8

HEARING MEASUREMENT

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8.1. INTRODUCTION (RATIONALE FOR AUDIOMETRY)

The audiogram is a picture of how a person hears at a given place and time under given conditions. The audiogram may be used to describe the hearing of a person for the various frequencies tested. It may be used to calculate the amount of hearing handicap a person has. And, it may be used as a tool to determine the cause of a person's hearing loss. Audiograms may be obtained in many ways; e.g., by using pure tones via air conduction or bone conduction for behavioral testing or by using tone pips to generate auditory brainstem responses.

The audiogram is a most unusual biometric test. It is often incorrectly compared to a vision test. In the audiogram, the goal is to determine the lowest signal level a person can hear. In the case of a vision test, the person reads the smallest size of print that he or she can see, the auditory equivalent of identifying the least perceptible difference between two sounds. In most occupational and medical settings, this requires the listener to respond to very low levels of sounds that he or she does not hear in normal day-to-day life. A vision test analogous to an audiogram would require a person to sit in a totally darkened room and be tested for the lowest luminosity light of various colors, red to blue, that can be seen.

The most basic audiogram is a screening test such as is used in the schools. A series of tones at fixed levels are present and the listener indicates which he or she can hear. The levels are set so that those who hear them should have hearing within normal limits and those who don't are referred for a threshold audiogram. The threshold audiogram produces a picture of how a person hears air-conducted signals, such as pure tones. A person sits in a quiet environment, listens for pure-tone pulses (beeps), signaling when they are heard. The test consists of presenting these beeps as varying intensities for different test frequencies, recording at each frequency the lowest intensity at which there are responses from the listener. At no other time during day-to-day life are people presented with perceptual tasks of similar demand.

8.1.1. Audiometry for Monitoring/Compliance

The same type of threshold audiometry is used to monitor the individual worker's response to noise exposure. A baseline audiogram is obtained before the worker is exposed to potentially

hazardous noise, periodically during the exposure times, and at the end of the worker's exposures. Permissible exposure levels, the amount of time a worker may be exposed to noise without the necessity of engineering controls to reduce the noise, removing of the worker from the noise, or requiring that the worker use hearing protection, are founded on the maximum acceptable excess risk level of developing hearing impairment. These risk estimates are based on pure-tone air-conduction audiograms. As an example, based on available data, the National Institute for Occupational Safety and Health (NIOSH 1996) calculates that 15% of workers exposed to noise levels of 85 dB(A) $L_{Aeq,8h}$ will develop hearing impairment over their lives.

Table 8.1.   Comparable American National Standards Institutes and International Standards audiometric standards.

Topic Area	ANSI Standard	ISO Standard
Audiometer Calibration	S3.6-1996 Specifications for Audiometers	ISO 8253 Audiometric Test Methods - Part 1 (1989): Basic Pure Tone and Bone Conduction Audiometry; Part 2 (1991): Sound Field Audiometry; Part 3 (199x): Speech Audiometry ISO 389-1985: Acoustics - Standard reference zero for the calibration of pure tone air conduction audiometers and Addendums 1, 2, and 3 IEC 60645-Part 1 (1987) Pure Tone Audiometers: Part 2 (199x) Equipment for speech audiometry, Part 3 (199x) Specifications of reference audiometric test signals of short duration, Part 4 (199x) Equipment for extended high frequency audiometry
Test Room Noise Levels	S3.1-1991 Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms	ISO 8253(1) 1989 Audiometric Test Methods - Part 1: Basic Pure Tone Air and Bone Conduction Audiometry ISO 6189-1983 Acoustics-Pure Tone Air Conduction Threshold Audiometry for Hearing Conservation Purposes
Sound Level Meters	S1.4-1983 (1990) American National Standard Specification for Sound Level Meters; S1.4A-1985 Amendment to ANSI S1.4-1983; S1.25 American National Standard for Personal Noise Dosimeters; S1.43-1997 American National Standard Specification for Integrating-Averaging Sound Level Meters	IEC 60651 (1979) IEC 60804 (1985)
Estimation of Noise-Induced Hearing Loss	S3.44-1997	ISO-1999 (1992)

($L_{Aeq,8h}$ is the equivalent noise level for an 8-hour exposure when the exchange rate is 3 dB. 88 dB(A) for four hours equals 85 dB(A) $L_{Aeq,8h}$ while 91 dB(A) for two hours is the same as 85 dB(A) $L_{Aeq,8h}$.) NIOSH defines hearing impairment as a pure-tone average in either ear for the audiometric test frequencies of 1000, 2000, 3000, and 4000 Hz that exceed 25 dB HTL (Hearing Threshold Level or Hearing Loss) re ANSI S3.6-1996, *Specifications for Audiometers*. See Table 8.1 for a listing of ANSI standards and comparable ISO and IEC standards.

In the United States, the Hearing Conservation Amendment of the Noise Standard of the Occupational Safety and Health Administration (OSHA 1983) requires employers to obtain baseline audiograms for all workers exposed to noise levels at or above the time-weighted average for eight hours (TWA_8) of 85 dB(A). (OSHA's TWA_8 is based on a 5 dB exchange rate with 90 dB(A) for four hours equal to a TWA_8 of 90 dB(A) and with 100 dB(A) for two hours equal to a TWA_8 of 90 dB(A). OSHA further requires that all exposed workers receive audiometry once per year for the duration of their work life in noise of 85 dB(A) TWA_8. Each worker's annual audiogram is compared to his or her baseline audiogram to check for changes in hearing that might have been related to the noise exposure. OSHA sets no time limit from administering the annual hearing test to comparing the results to the baseline audiogram (allowing up to a year in cases where mobile hearing services are used). OSHA requires that if a change of hearing of sufficient magnitude has occurred, the employer must take certain actions to avoid further worsening of hearing for the worker. This type of hearing testing program; i.e., regimental application of baseline and annual hearing tests according to the requirements of the OSHA, is referred to as monitoring audiometry for the purposes of compliance.

8.1.2. Audiometry for Intervention/Prevention

NIOSH recommends a more assertive use audiometry; e.g., one that is driven less by monitoring for hearing loss and driven more by hearing loss prevention. NIOSH recommends that all workers exposed to noise levels at or above 85 dB(A) $L_{Aeq,8h}$ receive audiometry. (NIOSH 1996). In addition to the baseline audiogram, which is preceded by a 12-hour period of no exposure to loud occupational or other noise, NIOSH recommends an annual test for workers whose exposure levels are less than 100 dB(A) $L_{Aeq,8h}$ and testing every six months for those workers who exposure levels are equal to or greater than 100 dB(A) $L_{Aeq,8h}$.

While OSHA requires that the baseline audiogram be administered following a quiet period, there is no regulatory guidance about quiet periods preceding annual audiograms. NIOSH recommends that annual audiograms be obtained during the work shift, preferably at the end of the work shift, to observe any temporary threshold shift the worker may have. NIOSH recommends immediate retesting of employees who do show a shift in order to validate the audiogram. If the change in threshold remains on the retest audiogram, NIOSH recommends providing a confirmation test which is preceded by quiet. For workers whose threshold shift was determined to be temporary by the confirmation audiogram, NIOSH encourages interventions that reconsider the exposure conditions, the adequacy of the hearing protection, and the worker's training. For workers whose threshold shift was determined to be permanent, NIOSH recommends ruling out etiologies other than noise and if the threshold shift is noise related, removing the worker to a quieter work environment or, at a minimum, one-on-one training in the fitting and use of hearing protectors.

