

K. J. Lee: Essential Otolaryngology and Head and Neck Surgery (IIIrd Ed)

Chapter 2: Audiology

Theories of Hearing

There are several theories regarding the manner in which sound is perceived by the human ear. The following are several of the most common and accepted theories.

The Place Theory

The place theory is based on the assumption that pitch discrimination is determined by a certain place along the basilar membrane being set into maximum vibration, which in turn excites the sensory nerve fibers at that place. It was presumed that every particular section of the basilar membrane is tuned so that its resonance characteristics will correspond to the frequency of some audible tone. This theory was propounded by Hermann von Helmholtz, who considered the 24,000 or so transverse fibers of the basilar membrane to be tuned like the strings of a piano or harp. It was thought that when sound waves containing those frequencies were received by the ear, the appropriate fibers would resonate automatically to those pitches, thus stimulating the hair cells of the *organ of Corti* which rests on those fibers of the membrane. It was assumed that because the transverse fibers at the base of the cochlea are short, they thought to resonate to lower pitches. Later exponents of the *place theory* did not think that the tuning of the basilar membrane was as sharp as Helmholtz has thought, but agreed that a particular region of stimulation in the basilar membrane was responsible for the perception of a particular pitch.

The Frequency Theory

The frequency theory explains pitch perception by suggesting that all parts of the basilar membrane are stimulated by every frequency and that the determination of pitch perception is based upon the number of times per second that the fibers of the auditory nerve discharge. For example, this theory holds that an auditory stimulus of 1000 Hz causes fibers within the auditory nerve to discharge at a rate of 1000 times per second, and that pitch is appreciated in the brain, not in the cochlea. The *frequency theory* also is known as the "telephone" theory, because displacements along the basilar membrane are in phase with the movements of the stapes, much like a telephone diaphragm. Studies of action potentials of nerve fibers have demonstrated that the maximum rate of discharge of nerve impulses from the peripheral auditory nerve fibers is about 1000/sec. This means that the discrimination of pitches above this frequency could not be explained on the basis of the frequency theory. Rutherford, and more recently Boring, were exponents of this theory.

The Volley Theory

The volley theory combines elements of the *place theory* and the *frequency theory*, and holds that perception of pitch for frequencies up to 5000 Hz can be explained on the basis of the frequency of nerve impulses firing in volleys. It holds that the primary explanation for perception of pitch for frequencies in excess of 5000 Hz is the place of greatest excitation along the basilar membrane. The volley theory is advocated by Weaver.

The Travelling Wave Theory

The travelling wave theory is one of the *place theories* which holds that pitch discrimination is determined when a certain place along the basilar membrane is set into maximum vibration. The place on the membrane where the nerve endings will be stimulated depends upon where the maximum displacement of the travelling wave occurs. Support for the *travelling wave theory* is contributed by experimentation carried out by George von Bekesy. According to Bekesy, the energy for creating the travelling wave comes from the stapes, but the wave starting at one end, runs along the length of the membrane, gradually increasing in amplitude until it gains maximum displacement. The wave travels from the base to the apex of the cochlea, and the maximum amplitude occurs at a point along the basilar membrane that corresponds to the frequency of the stimulus. Increasing the frequency of the tone moves the place of maximal vibration toward the base of the cochlea, decreasing the frequency moves it in the direction of the apex of the cochlea.

The above four theories of hearing, a few more acceptable than others, are explanations of how the human ear discriminates pitch. When intensity discrimination in the human ear is considered, it appears that the number of nerve fibers activated, the total number of impulses per second of all fibers, and the existence of fibers that tend to respond to stimuli which fit a particular category of intensity, are the factors on which intensity discrimination are dependent.

Bone Conduction

When testing pure tone thresholds under headphones, otherwise known as air-conduction testing, the integrity of the outer, middle, and inner ear is being tested as a whole. In essence, air-conduction results indicate the amount of hearing loss the patient is experiencing. When testing pure tone bone-conduction thresholds, the integrity of only the inner ear is indicated. Therefore, the combination of air-conduction and bone-conduction tests indicates the amount of conductive hearing loss present. The difference between air-conduction and bone-conduction results equals the conductive hearing loss.

Bone conduction testing is performed using a bone vibrator attached to the skull with a headband. Conventional bone-conduction testing is done at the mastoid process of the temporal bone. The vibrator sets the fluid of the cochlea in motion. Two patterns of skull and fluid vibration are as follows:

a. Below 800 Hz the skull vibrates as a unit and the ossicles, mandible, and cochlear fluid lag behind due to inertia. Since the ossicular chain lags, the stapes moves relative to the oval window and stimulates hearing as in air conduction.

b. Above 800 Hz compressional vibration occurs. This means that when the compressional forces of the skull are transmitted to the inner ear, the noncompressible fluids of the entire cochlea move toward or away from the mobile round window. Since the fluid is in motion, it may cause depression of the basilar membrane, resulting in the sensation of hearing.

Physiology of the Middle Ear Related to Hearing

The average surface area of the tympanic membrane - 70-80 mm².

Weight of tympanic membrane = 14 mg, elasticity = 4.9×10^{-8} dynes.

The average surface area of the vibrating portion of the tympanic membrane = 55 mm².

The surface of the footplate = 3.2-3.5 mm².

The surface area of the round window is 2 mm².

Lever mechanism = (Length of the long process of the malleus) / (Length of the long process of the incus) = 1.3 / 1 or 2.5 dB

Hydraulic action = (Vibrating TM) / (Footplate) = 55 / 3.2 = 17 or 25 dB

Total transformer ratio = (1.3 x 17) / 1 = 22 / 1 or 27.5 dB.

Glossary of Miscellaneous Terminology Related to Physiology of the Human Ear

1. The human ear has an auditory range from approximately 10 Hz through 24,000 Hz. The intensity range is from approximately 0 dB through 120 dB (0.0002 dynes/cm² through 200 dynes/cm²).

