows about the RAFT.	RAFT
49.	H	Cut the meat into small CHUNKS.	CHUNKS
50.	L	She hears Bob ask about the CORK.	CORK