Because the frequency of periodic audiograms is dependent upon the noise exposure level, and the testing paradigms are designed to identify and respond to temporary threshold shift, this type of audiometry is referred to as prevention driven. In an effective program, each worker at

risk of developing permanent threshold shift would be identified early by responding to the situation that produced a temporary threshold shift with the goal being to prevent any future temporary threshold shift. Elimination of temporary threshold shifts prevents permanent threshold shift, and thus prevents hearing loss due to noise exposure.

The rest of this discussion of hearing measurement will be based upon a prevention, rather than compliance, model.

8.2. ELEMENTS OF AUDIOMETRY

8.2.1. The Test Environment

Because audiometry requires determination of the lowest signal level that a person can hear, the audiometric test environment is very important. The audiometric test environment includes the space in which the test is administered, the instruments used to administer the test, and conditions under which the test is administered.

8.2.1.1. Noise levels

In a perfect hearing test, the lowest signal level to which a person responds will reflect only the limitations of his or her own auditory system. In many cases, however, auditory thresholds actually reflect the lowest signal that the person can hear against the background noise that is present in the test environment.

Every audiometer calibration standard either includes or references a corresponding standard for maximum permissible ambient noise levels for testing to audiometric zero. In the United States, the standard for audiometric zero is ANSI S3.6-1996 and the standard for maximum permissible ambient noise level is ANSI S3.1-1991. Audiometers calibrated according the ANSI standards or the corresponding ISO standards will make it possible to test to 0 dB HTL for persons whose hearing is that sensitive. The maximum permissible ambient noise levels for ANSI S3.1-1991 are displayed in Table 8.2.

Table 8.2. Maximum permissible background noise level during audiometric testing: Accordance with ANSI S3.1-1991, OSHA table D-2 (1981), and OSHA table D-1 (1983). Levels shown are octave-band sound pressure levels (dB re 20 μPa) for ears covered with standard MX41/AR cushions.

Octave-Band Center Frequency	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
ANSI S3.1-1991 (Rounded to the nearest whole decibel)	22	30	34	42	45
OSHA Table D-2	27	30	32	42	45
OSHA Table D-1	40	40	47	57	62

It is important to note that the levels in Table 8.2 represent conditions when the earphone cushions that are specified by the standards are used. Also displayed in Table 8.2 are the maximum permissible ambient levels specified by the OSHA Hearing Conservation Amendment

(OSHA 1983). The OSHA levels are much higher, being based on audiometers calibrated to much older American Standards Association (American National Standard Specification for Audiometers for General Diagnostic Purposes, Z24.5-1951). OSHA had initially proposed that these higher levels from Table D-1 of the Hearing Conservation Amendment be used for two years until industry came into compliance with the Hearing Conservation Amendment, afterwards switching to the levels from ANSI S3.1-1991 with a 5 dB adjustment at 500 Hz (OSHA 1981). After successive stays and issuances of the regulation, only the levels in Table 8.2 remain. Audiometry that relies upon OSHA's specifications will be unable to test to levels below 15 dB HTL (Franks, Engel, and Themann 1992)

8.2.1.2. Controlling the test environment

There are many ways to control the test environment. The optimal test environment is quiet and free of distractions. There should be no activity outside the test room that the listener can see or hear. A person with normal hearing may be able to follow a conversation outside the test room even if the ambient noise levels meet the level specified by ANSI S3.1-1991. While audible speech would not mask the test tones, it would distract the listener, making a difficult test more difficult yet. There is no such thing as a "soundproof" test room; i.e., a room which no outside sound can penetrate. It is important that rooms are designed to attenuate nominal outside noise to the point where it won't mask the test signals, and it is just as important to not have unnecessary noise generating activities in the area of the test room.

8.2.1.2.1. Single-person test rooms. In most audiometric testing situations, the listener will be seated in a small sound-treated room just large enough to accommodate him or her. The room will have a door, a window through which the listener may be observed, as well as lighting and ventilation systems. These rooms are often prefabricated and either are delivered assembled to a test site or are assembled at the test site. Figure 8.1 displays a single-person test room along with the typical floor plans..

The standard "mini" booth usually arrives preassembled and has wheels so that it may be moved within a test site. The "mini" booth usually has a folding shelf attached under the observation window on which the audiometer and other items may be placed. The booth is referred to as "mini" because of its small interior: 0.72 m x 0.66 m x 1.50 m. It is fabricated from 5 cm- thick panels. The typical attenuation provided by a "mini" booth is shown in Table 8.3.

There is also a transportable "mini" booth which can be set up at one test site and, after testing is completed, taken down and moved to a new test site set up. This room also uses 5 cm-thick panels and has a window and a shelf as well as lighting and ventilation. It even comes with a carrying case that can be placed in the back of a station wagon or small truck. However, because of its set-up/take-down features, its attenuation is less than that of the standard "mini" booth. This booth was designed at the request of the airlines so that the hearing conservationist could fly to one airport, set up the booth, test airline personnel, take down the booth, and load it back on an airplane for transport to the next airport where testing was to be done.

Another type of single-station test room is the standard stationary booth that is assembled from 7.5 cm or 10 cm-thick panels. As with the mini booth, there is an observation window as well as ventilation and lighting. The interior is larger than the mini booth, 0.80 m x 1.0 m x 1.7 m. Because it is built of thicker and heavier panels, the attenuation is greater, as is shown
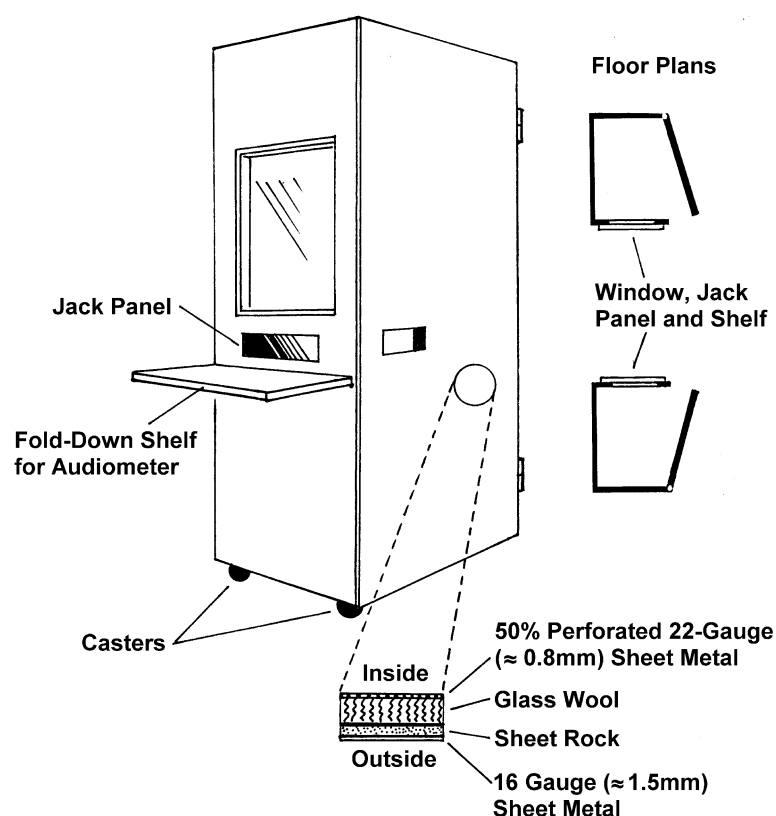
Figure 8.1. A typical "mini" sound booth.

in Table 8.3. In the stationary single booth, the ambient noise levels should be low enough to allow bone conduction testing with unoccluded ears as is specified in ANSI S3.1-1991. Stationary booths are quite rugged and have a use life of more than 30 years so long as the door gaskets and ventilation fans are replaced every four to five years. If there is significant vibration from the floor, the vibration isolators should also be replaced every four to five years.