2. In the middle ear, a high-frequency hearing loss will result with an increase of mass. An increase of stiffness will cause a low-frequency hearing loss.

3. Maximum conductive hearing loss:

a. With intact ossicular chain with no pars tensa - 40-45 dB

b. With ossicular discontinuity with no pars tensa - 40-45 dB

c. Ossicular discontinuity with intact tympanic membrane - 50-55 dB.

4. The resonant frequency of the external auditory canal is 3000 Hz. The resonant frequency of the tympanic membrane and ossicles is 800 Hz. The maximum increase in sound pressure occurs when the applied sound has a wavelength four times the effective length of the external auditory canal.

5. Other definitions related to perception of sound in the human ear:

a. *Hyperacusis* is an unusually low hearing threshold level. (It is not necessarily associated with intolerance to sound.)

b. *Dysacusis* indicates a disturbance of speech discrimination, abnormal tone quality, pitch, or loudness.

c. *Hypoacusis* is an unusually high hearing threshold level.

d. *Paracusis willisane* is the phenomenon whereby a person with conductive hearing loss hears better in background noise.

e. *Central hearing loss* occurs because of a lesion within the auditory nervous system, does not involve the primary neuron, and may or may not involve decreased hearing thresholds.

f. *Central auditory imperception* indicates receptive (sensory) aphasia, in which hearing thresholds are good but discrimination or understanding of the stimuli is poor.

g. *Monoaural diplacusis* is a hearing disorder which affects the perception of pure tones as impure or noisy.

Binaural diplacusis is a disorder in which the same pitch sounds different in both ears.

h. *Phonemic regression* occurs when discrimination is so poor that the listener is unable to differentiate phonemes. Presbycusis is a common problem among the geriatric population, whose common complaint is lack of understanding even if loud enough to hear. This problem is due to the loss of central communicating neurons and axons.

6. *Occlusion effect* occurs when the external auditory canal of the test ear is occluded. This will render the bone-conduction hearing thresholds improved in the normal and sensorineural hearing loss. This phenomenon will not occur with conductive hearing loss.

7. *Difference limen* indicates the smallest detectable change. This can be related to intensity or frequency.

8. The concept that the round window is exposed to the external auditory canal and the oval window is protected is defined as sonoinversion.

9. Interaural attenuation for air conduction is 40-50 dB and for bone conduction is 0 dB.

10. Usual norms:

a. 4-month-old baby: responds to mother's sounds

b. 6-month-old baby: turns head to a source of sound located 3-4 ft away

c. 24-months-old baby: responds to some words and perhaps phrases; able to obtain thresholds with play audiometry

d. 40-month-old baby: is able to perform a conventional audiogram if cooperative.

11. Any conductive hearing loss greater than 40 dB suggests ossicular problems.

Tuning Fork Tests

Every otologic patient should be tested with a tuning fork before an audiogram is performed. If the responses to the tuning fork do not agree with the audiogram, the situation should be resolved with repeated testing and repeated audiometric studies. Clinically, the most useful fork is the 512. A negative Rinne response to the 512 fork indicates a 25-30 dB or greater conductive hearing loss. A 256 fork may be felt rather than heard. Besides, ambient noises are also in the low frequencies, around 250 cps. When striking the fork, it is essential to strike it gently to avoid overtones. The maximum output of a tuning fork is about 60 dB.

Weber Test

In Weber's test the tuning fork is placed on a midline structure on the skull. The forehead, the nasal bone, and the incisor teeth are favorable sites. In a normal individual the tone is heard symmetrically in both ears. In a person with a sensorineural hearing loss, the tone lateralizes to the opposite ear. It lateralizes to the ear with conductive hearing loss. Possible reasons for this are:

- a. Less masking noise via air conduction from the environment in the ear with conductive hearing loss.
- b. An abnormal conductive mechanism prevents escape of energy through the ossicular chain thus enhancing bone conduction.

Rinne Test

Rinne's test compares the loudness of the sound perceived when holding the tuning fork next to the external auditory canal with holding it against the mastoid. It is important to place the fork firmly against the mastoid (preferably near the postero-superior edge of the bony canal) and to hold the tines of the fork about 1 in. lateral to the tragus.

A negative Rinne with a 256 fork implies a conductive deficit of 15 dB or more. However, the 256 fork is not a reliable fork to use for this test. The 512 fork is the most commonly used fork. A negative Rinne with this fork implies a 25-30 dB or more conductive hearing loss. A 1024 fork would give a negative Rinne when a conductive loss is 35 or more.

Bing Test

The tuning fork is applied to the forehead and lateralization is noted when present. The external auditory meatus of one side is then occluded. The patient indicates whether the intensity of the sound has increased or whether it lateralizes to the occluded side. This is repeated with occlusion of the opposite ear.

In an ear with a normal sound-conduction mechanism (i.e. a normal ear or one with sensorineural hearing loss) occlusion of the meatus would intensify the sound or cause lateralization to that ear. An ear with a significant conductive hearing loss would have no effect from occlusion of the meatus.

Gelle Test

A tuning fork is placed against the mastoid. The intensity of the sound heard is compared with various amounts of pressure applied against the tympanic membrane. An increase in pressure results in a decrease in intensity of bone conduction if the tympanic membrane and ossicular chain are mobile and intact. When ossicular discontinuity or fixation is present, there is no decrease in intensity with an increase in applied pressure.

Lewis Test

A tuning fork is placed against the mastoid. When it is no longer heard, it is placed against the tragus with gentle occlusion of the meatus. The patient is then asked if he hears the tone again. The interruption of this test is neither simple nor consistent.

Schwabach Test

Schwabach's test compares the hearing acuity of the patient with that of the tester as transmitted by a vibrating fork applied on the mastoid (assuming the tester has normal hearing).