Table 8.3. Representative noise reduction data of various thickness panel construction for audiometry testing rooms (dB).

1/1 octave-band center frequency

Panel thickness	125	250	500	1000	2000	4000	8000
10 cm panel	28	36	48	57	61	61	57
7.5 cm panel	24	31	71	46	55	55	52
5 cm panel	15	31	34	42	49	50	51
Transportable	12	26	27	27	30	35	35
Double walled	47	62	83	91	99	97	>91

8.2.1.2.2. Multiple-person test rooms. It is sometimes necessary to test more than one person at time. In some settings this may be accomplished by installing more than one test booth. In others, one larger booth may be set up capable of supporting multiple testing stations. Such booths may be large enough to accommodate testing as many as twelve persons at a time. Most, however, are built to accommodate six to eight persons simultaneously. These booths are most often constructed of 10 cm-thick panels. In the United States the most common users of multiple-station test booths are the military and mobile hearing conservation test providers. The multiple-station test booths are often built into trailers or trucks.

The drawback to multiple-station test booths is the potential distraction of listeners by those around them and the increased ambient noise levels created by having several persons in a small enclosure. Sometimes, persons with normal hearing can hear the high intensity test signals being presented to those with substantive hearing loss, making it difficult to determine to which tone they should respond. It is also difficult for the audiometrist to detect testing problems when they occur and it is difficult to intervene for one listener having trouble while others are completing their hearing test. Also, the time it takes to complete a hearing test when microprocessor audiometry is used will be different for each person, so it is necessary to have people who have completed the test remain seated and quiet while others are finishing.

The addition of curtains or panels to separate listeners in a multiple-person test booth would appear to be beneficial by reducing distractions. However, it also makes the space seem smaller and blocks the audiometrist's view of the listeners. When self-recording audiometry has been used in multiple-person test rooms, there have been cases when a person with a hearing loss enlisted the support of a "buddy" with good hearing to sit at an adjacent station. The "buddy" would press his own response switch and that of the person next to him, pressing both buttons when he heard the signals. As a result, his neighbor's audiogram showed good hearing when in fact that person had a severe high-frequency hearing loss. An open booth with good lighting set up so that the audiometrist and listeners have good two-way visual contact can inhibit such behaviors when multiple-person test booths are used.

8.2.1.2.3. Selecting the test area and the test booth. While an area with little traffic may seem to be the obvious location for a test booth, it is necessary to measure the ambient sound levels in the space before selecting a booth configuration. It will be necessary to choose a test booth with adequate noise reduction to ensure that the ambient noise levels are below those specified in ANSI S3.1-1991, as shown in Table 8.2. The best way to determine the booth specifications is to subtract the values for each panel thickness in Table 8.3 from the ambient noise levels measured where the booth will be used. The ambient noise levels in the areas intended for the booth should be measured when there is normal traffic and building activity. If the calculated values are below those in ANSI S3.1-1991, the booth should be adequate. If the calculated levels are higher than those in ANSI S3.1-1991, the booth will not be adequate and a thicker-walled structure will be needed.

In some unusual settings a double-walled booth may be needed. This is a "booth within a booth" with both booths constructed from 10 cm-thick panels. Because these structures are very heavy, the floor of the building where they will be assembled must be rated for loads of 45 kilograms or higher. Typical noise reductions for a double-walled room is shown in Table 8.3.

8.2.1.3. Noise-reducing earphone enclosures

The standard earphone assembly in the United States uses an MX41/AR supra-aural earphone

cushion. "Supra-aural" means that the cushion sits on the pinna. Compared to a circum-aural cushion, the MX41/AR cushion has many leaks and is not a good attenuator of external sounds. Nevertheless, the maximum permissible noise levels of ANSI S3.1-1991 and the calibration values of ANSI S3.6-1996 are based on the use of the MX41/AR cushion. Changing to a different cushion or placing a shell around cushion changes both the attenuation and calibration of the earphone assembly. Therefore, NIOSH recommends that noise-reducing earphone enclosures not be used. OSHA will issue a deminimus citation when they are used in a test booth with ambient noise levels that meet the OSHA maximum allowable ambient noise levels or a serious citation when they are used in place of a test booth that meets OSHA's ambient noise limits.

In spite of all the reasons against using noise-reducing earphone enclosures, they are fairly common. There are three enclosures in use at present. They are the Aural Dome, the Amplivox Audiocup, and the Madsen/Peltor Audiomate. All three accommodate the Telephonics TDH series earphones and MX41/AR cushion. They replace the earphone assembly headband and provide an outer earcup with a circumaural cushion that seals around the ear much as a noise reducing circumaural earmuff provides a seal around the ear. Since these devices essentially place the standard earphone/cushion inside an earmuff, it would seem that they ought to reduce ambient noise levels, making a quieter situation for testing at low hearing levels while not changing calibrations. Unfortunately, they don't effectively reduce ambient noise and they do affect calibration.

Studies by Franks, Merry and Engel (1989) found that Audiocups have insufficient attenuation in the low frequencies where test booth noise levels are usually the highest. Frank and Williams (1993a) found that if one is using the OSHA maximum permissible ambient noise levels, the real-ear attenuation at threshold of the Audiocup is insufficient to enable testing down to 0 dB HL. Other studies have found that while the earphone may be calibrated while in the enclosure, use of the enclosure has an effect on hearing thresholds at 3000 and 6000 Hz (Frank and Williams, 1993b). Flottorp (1995) studied placement of the earphone cushion, finding large changes in hearing thresholds at 3000 and 6000 Hz for placements common in occupational hearing conservation test settings. Because noise-reducing earphone enclosures cover the earphone and cushion, it is not possible to ascertain the exact placement of the earphone and cushion and the exact alignment of the earphone and the ear canal opening when noise-reducing earphone enclosures are used.

New active noise-reducing earphones that have pass throughs for communication and warning signals are presently being studied. It is conceivable that the noise-reducing circuitry can be used to reduce low-frequency (< 1000 Hz) noise levels. However, none of the active noise reduction headsets are able to employ the MX41/AR cushion, and so a great deal of laboratory work would be necessary before these systems could be found to be suitable for use in hearing testing.

8.2.1.4. Documenting ambient noise levels in the test booth

Test room ambient noise levels should be measured during the normal course of business in the audiometric testing area. For example, if the testing area is in an occupational health setting, ambient noise levels should be measured while other normal activities of the setting are underway with the exception of having a person inside the test booth. The booth ventilation and lighting systems should be turned on as well. Most modern sound level meters meeting the specificationsof type II (ANSI S1.4-1983) should be capable of measuring these noise levels. It

may be easier to mount the sound level meter on a tripod than to hold it while taking readings.

Noise levels should be measured in octave bands. It is not sufficient to take an A-scale or C-scale reading. Octave band filters should meet the Class II requirements of ANSI S1.11-1966 1971), *Specifications for Octave, Half-Octave, and Third-Octave Band Filter Sets*. Once the octave-band levels have been measured, the C-scale measurement may be taken and used to monitor the ambient noise levels as any change in the octave-band levels will be reflected in the C-scale reading.

For a fixed facility, although there is no regulatory guidance, it should be adequate to measure the test room ambient noise levels annually. For mobile facilities, ambient noise levels should be taken daily or whenever the facility is relocated, whichever is most frequent (NHCA 1996). The noise levels should be kept as part of the record keeping system and should also be recorded on each audiogram. Additionally, the make, model and serial numbers of the sound level meter, octave-band filter set, and calibrator should be kept along with the calibration date of each instrument.

Sometimes, it may be necessary to perform audiometry even when the test room ambient noise levels are higher than specified by the standards. At such times, it will not be possible to test to audiometric zero at the frequencies for which the noise levels are too high. The audiometrist should make certain to annotate each audiogram with a statement that the minimum test hearing level could not have been zero. For example, if the octave-band ambient noise level at 1000 Hz was 40 dB SPL instead of the 30 dB SPL specified by the standard, the note would say that hearing thresholds of less than 10 dB HL at 1000 Hz were unreliable.

8.3. PURE-TONE AUDIOMETRY: AUDIOMETERS AND METHODS

The pure-tone air-conduction audiogram allows determination of the lowest sound levels a person can hear at given test frequencies. The entire auditory system, from ear canal to auditory cortex, is tested. There are various testing methods and instrument types for determining these levels. The methods are all based on presenting to the listener sound levels from just audible to just inaudible. The listener's threshold is somewhere between these two levels. When a testing program is established, a method is selected and an audiometer for applying that method is chosen.

There are three main testing methods: manual audiometry, self-recording audiometry, and microprocessor-controlled audiometry. Each method has its own instrumentation requirement so that a manual audiometer cannot be used for self-recording, just as a self-recording audiometer cannot be used for manual or microprocessor-controlled audiometry. Thus, once a testing method has been selected, the choice of audiometer to use will be limited to the set of instruments which perform that test method. Most microprocessor-controlled audiometers may be used for manual testing.

There are differences in thresholds determined by the various testing methods. It is very important that once a method is selected for a test site or for a group of workers, the method be used consistently. If one were to test a group of workers one year by microprocessor-controlled audiometry, by manual audiometry the next year, and by self-recording audiometry the following year, there would be apparent changes in the workers' hearing that actually were due to the change of testing methods. Thus, it would be more difficult to detect true changes in workers' hearing due to noise exposure.

8.3.1. Manual Audiometry - The Benchmark

Manual audiometry is the standard for clinical testing. The signal frequency, intensity, and presentation are controlled by the tester. The tester follows a standard procedure for presenting the test signals. By observing intensities to which the listener responds and those intensities for which there is no response, the tester determines the signal intensity at threshold for each test frequency and records it on an audiogram chart or table.

8.3.1.1. Instruments

A typical manual audiometer, such as the one shown in Figure 8.2, permits the selection of the test frequency, the intensity, right or left earphone, continuous or pulsed tones, and presentation of the signal. Most modern manual audiometers also have a listener response button and a light or other indicator on the audiometer to show that the response button has been pressed. A type 4 audiometer as defined by ANSI S3.6-1996 will have an intensity range from 0 to 90 dB HL for all test frequencies. A manual audiometer may also support other testing such as bone conduction, masking, speech threshold and intelligibility, but those tests are seldom used in the occupational setting.
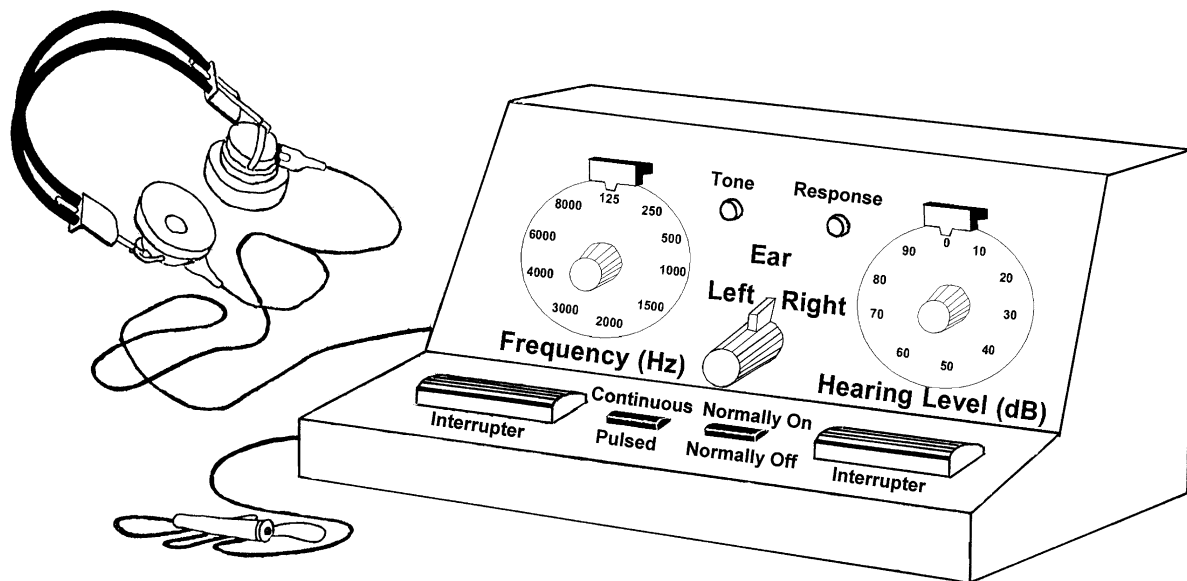
Figure 8.2. Manual audiometer

8.3.1.2. Methods

There are three basic methods that may be used to test hearing: the method of constant stimuli, method of limits, and method of adjustment. In the method of constant stimuli, the listener is presented with a series of tones at each intensity and the number responses for each intensity is recorded. The intensity at which the number of responses equals half the number of presentations is defined as threshold (the 50% point). In the method of limits, various intensities are presented and how the listener responds at each intensity is recorded. The lowest intensity to which the listener responds at least 50% of the time is recorded as threshold. In the method of adjustment, the listener has control of the signal intensity and sets it to a level so that the signal

is just-barely heard, such that if it were less intense it could not be heard at all. This intensity setting is recorded as threshold.

There is a trade off between time to administer these three methods and the accuracy of the threshold determination. While the most accurate, the method of constant stimuli takes the longest amount of time. The method of adjustment takes the least amount of time, but is the most inaccurate. That leaves the method of limits as the method upon which manual audiometry is based.

The version of the method of limits used in manual audiometry is referred to as the modified Hughson-Westlake procedure (Carhart and Jerger, 1959). This procedure is detailed in ANSI S3.21-1978 (R-1992). In this procedure the signal intensity is first presented at a level the listener can hear clearly. Then the intensity is reduced in fixed-size decrements until the listener no longer responds. The intensity is then increased in smaller fixed-size increments until the listener responds again. From this point on, whenever the listener responds, the signal is decremented and whenever the listener fails to respond the signal is incremented. The intensity, when the signal is being incremented, to which the listener responds two out of three times is recorded as threshold. Figure 8.3 displays a flow chart for administering the modified Hughson-Westlake procedure (after Martin, 1986).

There are other variations on the method of limits. If the signal is presented at a level the listener cannot hear, incremented until there is a response, decremented until there is no response and then incremented until there is a response again, the level at which there are two responses for three presentations may be lower than for the modified Hughson-Westlake method. But, the task will be much more difficult for the listener and will take more time to administer. If the Modified Hughson-Westlake method were used, but the threshold level was determined on all responses to signals, increasing or decreasing, there would be many inconsistencies, making it much more difficult to assign threshold to any intensity.