The tuning fork can also be used to test recruitment and diplacusis between the two ears.

Audiology

The Decibel

In general, the decibel (dB) is a measure of the intensity of a sound and may refer to either sound power or sound pressure. In the usual application, the measurement of hearing by audiometry, the decibel refers to sound pressure. Some sources have erroneously stated that 1 dB is equal to the smallest "just noticeable difference" that the ear can detect. While this is approximately true, it would be more accurate to say that the just noticeable difference varies as a function of sound intensity. For very faint sounds, the difference must be 3 or 4 dB to be perceived while for very intense sounds the normal ear can detect changes as small as 0.3 dB. A tone that is made 10 dB more intense than another, is likely to be perceived as twice as loud.

To further understand the decibel, it should be noted that intensity is a physical attribute of sound which can be manipulated and measured with appropriate electronic equipment in a laboratory. The psychologic correlate of intensity is loudness. The sensation of loudness is related to stimulus intensity but not on a one-to-one basis. For soft sounds, a relatively small change in absolute intensity units will cause a change in loudness. However, for relatively loud sounds, it is possible to make large changes in absolute intensity units without getting a perceived change in the sensation of loudness. In terms of sound pressure, the loudest sound that the normal ear can tolerate is about 10 million times that of the softest sound it can hear. Since the ear detects differences in loudness by ratios of pressure or power rather than by actual differences, a logarithmic system employing decibels has been adopted by acoustic scientists and engineers.

Technically, the decibel can be defined as the logarithm of the ratio of two sound powers. This formula which relates intensity or sound power to decibels is:

$$\mathbf{NdB = I1/I0}$$

where power is given in watts per square centimeter. Since it is a mathematical fact that acoustic pressures are proportional to the square root of the corresponding acoustic powers, it is possible to derive a formula which relates changes in sound pressure to decibels. It has already been noted that for purposes of hearing measurement we usually deal with acoustic pressure. The formula relating changes in sound pressure to decibels is:

$$\mathbf{NdB = 20 \log P1/P2}$$

P1 = the greater pressure in dynes/cm²

P2 = the lesser sound pressure.

Remember that we are interested in the ratio of one pressure to another.

Suppose that we would like to know how many decibels a tone will increase if we increase the sound pressure 100-fold. The formula would be applied as follows:

$$\mathbf{NdB = 20 \log 100/1}$$

the pressure ratio P1/P2 with a 100-fold increase in pressure would be 100:1.

$$\mathbf{NdB = 20 \text{ LOG } 100 = 20 \times 2 = 40 \text{ dB.}}$$

The log of a number is the power to which the base 10 must be raised to give that number. Common log tables are available to make this determination, although when the number under discussion is 1, followed by a number of zeroes, the log of that number can be found by simple adding up the zeroes. For example, the log of 1000 = 3, the log of 10,000 = 4, etc.

Unless otherwise stated, the standard reference pressure is 0.0002 dynes/cm². The standard reference for power is 10⁻¹⁶ W/cm². When decibels are calculated using the standard reference pressure as the denominator of the pressure ratio in the decibel formula, it is customary to refer to the results as dB SPL (sound pressure level).

Some common sound pressure levels associated with different sounds are listed in Table 2.1.

Table 2.1. Sound Pressure Levels Associated with Different Sounds

Sound	Decibels (dB SPL)
Rocket launching pad	180
Jet plane	140
Gunshot blast	140
Riveting steel tank	130
Automobile horn	120
Sandblasting	112
Woodworking shop	100
Punch press	100
Pneumatic drill	100
Boiler shop	100
Hydraulic press	100
Can manufacturing plant	100
Subway	90
Average factory	80-90
Computer card verifier	85
Noisy restaurant	80
Office tabulator	80
Busy traffic	75
Conversational speech	66
Average home	50
Quiet office	40
Soft whisper	30

Noises over 140 dB SPL may cause *pain*. *Long exposure* to noises over 90 dB SPL may eventually harm hearing.

Audiometric Reference Levels

Sound Pressure Level

Stimulus levels in pure tone audiometry may be stated with reference to *sound pressure level* (SPL), *sensation level* (SL), or *hearing level* (HL). From the discussion of the decibel it may be recalled that the standard reference for pressure is $0.0002 \text{ dynes/cm}^2$ or the standard reference for power is 10^{-16} W/cm^2 . Whenever decibels are discussed in terms of the pressure standard they are given as dB SPL. A 50 dB SPL tone is 50 dB above the reference pressure, $0.0002 \text{ dynes/cm}^2$. Occasionally, steady state industrial noise or audiometric masking noise will be specified in SPL.

Hearing Level

Audiometric test tones are specified in *hearing level* (HL) rather than SPL because the normal ear is not equally sensitive to low- and high-pitched tones. According to current standards (ANSI, 1969) it takes 39 dB more SPL for the normal ear to barely hear a 125 Hz tone than it does for it to barely hear a 1000 Hz tone. Since it is desirable to have a 0 dB dial

reading at the point where the normal ear can just barely hear the stimulus, regardless of frequency, the audiometer has been designed to compensate for differences in hearing sensitivity as a function of frequency.

If 0 dB HL is set on the attenuator dial, the sound pressure generated by the audiometer will automatically change, whenever the frequency selection dial is rotated to select a different test frequency. Table 2-2 shows how many decibels SPL is required at each frequency to achieve 0 dB HL according to current as well as past standards.

Table 2-2. Number of Decibels at Each Frequency to Achieve 0 dB HL

Frequency (Hz)	Present Standard (ANSI - 1969, same as ISO, 1964) dB re 0.0002 dynes/cm ²	Past American Standard (ASA - 1951) dB re 0.0002 dynes/cm ²
125	45.5	54.5
250	24.5	39.5
500	11.0	25.0
1000	6.5	16.5
1500	6.5	
2000	8.5	17.0
3000	7.5	
4000	9.0	15.0
6000	8.0	
8000	9.5	21.0

Sensation Level

Sensation level (SL) is another way to refer to stimulus intensity. Its reference is the threshold of the individual being tested. Thus, 30 dB SL means 30 dB above the individual's threshold for test stimulus, whether it be tone or some other type of sound.