When hearing is tested for clinical purposes, thresholds are found for octave frequencies from 125 to 8000 Hz, and sometimes including the half-octave frequencies of 750, 1500, 3000, and 6000 Hz. When hearing is tested for occupational haring loss prevention programs, only the frequencies 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz are tested. In the United States, the OSHA Hearing Conservation Amendment (OSHA 1983) does not require testing at 8000 Hz. However, since a notch in the audiogram shape at 4000 and/or 6000 Hz with recovery to better hearing at 8000 Hz is the signature of a noise-induced hearing loss, having a threshold for 8000 Hz is important for the professional reviewer to sort out hearing loss most likely due to noise from hearing loss due to some other cause.

When beginning a hearing test it is important to start with the listener's better ear. If the listener notices no difference between the right and left ears, the right ear should be the default starting ear. An effective way to sequence the ears and test frequencies is to start with the determination of threshold in the better/right ear at 1000 Hz. Then threshold is determined at 500 Hz, followed by a retest of threshold at 1000 Hz. If the first and second thresholds at 1000 Hz agree within 5 dB, testing may continue for 2000, 3000, 4000, 6000, and 8000 Hz. Then testing is started for the worse/left ear with the frequency sequence of 1000, 500, 2000, 3000, 4000, 6000, and 8000 Hz. A pulsing tone with on/off times of no less than 200 msec duration should be used if the audiometer has the feature.

If the first and second thresholds for the better/right ear at 1000 Hz do not agree within 5 dB, it will be necessary to stop testing, refit the earphones, and re-instruct the listener. Then 1000 Hz would be tested again, followed by 500 Hz with a return to 1000 Hz. If the thresholds at 1000 Hz agree this time within 5 dB, the rest of the test may be completed. If not, the listener
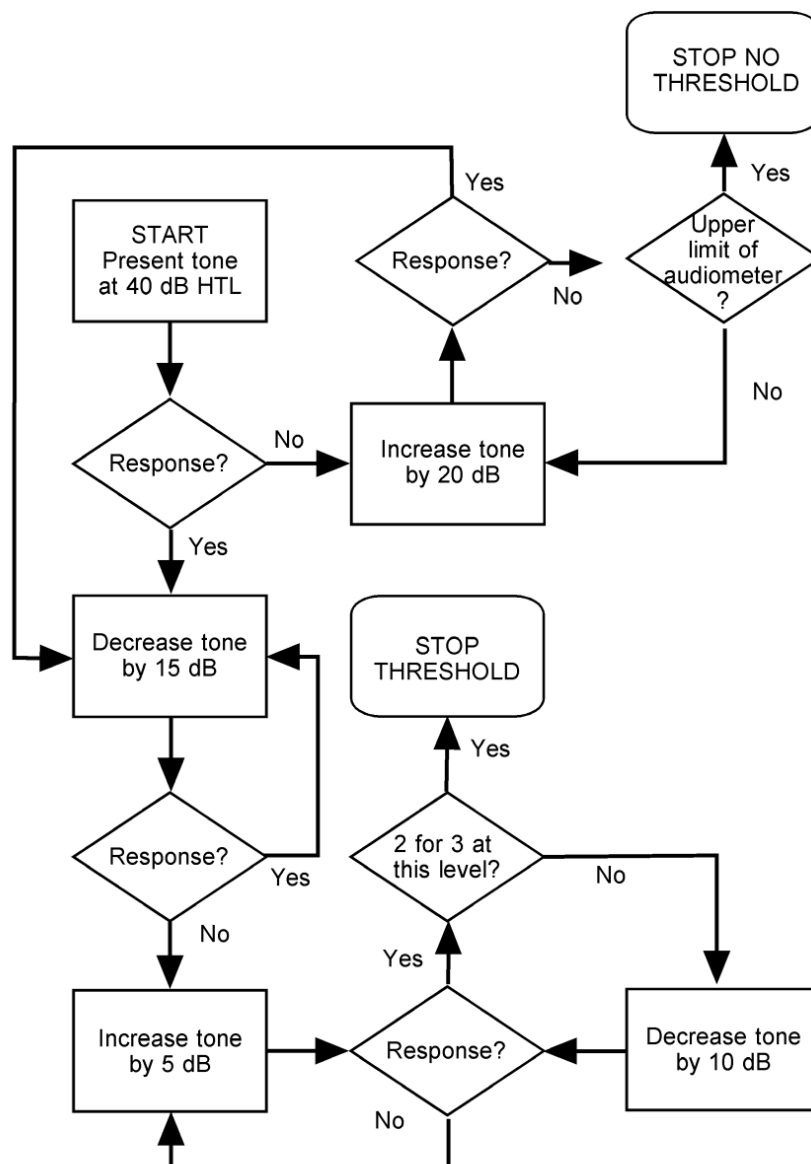
Figure 8.3. Modified Hughson-Westlake flow chart. (Adapted from Martin 1983)

should be referred to a clinical setting for testing. It is not necessary to do the 1000 Hz retest for the worse/left ear since the retest is a confirmation that the listener is responding consistently. Once that is determined, it is not necessary to reconfirm it.

8.3.1.3. Recording of Results

Thresholds of hearing may be recorded on a graph or in a table. Typically, the graphic form is used in clinical settings and is referred to as an audiogram. Audiograms are very helpful in explaining results because the listener can easily envision the test outcome. The procedure for graphing audiometric thresholds is specified in ANSI S3.21-1978 and an example graphical audiogram is displayed in Figure 8.4. Thresholds for the right ear are recorded with an O while thresholds for the left ear are recorded with an X. If working with colored pencils or pens, the

 right-ear O is written in red ink while the left-ear X is written in blue ink. Lines are drawn to connect the symbols. Since hearing levels typically are determined to the nearest 5 dB, the symbols should be aligned at the 5 dB points.

Audiogram shows frequency in Hz increasing from left to right as a logarithmic scale while intensity in decibels increases downward in a linear scale. The preferred aspect ratio is 20 dB per octave or 50 dB per decade of frequency. Thresholds for the right ear are drawn as circles, in red, and are connected with red solid lines, while thresholds for the left ear are drawn as X's, in blue, and are connected with blue solid lines. (ANSI S3.21-1978 (R-1992))

The graphic audiogram is plotted so that poorer hearing thresholds are plotted near the bottom of the chart and normal thresholds are plotted near the top. The graphic audiogram also has some other characteristics. The distance between each octave plotted along the abscissa (x axis) corresponds to the same distance represented by a 20 dB range on the ordinate (y axis). Frequency is plotted logarithmically so that there is equal distance between the octaves.