The term SL often is used to specify the level at which speech discrimination tests are administered. For instance, if an individual's speech reception threshold is 40 dB HL, a speech discrimination test administered at the 30 dB sensation level will be given at a hearing level (HL) of 70 dB. If his speech reception threshold was 10 dB HL, the speech discrimination test would have to be given at the 40 dB hearing level to meet the condition of a 30 dB SL presentation.

The SISI test, which employs pure tones, is usually administered at the 20 dB sensation level.

Summary

Zero decibels SPL is equivalent to a sound pressure level of 0.0002 dynes/cm²; zero dB intensity level is equivalent to 10⁻¹⁶ W/cm².

Zero decibels HL (audiometric zero) has different sound pressures for different frequencies. This is because the normal ear requires less sound pressure to make a tone audible in the middle frequencies than in the very low or very high frequencies. For example,

zero dB HL for 250 Hz is 24.5 dB above 0.0002 dynes/cm² (24.5 dB SPL), while zero dB HL for 2000 Hz is 8.5 dB above 0.0002 dynes/cm² (8.5 dB SPL). To simplify the appearance of an audiometric curve, the audiometer is set such that zero dB for each frequency does not generate zero dB SPL (0.0002 dynes/cm²) but produces the necessary energy to be just audible to the normal subject. Hence, the zero dB on the audiometric dial is not zero dB SPL or 0.0002 dynes/cm² but rather the threshold of normal subjects. For example, a patient whose threshold at 500 Hz is 30 dB has a threshold that is 30 dB higher than that of normal subjects at 500 Hz but not 30 dB higher than 0.0002 dynes/cm².

Sensation level (SL) for auditory stimulus is based on the individual's threshold for that stimulus whether the hearing is normal or impaired. The 20 dB SL for a 500 Hz tone in a person who has an audiometric threshold of 50 dB HL for the 500 Hz tone is 70 dB HL.

Review of Standard Audiometric Test Battery

There are several standard test procedures included in the audiometric test battery, all of which provide the otolaryngologist with valuable information regarding the integrity of the ear and the hearing mechanism. A brief description of the standard audiometric test battery follows.

1. *Standard pure tone air-conduction and bone-conduction* testing provides information regarding the nature and degree or severity or both of hearing loss. It can determine whether the hearing loss is conductive if an air-bone gap is present, or sensorineural if there is no evidence of an air-bone gap. The configuration or shape of the hearing loss can be classified from these results, i.e. flat, low frequency, or high-frequency hearing loss.

2. *Speech reception threshold (SRT) and speech discrimination testing (SD) testing* may be performed using live-voice or tape-recorded presentation of standard *spondee* word lists (Table 2-3) for SRT, and standard *phonetically balanced* word lists (Table 2-4) for SD testing. The SRT is one means of determining the reliability of pure tone test results, since the *pure tone average(s)* should coincide with SRT(s). The *speech discrimination* score provides information about the clarity of speech stimuli at loudness levels relatively comfortable to the listener. If phonemic regression or presbycusis is evident, or if the pure tone configuration indicates hearing loss (especially in the high frequencies), speech discrimination scores may be poor.

Table 2-3. Adult Spondee Word (Familiarization) List

airplane, armchair, baseball, birthday, cowboy, daybreak, doormat, drawbridge, duckpond, eardrum, farewell, grandson, greyhound, hardware, headlight, horseshoe, hotdog, hothouse, iseberg, inkwell, mousetrap, mushroom, northwest, oatmeal, padlock, pancake, playground, railroad, schoolboy, sidewalk, stairway, sunset, toothbrush, whitewash, woodwork, workshop.

Table 2-4. Adult Phonetically Balanced Word List (Sample)

CID 1A: an, yard, carve, us, day, toe, felt, stove, hunt, ran, knees, not, new, low, owl, it, she, high, there, earn, twins, could, what, bathe, ace, you, as, wet, chew, see, deaf, them, give, true, isle, or, law, me, none, jam, poor, him, skin, east, thing, dad, up, bells, wire, ache.

CID 2A: your, bin, way, chest, then, ease, smart, gave, pew, ice, odd, knee, move, now, jaw, one, hit, send, else, tear, does, too, cap, with, air, and, young, cars, tree, dumb, that, die, show, hurt, own, key, oak, new, live, off, ill, rooms, ham, star, eat, thin, flat, well, by, ail.

3. *Tympanometry*, which will be discussed in greater detail in a later chapter, is an objective test used to indicate the integrity of the middle ear system. There are three basic tests performed:

a. *The tympanogram* is a graphic representation of the function of the tympanic membrane and middle ear system. It will indicate a type A (normal) tympanogram if the tympanic membrane and ossicles are intact and if there is no evidence of middle ear effusion. The type B (flat) tympanogram can indicate the presence of middle ear effusion or a tympanic membrane perforation. A type C (negative-pressure) tympanogram will show the degree of negative pressure present in the middle ear, which may indicate eustachian tube dysfunction.

b. *Stapedial reflex* testing is performed to show the hearing level at which the stapedius muscle will contract, changing the impedance of the middle ear. The results of this test may indicate normal function, absence of the reflexes due to middle ear pathology, reflexes at levels higher than normal (hearing loss), or reflexes at levels lower than normal (possible recruitment with hearing loss). Other stapedial (acoustic) reflex tests may be performed to determine the presence of cochlear vs. retrocochlear hearing loss, such as *ipsilateral reflex* testing and *acoustic reflex decay* testing.

c. *Eustachian tube* testing may be performed in the presence of an intact tympanic membrane or with perforated tympanic membranes and myringotomy tubes. The most common test used with perforated tympanic membranes or myringotomy tubes is the *swallow test*, by which pressure equalization should occur with normal eustachian tube function. When there is an intact tympanic membrane, the presence of a type C (negative pressure) tympanogram is a good indication of the presence of eustachian tube dysfunction.

The above tests are part of the standard audiometric test battery and can provide the otolaryngologist with reliable information in a relatively short period of time. Further discussion of the implications of these tests will appear later in this chapter, and in other chapter.

Special Audiometric Tests

Special audiometric tests are performed to provide information over and above standard pure tone audiometry. These special tests provide "differential diagnosis" regarding cochlear vs. retrocochlear hearing loss, thereby providing the site of the lesion. The following tests are usually performed as a battery, not individually.

Bekesy's Audiometry

Thresholds are obtained automatically using pulsed and continuous tones. The audiometer automatically sweeps across the frequency ranges while the patient controls the intensity of the pure tones with a switch, attempting to maintain threshold. Thresholds are recorded on a graph. The pulsed and continuous tone threshold graphs are compared as indicated by five types of configurations.

Type I

Pulsed and continuous tracings interweave with each other across all frequencies; associated with normal/conductive hearing loss.

Type II

Pulsed and continuous tracings interweave through approximately 1000 Hz, but then the continuous tracing drops to about 20 dB poorer below the pulsed tracing. Associated with *cochlear* site of lesion.

Type III

Pulsed and continuous tracings interweave in the low frequencies only, then the continuous tracing drops to more than 20 dB poorer below the pulsed tracing. The continuous tracing may exceed the limits of the audiometer. Associated with *retrocochlear* site of lesion.

Type IV

Pulsed and continuous tracings never interweave, with the continuous tracing always poorer (to audiometer limits) than the pulsed tracing. Associated with *retrocochlear* lesion.

Type V

Pulsed and continuous tracings are separated, with the continuous tracing better than the pulsed tracing; associated with nonorganic or functional hearing loss.

Tone Decay Testing

This testing is utilized to determine the presence of retrocochlear hearing loss. Continuous pure tone stimuli are used to measure adaptation at threshold. With tone decay present, it becomes necessary to increase the intensity of the stimulus to keep it audible at threshold. Persons with retrocochlear lesions exhibit rapid tone decay, 30 dB of tone decay in 1 minute being considered marked decay. Several tests are used, including the Carhart's and the Rosenberg's tests. In these tests, the difference between threshold and the level at which the patient finally heard the tone for a full 1 minute indicates the amount of tone decay.

Suprathreshold Adaptation Test (STAT)

The STAT is similar in nature to conventional tone decay tests, but is performed at 110 dB SPL at 500, 1000, and 2000 Hz. The premise that symptoms of abnormal tone decay first appear at the highest testable sound intensities is the basis for the STAT. If the patient can hear the tone for a full 1 minute the test is negative for retrocochlear pathology. If he cannot hold the tone for 1 minute, the results are considered positive for the presence of a retrocochlear lesion.

Performance: Intensity Function for Phonetically Balanced Words (PIPB Function)

In this test, PB word lists are presented in 10-20 dB steps above the SRT. Scores should improve with increases in intensity; PB scores will improve until a maximum score or PB max is obtained, at which point the score will not change significantly with further increases in intensity. Scores are not expected to change more than 19% once PB max is reached. However, when presentation levels are increased, the individual with a retrocochlear lesion will show reduced speech discrimination scores (greater than 20% change) after PB max is obtained. This is termed "rollover" phenomenon. When scores rollover *exactly* 20% the results are questionable.

Short Increment Sensitivity Index (SISI)

The SISI is a test which assesses the ability of an individual to detect 1 dB intensity increments at 20 dB SL. It is based on the difference limen for intensity. Persons with a cochlear site of lesion are able to detect a 1 dB increment. A continuous pure tone is presented monaurally at 20 dB SL in regard to pure tone threshold at that frequency. Periodically, 1 dB increments are superimposed on the continuous tones. The patient signals every time he hears the increment. Normal individuals and those with retrocochlear lesions are not able to detect the changes in intensity. Those with cochlear hearing loss can easily detect the increments, showing high scores on this test.

0-30% detection: normal or noncochlear (negative results)

30-60% detection: questionable results

60% detection or better: cochlear pathology (positive results).

Alternate Binaural Loudness Balance (ABLB)

This test for recruitment is generally performed when one ear is within normal limits and the impaired ear is at least 20 dB poorer at the test frequency. The patient indicates when a presented stimulus sounds equally loud to both ears. Recruitment is an abnormal growth in loudness, and is evident when the perceived loudness of the signal grows more rapidly in the affected ear, than in the normal ear. Recruitment is usually manifested in pathologies associated with acoustic trauma, ototoxic drugs, Ménière's disease, and indicates cochlear pathology.

1. *No recruitment*: Between ears, equal loudness at equal sensation levels (SL).
2. *Complete recruitment*: Between ears, equal loudness at equal hearing levels (HL).
3. *Partial recruitment*: Between ears, equal loudness occurs in-between the above.
4. *Derecruitment*: Equal loudness occurs with 10 dB or greater sensation levels (SL) in the poor ear than in the good ear: retrocochlear lesion.
5. *Interpretation*: Results are reported as (a) normal or cochlear, (b) retrocochlear, or (c) questionable. If performance climbs to a maximum and then remains there or declines less than 20% as intensity is increased above the level yielding the maximum percentage correct, results are reported as *normal or cochlear*. If performance declines more than 20% when intensity is raised above the level yielding maximum performance, results are reported as retrocochlear. Questionable findings are indicated in those subjects who rollover exactly 20%.