The audiogram form can be traced back to the 1920's when Western Electric developed the first electronic audiometer. In the absence of a calibration standard, it was decided that the average hearing of a group of company employees who should have had normal hearing would be 0 dB Hearing Loss. Anyone else tested would be compared to the normative employee group and their hearing loss would be plotted on the chart going down to represent decreased hearing (rather than going up on the chart to represent increased intensity of the signal at threshold). At that time, signal levels were measured in terms of voltage applied to the earphone rather than acoustic output from the earphone. Until the 1950's, each audiometer manufacturer had its own reference group of normal hearers so that 0 dB Hearing Loss was not necessarily the same signal level for competing brands of audiometers.
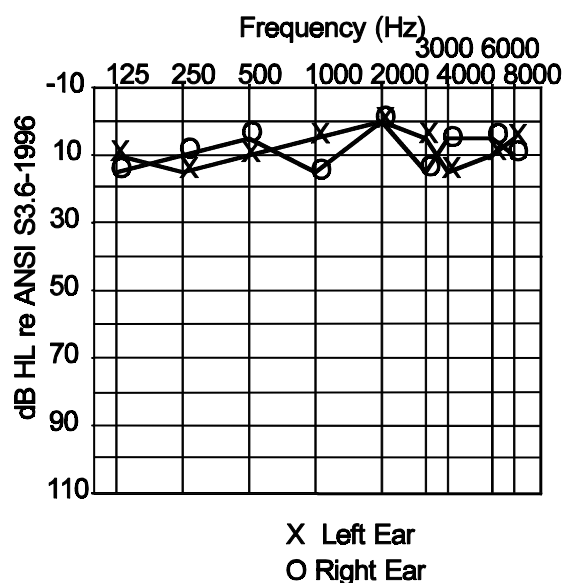

Figure 8.4. Typical graphic audiogram.

Hearing threshold levels may also be presented in a tabular format, referred to as the tabular audiogram. Table 8.4 displays an example. The advantage of the tabular audiogram is that it does not require drawing on a chart or having to read a chart or worry about colors of the lines and symbols to interpret the audiogram. The disadvantage is that is not readable at a glance as is the graphic audiogram and it does not provide much assistance for counseling listeners about

their test results. Another advantage of a tabular audiogram is that one sheet of paper may contain multiple audiograms, effectively holding a record of all the tests a person may have had over a 20 to 40-year range.

Table 8.4. Tabular audiogram. Hearing thresholds are entered for each frequency. Multiple tables may be placed on single page to show hearing tests results in a serial audiogram form.

Frequency (Hz)	500	1000	2000	3000	4000	6000	8000
Right Ear (dB)	5	10	0	15	5	5	10
Left Ear (dB)	10	5	0	5	15	10	5

There is some concern that if the tester has access to a serial audiogram form with past audiometric data, there will be less care in performing the hearing test and hearing levels may be more likely to be consistent with the prior audiograms. However, a conscientious tester can avoid being influenced by prior test results. Additionally, by having access to prior tests, calculations can be made immediately to see if the changes in hearing are large enough to be considered a significant threshold shift.

Testers should make sure to record the following on the audiogram: audiometer make model, and serial number; the dates of its most recent functional and exhaustive calibrations; identification of the tester; identification of the reviewer; acceptability of the audiogram (good, fair, poor); any audiogram classification codes employed; and additional comments that might be relevant to the hearing test. This applies to both graphic and tabular audiograms.

8.3.1.4. Pitfalls

The disadvantage of manual audiometry is that the tester can make mistakes that won't be reflected in the audiogram. With several control switches to manipulate in the course of the hearing test, it is possible to make an error. Failing to change the earphone selector can result in testing the same ear twice. The threshold may be recorded on the wrong place on the graph or in the table. The tester must evaluate each listener response, make presentation level decisions accordingly, and determine which hearing level is threshold. Many testers tend to develop their own method after a time. This alone will introduce error into the audiogram.

8.3.2. Self-Recording Audiometry

Self-recording audiometry (also known as Bekesy audiometry) was introduced by George von Békésy in 1947 as an improvement over manual audiometry. Self-recording audiometry employs the use of a recording attenuator to perform the hearing test. The attenuator can either increase or decrease the signal intensity at a fixed rate of so many decibels per second (dB/sec). The listener has control of the attenuator action. By pressing the response switch, the listener will cause the signal intensity to be decreased. Upon release of the response switch, the signal intensity will be increased. The listener's threshold is somewhere between the point of pressing and the point of releasing the switch.

8.3.2.1. Instruments

Figure 8.5 shows a self-recording audiometer. These are no longer manufactured or repaired by the manufacturers in the United States, although through the middle of the 1980's they accounted for 70% of the audiometers in use in occupational settings. The audiometer records the listener's responses directly on the card. The card is marked for test ear, test frequency, and signal intensity. A pen attached to the recording attenuator draws the tracings on the card that correspond to the attenuator's setting, moving down the card as the signal level increased (no button press) and up the card as the signal level decreased (button pressed). In some cases the card is immobile and the pen not only moves in keeping with the attenuator's actions, but also moves to the from left to right at a selected rate of so much time per frequency; usually 30 seconds. In other cases, such as is shown in Figure 8.5, the card mounts on a table that moves at a fixed rate underneath the pen as the pen moves up and down in keeping with the attenuator's actions.
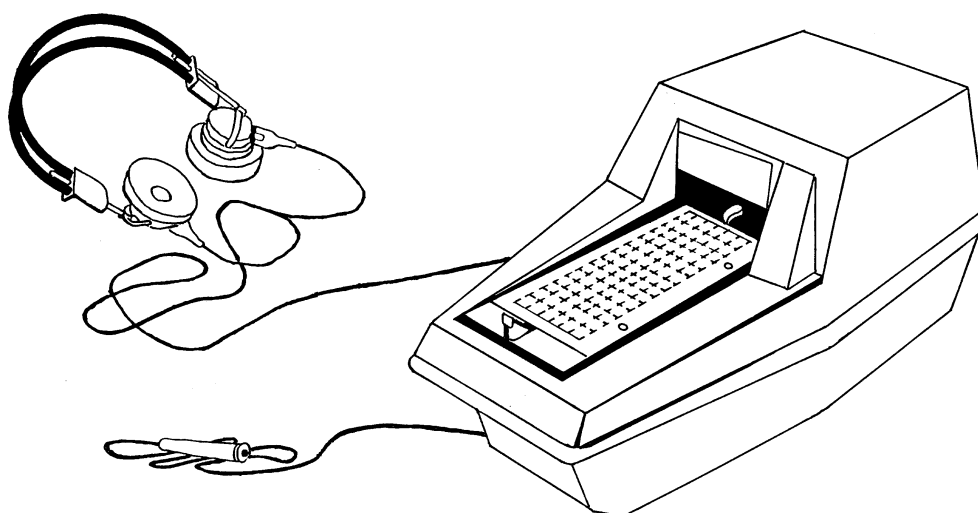

Figure 8.5. Self recording, Békésy, audiometer.

One of the reasons for the popularity of self-recording audiometers was that they could be used in multiple-person testing situations. Many audiometers could be placed in a rack, each with earphone and response switch wired to a test station in the test booth. Once instructions were given and earphones were fitted to each listener the test could be started for everyone at once. Because the test took 7.5 minutes to administer, testing for everyone would be finished at the same time. OSHA requires that self-recording audiometers to present a pulsing 200 msec-duration tone with a 50% duty cycle (200 msec on, 200 msec off) (OSHA 1983).

Figure 8.6 shows a typical audiogram card for a self-recording audiometer. There is a section for each frequency that is wide enough to contain 30 seconds of tracings. The frequencies are laid out on the card in the order that they are presented by the audiometer. The tracings provide a graph of hearing for each ear that is comparable to the audiogram graph for manual hearing testing. Once the audiogram is scored, the chart can be used as an effective counseling tool to explain the test results to the listener.