Glycerol Test for Ménière's Disease

Pretest restrictions: NPO for 6 hours before test, no sedatives, tranquilizers, strong analgesics, antivertiginous medications for 48 hours before the test. Caution should be exercised in patients with cardiovascular disorders, diabetes, and gastrectomy surgery.

Dosage: 1.2 mL of 95% glycerin per kilogram in an equal volume of saline with several drops of lemon juice. *Audiologic testing* consists of *pure tones* (AC and BC), *SRT*, and *PB-max* (NPO during test).

1. Preingestion of glycerol.
2. One hour postingestion.
3. Two hours postingestion.
4. Three hours postingestion.

Side Effects

1. Thirst (usual).
2. Headache (23%).
3. Nausea (37%).
4. Emesis (5%).
5. Drowsiness.

Positive Test

1. Fifteen decibels or more improvement at any one frequency or 10 dB or more improvement at two or more frequencies between 250 Hz and 2000 Hz.
2. Twelve percent or more improvement in PB max.
3. Ten decibels or more improvement in SRT.

The test is inaccurate for minimal loss.

Functional Hearing Loss

Functional hearing loss, also called nonorganic hearing loss, psychogenic hearing loss, malingering, and pseudohypoacusis, describes a hearing loss which has no organic etiology. When a patient exaggerates a hearing loss, several indications will be present. It is necessary for the audiologist to be aware of the situation and attempt to determine the true hearing level.

Functional hearing loss becomes evident when the individual does not respond consistently to pure tones, when pure tone averages do not agree with *speech reception thresholds*, when the individual may use half-word responses for SRTs, and when the individual may use rhyming word responses during speech discrimination testing, among other inconsistencies. Very often a functional hearing loss is presented only in one ear. A functional hearing loss also may be exaggeration or overlay of a true organic hearing loss. It is not always in the realm of the audiologist's or otolaryngologist's expertise to determine the cause for feigning a hearing loss, nor should they attempt to analyze the cause.

The following tests are used for determining the true hearing level.

Stenger's Test

Stenger's test is used when one ear presents a functional component. It will indicate the presence of functional hearing loss and approximate the true threshold of hearing. The basis for the Stenger test is the theory that when two tones of identical frequency are sounded simultaneously in each ear, an individual with normal hearing or equal bilateral hearing loss will be aware of only the louder tone.

Present a tone at 5 dB SL in the normal ear, and present the same tone to the suspected functional ear. Hold the intensity constant in the normal ear. Continuously increase the intensity to the suspected ear. The patient will continue to respond as long as he hears the tone if there is true hearing loss. If the suspected ear has a functional hearing loss, the tone will be heard in the "poor" ear as intensity is increased. Then he will stop responding to the tone, since he "shouldn't" be hearing in that ear. The intensity at which he ceases to respond is close to threshold.

The Stenger's test also may be performed with speech stimuli in the same manner as with pure tones.

Lombard's Test

Lombard's test is based on the principle that a speaker unconsciously tends to raise his voice when he is speaking in a noisy environment so that he may hear himself speak. Masking noise is introduced to the patient under headphones while he reads aloud. In a true organic hearing loss, the individual will not raise his voice because he will not hear the masking. With a functional hearing loss, he will increase the volume of his voice as the intensity of the masking increases in the affected ear. This may be performed on unilateral or bilateral functional hearing loss.

The Doerfler-Stewart Test

This test is used for detecting bilateral functional hearing loss. Spondee words are presented binaurally through headphones in the presence of masking noise. Normal individuals and those with true organic hearing loss can repeat spondee words when masking noise levels equal or slightly exceed the levels of speech signals. Those with functional loss may cease responding when the intensity of the masking noise is 10-15 dB less than the level of the spondees. Once, this was considered a strong test of functional hearing loss.

Delayed Auditory Feedback (DAF)

The DAF test uses a 0.2 second delay of the patient's voice when reading aloud. This slight delay will cause a disruption of fluency. The subject reads aloud into a microphone attached to a tape recorder. The recorder plays back the discourse through headphones on a 0.2 second delay. The intensity of the played-back speech is increased until the individual begins to speak in dysfluencies (since he can hear himself delayed). The level at which the dysfluencies begin may be considered close to SRT.

Evoked Response Audiometry (ERA)

The ERA test is a truly objective measure of hearing, based on transient changes in the electric activities of the central nervous system in the presence of sound stimulation. This evaluation requires no voluntary response from the patient, and will be discussed in greater detail in a later chapter.

Stapedial Reflex Testing

This is another objective test which may be helpful in estimating pure tone thresholds based on the levels at which the acoustic reflex is present compared to norms for normal hearing reflex thresholds.

Electrodermal Audiometry

Electrodermal audiometry is a test which used a slight electric shock to condition a reflex when pure tones were presented. Because of the questionable nature and unpleasantness of this method, it is rarely, if ever, used at this time.

Acoustic Trauma and Noise-Induced Hearing Loss

Temporary Threshold Shift (TTS)

This phenomenon is indicated by the human ear's ability to recover from brief exposure to loud sounds. When the ear is exposed to such sounds as machinery, explosions, and the like, the hearing threshold levels become poorer because of auditory fatigue. The recovery of normal thresholds is usually complete and occurs within 1 hour to 2 weeks, depending on the intensity of the sound source and on the length of noise exposure. This is a *temporary threshold shift*. The greatest shift is for tones about one-half octave above the exposure tone, but other higher frequencies may be affected as well. Usually low frequency hearing is not affected. This also has been shown in data showing that when the maximum energy is in the low frequencies, the TTS is less than when maximum sound energy is in the higher frequencies.

If the exposure is intermittent, the TTS is less. With more constant exposure, TTS becomes greater and may take more time to recover. This phenomenon applies to periodic exposure to loud sources.

Permanent Threshold Shift (PTS)

A PTS occurs over time in individuals who are exposed to high levels of noise without ear protection, and results in permanent (sensorineural) hearing loss. This shift in hearing depends upon the intensity and duration of exposure.