Note that the 1000 Hz retest in this case is at the end of the frequency sequence for the first test ear. It may seem that this method of testing needs no attention once started. However, it is

important that the retest tracings obtained 3.5 minutes into the test (i.e., at the 1000 Hz retest) be monitored so that the test may be stopped if the retest threshold is not within 5 dB of the first 1000 Hz threshold. Of course, when the audiometry is conducted in a multiple-person test booth, it is not practical to stop testing for one person, so the test would be allowed to continue.
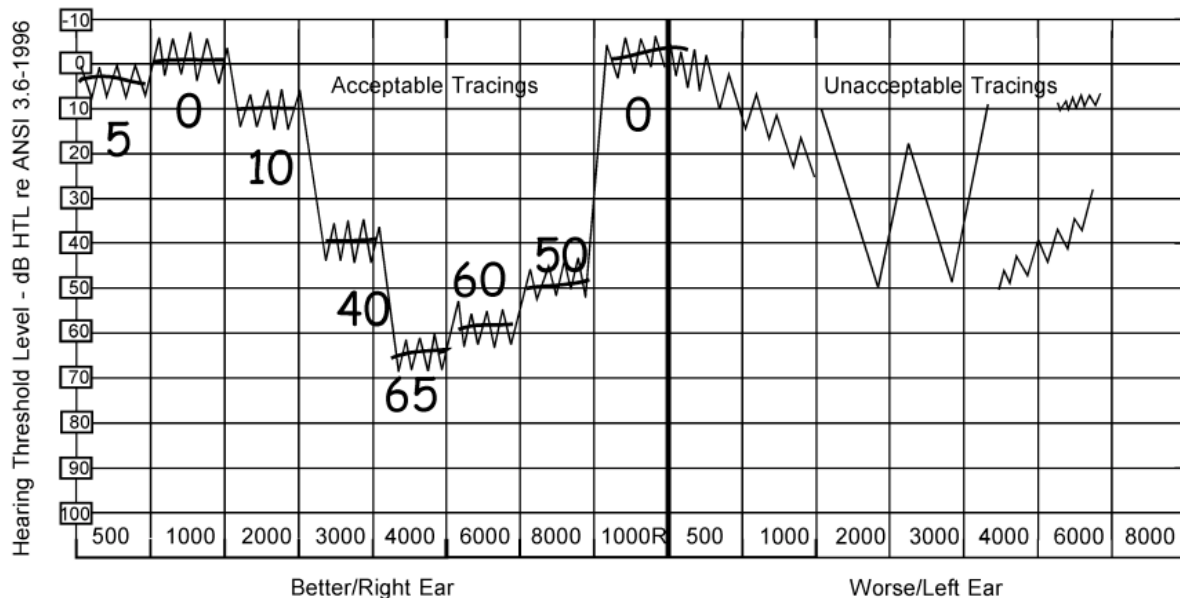

Figure 8.6. Example of audiogram from self-recording audiometer with examples of acceptable and unacceptable tracings.

Figure 8.6 shows an acceptable audiogram for the better/right ear. The tracings are consistent over the range of each test frequency such that it is easy to draw a line through the center of the tracings to determine a threshold. As a rule of thumb, a good tracing also has excursions of no less than 3 dB and no wider than 13 dB.

The chart for the worse/left ear shows some examples of unacceptable tracings.

• In the first case, the tracings may indicate a person who didn't understand the instruction and is pressing and releasing the button without regard to the tones. It may also indicate a person who is searching for a loudness range to trace rather than an audibility range.

• The second case may happen when a person presses the button only when sure of hearing the signal and releases it when sure that the signal can't be heard. With tracings this wide, it is impossible to determine where threshold is.

• The tight trace on the chart occurs when a person is quickly pressing and releasing the button. It is not possible for a person to make decisions about audibility/inaudibility so quickly when the attenuation rate is 5 dB/second.

• The rising trace occurs when the listener hears the tone and presses the button, releases the button because the signal has gotten fainter, discovers that the signal is still audible, presses the button again, and so on.

In all cases producing tracings such as these, the test should be stopped, the person should be reinstructed and testing should be started over.

8.3.2.2. Methods for scoring

Scoring the audiogram to obtain hearing thresholds is fairly simple for audiograms with acceptable tracings. A tracing to be scored should have at least six crossings. That is, there should be at least 3 excursions from button press to button release and 3 from button release to button press. The first step in scoring is to draw a line across the center of the tracings. The second step is to determine the hearing threshold level for the line. The third is to the round the hearing threshold level to the nearest 5 dB. That value should then be written above or below the tracing for each frequency. The audiogram for the better/right ear in Figure 8.6 shows the horizontal line drawn for each test frequency and the value of the assigned hearing threshold level.

In the United States, OSHA requires the following from Appendix C(2)(E) of the Hearing Conservation Amendment (OSHA 1983): *It must be possible at each test frequency to place a horizontal line segment parallel to the time axis on the audiogram, such that the audiometric tracing crosses the line segment at least six times at that test frequency. At each test frequency the threshold shall be the average of the midpoints of the tracing excursions.*

Some audiologists have adopted the practice of determining the mid point for each excursion to the nearest decibel, calculating the average for all of the excursions, and then recording the hearing threshold in 1 dB rather than 5 dB increments. While this may be appropriate for a trained listener in a laboratory setting, the gains from this type of precision for occupational hearing loss prevention purposes are minimal.

8.3.2.3. Recording of results

While it is necessary to maintain the audiogram cards for the record, when multiple years of test results are available, it will be helpful to transfer the threshold levels to a tabular form. Thus, while the card is the legal record and should not be destroyed, the tabular transfer record can be used more easily to review the chronology of test results to determine if there has been a significant threshold shift since the baseline audiogram.

Testers should make sure to record the following on the audiogram: audiometer make model, and serial number; the dates of its most recent functional and exhaustive calibrations; identification of the tester; identification of the reviewer; acceptability of the audiogram (good, fair, poor); any audiogram classification codes employed; and additional comments that might be relevant to the hearing test.

8.3.2.4. Pitfalls

There were two primary reasons for the initial popularity of self-recording audiometry. The first was that it did not require ongoing decisions from the tester as did manual audiometry and so should be free from tester bias and tester error. The second was that it worked well in group audiometry settings. However, unless the tester was careful to inspect each audiogram, audiograms with unscoreable tracings could become the permanent record.

There are people who simply cannot perform the listening task necessary for self-recording audiometry. Experience has shown that about one in seven persons will need to be reinstructed and retested. Of those about half will not be able to provide acceptable tracings for the retest. Those persons must be tested some other way, such as with a manual audiometer.

As stated earlier, self-recording audiometers are no longer manufactured in the United

States. However, there is a resale market of used U.S. manufactured audiometers and there are European manufacturers. Because the self-recording audiometer draws an audiogram, it will be necessary to have access to consumable supplies such as audiogram cards and marking pens. Without the proper card or pen, the unit can't be used.

8.3.3. Computer-Administered (Microprocessor) Audiometry

The first commercial microprocessor audiometer was the MAICO 26 introduced in 1975 and advertised as the 'unBekesy" audiometer. The microprocessor audiometer employed the modified Hughson-Westlake procedure in its code. When the test was completed, the audiometer printed out a tabular audiogram that contained additional information including the listener's identification number, the time and date of the test, and pure-tone averages over 500, 1000, and 2000 Hz, 1000, 2000, and 3000 Hz, and 2000, 3000, 4000 Hz, all of which could be used for calculations not related directly to obtaining a hearing test.