It is important to make the distinction between *acoustic trauma* and *noise-induced hearing loss*. The former refers to a sudden permanent or temporary hearing loss related to a brief exposure to an explosion-type sound. Noise-induced hearing loss results from exposure to high levels of noise for an extended period. The audiometric evaluations indicate a similar pure tone configuration, so a complete case history is imperative. However, noise-induced hearing loss is relatively permanent in nature.

The typical audiometric configuration in noise-induced hearing loss in the early stages shows normal hearing at 250-2000 Hz with a dip at 4000 Hz of varying degree, returning to normal in the higher frequencies. As this hearing loss progresses with more exposure to high noise levels, the frequencies surrounding 4000 Hz become more involved in the hearing loss, eventually resulting in a "ski slope" audiometric configuration.

Periodic hearing evaluations should be performed on those regularly exposed to high levels of noise, and on those who are no longer working in noise. However, a respite from noise exposure (at least 14 hours for industrial hearing screenings) is necessary to allow for recovery of any TTS overlay on a PTS.

OSHA Damage Risk Criteria

OSHA has developed standards for permissible durations of exposure without ear protection. These standards are printed in Table 2-5. However, they may be revised following more research from OSHA, whose industrial noise regulations recently have been in a state

of flux.

Table 2-5. OSHA Permissible Noise Exposure Levels

Duration/day (hr)	Sound Level (dBA)
8	90
6	92
4	95
3	97
2	100
1-1.5	102
1	105
0.5	110
0.25 or less	115.

It is known that noise-induced hearing loss can be prevented by reducing levels of noise exposure or time of exposure *and* by the use of personal ear protection, in the form of earmuffs or earplugs. Various manufacturers have developed disposable, reusable, custom-shaped and standard sized earplugs and more efficient earmuffs. These developments were made to encourage more use of personal ear protection by workers, but the number of individuals who prefer not to wear ear protection are staggering. Therefore, despite OSHA regulations and cooperation from employers regarding provision of ear protection and reevaluating hearing status regularly, many persons will still exhibit noise-induced hearing loss in the future.

Ear Protectors (Table 2-6)

Table 2-6. Attenuation in dB in the Various Frequencies (Hz)

Protection Type	250	500	1000	2000	3000	4000
Fluid						
sealed muffs	28	38	39	41	44	47
V-51R plug	11	13	19	27	30	25
Glass down	11	13	17	29	34	35
Waxed cotton	10	12	16	27	31	32
Dry cotton	3	4	8	12	14	12.

Four Thousand Hertz Dip (8-10 mm Region of the Cochlear Duct)

The 4000 Hz sensorineural dip is one of the principal audiometric features of a hearing loss resulting from excessive noise. There are basically three theories to explain this. One hypothesis is that the area of the organ of Corti responsive to 4000 Hz is highly susceptible to damage, possibly as a result of vascular insufficiency. The second hypothesis believes that the resonance characteristics of the ear canal produce the 4 kHz notch. The third view contends that the mechanical stress on the basilar membrane is excessive in the 4000 Hz region because of the mechanics of cochlear action. This latter explanation is based on the

asymmetric distribution of the amplitude of displacement of the basilar membrane. It is believed that the stress is due to the acceleration of the basilar membrane during stimulation. Acceleration of the basilar membrane is greatest at the basal end and becomes progressively less at the apical end. Greater losses for frequencies above 4000 Hz do not occur because there is less auditory sensitivity in that region. The mechanical hypothesis is preferred by a number of investigators since there is evidence from auditory fatigue studies that stimulation by a given level tone caused no greater auditory fatigue at 4000 Hz than at 1500 Hz. It also has been found that the recovery rate for 4000 Hz did not proceed less rapidly than at other frequencies.

Hearing Handicap

Hearing loss, and therefore the degree of hearing loss, may be described in several ways. It may be described in relation to decibels of hearing loss, and it may be described subjectively, i.e. mild, moderate, severe, or profound. It also may be described in relation to how well the hearing impaired individual can communicate in the everyday world. Table 2-7 (ASHA, 1981) shows several scales in common use for describing the degree of hearing loss in relation to the decibel levels involved.

Table 2-7. Scale of Hearing Impairment

Average Hearing Threshold Level in dB (re: 1969 ANSI)	Hearing Loss Label
10-15	Normal hearing
16-25	Slight hearing loss
26-40	Mild hearing loss
41-55	Moderate hearing loss
56-70	Moderately severe hearing loss
71-90	Severe hearing loss
91 +	Profound hearing loss.

Evidently the decibel levels and descriptors are not in agreement from one scale to the next. Hence, one particular audiogram may be described any number of ways using any scale above. The main point in describing hearing loss is consistency. The individual otolaryngologist or audiologist must be consistent in describing audiometric results in the same manner from one time to the next, and from one patient to the next. Once a pattern has been developed, it is important to maintain this same scale to keep consistent records. It is also helpful to describe the configuration of the audiogram, since this information can be useful, especially when looking at SRTs and speech discrimination scores.

One consistent, however controversial, method of measuring hearing impairment is the *AAO percentage of hearing impairment formula*, reproduced and explained in Table 2-8. This formula is currently acceptable for use in insurance and compensation claims. Controversy may arise because of the correction for age over 40 years, since it appears to assume a certain degree of hearing loss after that age. It has been maintained that the individual physician may choose to eliminate this section of the formula and only use the absolute hearing loss figures when describing the percent of hearing impairment.

Table 2.8. AAO Formula for Calculating Percentage of Hearing Impairment

The following formula is used for calculating the percentage of hearing impairment:

... dB HL Pure tone average (500, 1000, 2000, 3000 Hz)
 - 26 AAO limits
 ... dB HL Corrected hearing loss
 x 1.5
 ... % Percent hearing impairment - calculated for each ear
 separately. Then:

Better ear % x 5 = ... + Poorer ear % = ... / 6 = ... % for binaural loss.

If person is 40 years of age or less, it is not necessary to correct the above percentages for age. If over 40 years of age, the following correction formula is used:

(Age - 40) x 0.5 = ... Correction factor in dB (0.5 dB/yr over 40 years old).

Then:

... dB HL Corrected hearing loss (from initial calculation).
 - ... dB Correction factor
 = ... dB Adjusted hearing level
 x 1.5
 = ... % Adjusted percent hearing impairment - calculated for each ear
 separately. Then:

Better ear % x 5 = ... + Poorer ear % = ... / 6 = ... % for binaural loss.

It is important to note at this point that the former scales indicate descriptors of the hearing loss in question and may be more useful from a (re)habilitative point of view insofar as the estimation of communication ability. The *AAO percentage of hearing impairment formula* represents an absolute number value of the hearing loss. Therefore, in certain instances one method would be more useful than the other.

Testing Infants and Children

Until age 2 years the human infant does not respond to sound stimuli in the same manner as the older child or adult. The human infant, although it may have normal hearing, does not respond to the softest sounds it can hear, or to the softest sounds to which the adult can respond. Much research has been conducted to obtain normative data, as reproduced below. It is possible to test infants in the sound field using the data present. Infant localizations to sound sources also mature.

Attempts have been made at maintaining infant *high-risk registers* in hospitals for identifying neonates at risk for hearing loss. Difficulties arise with identifying and testing large numbers of at-risk infants before discharge. Methods of weeding out those infants who must be screened are still being developed. The use of portable auditory screeners in the

nursery is now being eliminated with the further development of *brain stem evoked response (BSEER)* audiometry. This relatively quick and efficient test can provide full information regarding the neonate's hearing, and will be discussed in detail in a later chapter. The largest problem with the *high-risk registry* is follow-up. It is imperative that once an infant has been identified as hearing impaired or has failed an initial hearing screen, he should be reevaluated at a later date for more complete results and prognosis for amplification as soon as possible.

The main purpose of the *high risk register* and other similar early screening programs is to provide early identification of hearing loss for early amplification. The later the child is identified as being hearing impaired, the later he will be amplified. This results in later language development. It is vital to the child's early development that sound stimulation be provided in the form of amplification (or other appropriate method) as *soon as possible*.

Hearing Aids

After any patient has been identified as having a hearing loss and as a candidate for amplification, the otolaryngologist may perform the following functions in counseling the patient:

1. The physician may describe the audiometric results (pure tones, SRT, speech discrimination scores relative to normal communication), and the patient's prognosis for success with amplification.
2. The physician may discuss binaural vs. monaural amplification with the prospective candidate. Very often the financial aspect may prevent binaural amplification. In other situations, binaural hearing aids are necessary, especially when they involve infants and children.
3. The patient may query regarding a behind-the-ear vs. an in-the-ear fitting. In many cases, an in-the-ear hearing aid would be most appropriate, but most often a behind-the-ear hearing aid is chosen. Discussing this may be left to the audiologist or hearing aid dispenser involved, whose experience may dictate the type of fitting to be attempted.
4. As a general rule, the better ear would be fitted with a hearing aid, or at least the ear with the better speech discrimination score. This rule is not steadfast, and may change with different patient situations and needs.

Basically, a hearing aid consists of three parts:

1. Microphone: Changes sound energy into electrical energy.
2. Amplifier: Amplifies the converted electrical energy.
3. Receiver: Converts the amplified electrical energy back into sound energy.

The hearing aid's main function is to amplify all sounds. It makes things louder, not necessarily clearer. Therefore, it is necessary for the new hearing aid user to experience an adjustment period with this new hearing aid. The wearer must become accustomed to listening

again, and to hearing the new sounds which the hearing aid is amplifying. He needs to weigh his expectations for amplification with the actual result he has achieved. It is important that the otolaryngologist and audiologist work with the wearer cooperatively when handling and counselling regarding amplification, so that he can become comfortable with amplification.

Depending upon the nature and severity of the hearing loss, how long the patient has been hearing impaired, and the type and intensity of counseling the patient received before, during, and after evaluating hearing aids, his prognosis for successful use of amplification can be very good. More persons who previously had been told that they could not be helped by amplification are successfully wearing hearing aids. The numbers can become better with more intensive counseling and acceptance of amplification in the future.

Table 2-9. Enzymes Found in the Organ of Corti and Stria Vascularis

Succinate dehydrogenase
 Cytochrome oxidases
 Diaphorases (DPN, TPN)
 Lactic dehydrogenase
 Malic dehydrogenase
 Alpha-glycerophosphate-dehydrogenase
 Glutamate dehydrogenase.

Table 2-10. Normal Labyrinthine Fluid Values

Na mEq/L	141	141	157	147	6	14.9	153
K mEq/L	5	3	3.8	10.5	171	155	8
Cl mEq/L	101	126	-	-	120	120	-
Protein mg%	7000	10-25	215	160	125	-	5200
Sugar mg%	100	70	85	92	9.5	39.4	-
pH	7.35	7.35	7.2	7.2	7.5	7.5	-.

Table 2-11. Electric Potentials of Ear Components

A.	Endocochlear potential	Scala media + 80 mV
	Endolymph potential	Scala vestibuli + mV
	Resting potential	Scala tympani 0
	DC potential	Hair cell and cortilymph - 80 mV
		Endolymphatic sac (+)
		Cells of Hensen and Claudius (-)

B. Action potential of the nerve.

C. Cochlear microphonics (due to stimulation of outer hair cells).

D. Summation potential (due to stimulation of inner hair cell and is more significant in higher frequencies).

(The recording of endocochlear potential and summation potential requires an intracochlear electrode while the action potential of the nerve and cochlear microphonics can be picked up with a round window electrode).