8.3.3.1. Instruments

Figure 8.7 shows a stand-alone microprocessor audiometer. Instead of dials for selecting frequency and intensity, and switches for selecting ears and presenting tones, it has a multifunction keypad. The keypad may be set up in the 10-key fashion of a calculator and numeric data such as the listener's identification number, date and time of test, and tester's identification number may be entered. These numbers will appear on the printout of the audiogram and all but the tester's identification number will be maintained for subsequent tests unless changed. Some microprocessors accept entry of the listener's baseline audiogram and at the completion of the test perform the calculation for significant threshold shift.
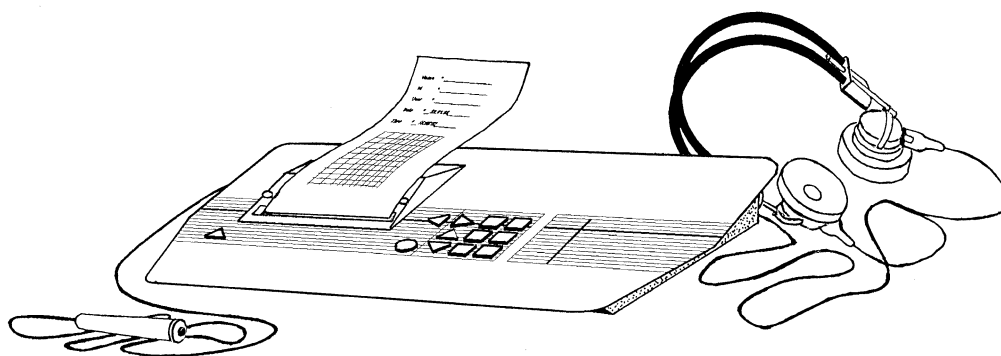

Figure 8.7. Microprocessor audiometer.

The numeric keypad has other functions such as selecting the initial test ear, scrolling through menu items seen on the audiometer's display panel, and performing manual audiometry. Finally, the keypad may be used to display the audiogram plus any stored audiograms and to direct the output of the audiogram to a printer or to a computer.

The microprocessor audiometer offers significant advantages over manual and self-recording audiometers. Since it follows a program for sequencing test frequencies and test ears, it is not possible to skip a test frequency or fail to switch ears as can happen with manual audiometry. Its program also determines how tones will be presented, how intensity will be

changed in relation to listener responses, and how threshold will be defined. Thus, it provides a continuity from test to test, and when used in a multiple-person test setting, from audiometer to audiometer, that may be difficult to achieve with manual audiometry. Because there are no moving parts other than a printer, if included, it is more rugged than a self-recording audiometer.

Most microprocessor audiometers available today present the test tones to the listeners as a sequence of three 200 msec tone pulses (a tone triad). There usually is no provision for any other mode of tone presentation. The tone triad is easy to recognize and makes the testing process easier for the listeners.

8.3.3.2. Fault conditions

A simple computer program can be written to test hearing following the modified Hughson-Westlake method as is displayed in Figure 8.3. However, that procedure does not take into account listeners who press the response button when no tone has been presented. It also does not account for the listener who can't respond consistently at any presentation level or who keeps the response button pressed all of the time. Most microprocessor audiometers have rules for these occurrences in their programming. Repeated presses of the response button when no tone is present will cause the audiometer to stop testing and alert the tester of the program, providing the option to continue testing after the listener has been reinstructed or abort the test. If the listener doesn't respond consistently enough for a threshold to be determined, many of the microprocessor audiometers will move on the next ear-frequency condition and then return to the problem ear-frequency at the end of the test. If threshold still cannot be determined, the audiometer will alert the tester of the problem and provide the options of continuing after reinstruction or stopping the test. Some microprocessor audiometers will allow the problem ear-frequency conditions to be tested manually and will integrate the manually-determined threshold with the others already determined. Others will not allow a return to microprocessor audiometry once manual audiometry has started, requiring the rest of the test to be performed manually.

8.3.3.3. Recording of results

As with self-recording audiometers, the microprocessor audiometer provides its own record of the results. In this case the record is tabular. An example of such a record is shown in Figure 8.8 from a microprocessor audiometer with a built-in printer. In addition to the hearing thresholds for each ear-frequency condition, the record may provide a detailed summary of presentations and responses for each ear-frequency condition as well. The averages for key frequencies that are useful for calculating significant threshold shift and percent hearing handicap may also appear. In many cases, the listener can sign the tape with the audiogram as verification that this displays the results of his or her test.
As with self-recording audiometer charts, it is best to transcribe the audiogram to some other record keeping system as well. That system may be the serial-audiogram form. However, to do that would be to fail to take advantage of the microprocessor's ability to transfer audiometric data into a computerized database without the possibility of transcription error. For this purpose, there are commercial hearing conservation database programs that work with every microprocessor audiometer available and there are programs that audiometer manufacturers have developed for their systems.

While some microprocessor audiometers have the capability of holding up to 200 audiograms in memory so that they may be batch uploaded into the computer database at the end

```
Name:              John Doe
ID Number             111-22-3333
Test Date             11223333
Test Time             11:22:33

Audiogram
Frequency  Left Ear    Right Ear
500        10            10
1000       10            10
2000       10            10
3000       10            10
4000       10            10
6000       10            10
8000       10            10

Ave 512    10            10
Ave 123    10            10
Ave 234    10            10
Ave 5123   10            10
Ave 1234   10            10

Tester ID
Signature
Audiometer Serial Number
Date of Calibration
Test Room Noise Level   dB(A)
```

Figure 8.8. Microprocessor audiogram printout.

of a testing day, a week or whatever, this is not a good practice. It is better to have direct, live access to the computer with the database or at least to that portion of the database relevant to testing. This allows immediate comparison to baseline audiograms and other information while the person is being tested. Thus, rational, realistic, and practical decisions can be made on the spot instead of days or weeks later when the opportunity to follow up with the person has been lost. It is possible to transfer the baseline audiograms of each person to be tested into the audiometer's memory so that it may perform the calculations for significant threshold shift, but it is less cumbersome to have the audiometer connected to the database and let the computer do the calculations.

Testers should make sure to record the following on the audiogram: audiometer make model, and serial number; the dates of its most recent functional and exhaustive calibrations; identification of the tester; identification of the reviewer; acceptability of the audiogram (good, fair, poor); any audiogram classification codes employed; and additional comments that might be relevant to the hearing test.

8.3.3.4. Pitfalls

The microprocessor audiometer has taken the place of the self-recording audiometer in the multiple-person testing environment. It is attractive because at face value it performs the equivalent of the manual test. Once instructions are given and earphones are fitted, all audiometers may be started at once.

However, the tests will not all end at the same time. Some persons with good hearing or with lack of tinnitus may finish very quickly while others with poorer hearing or tinnitus who are

uncertain of what they are hearing will require many more presentations and will finish later. For those with many false positives or for whom the audiometer is not able to resolve threshold at one or more frequencies, the audiometer will have stopped, awaiting intervention by the tester. The tester must be able to intervene in these cases without disrupting the test sequence for those whose hearing tests are not complicated.

Some microprocessor audiometers have a talk-through circuit so that the tester can tell those with tests that have halted what to do or what to expect next. The talk-through circuit can be used to tell those whose tests are completed to not remove their earphones and to sit and wait quietly until the tester comes into the test booth. The tester could also provide reinstruction for some and then resume the test. However, talk-through circuits only enable one-way communication, so it is not possible for the listener to tell the tester what the problem may be.

In the United States, the Hearing Conservation Amendment, 29 CFR 1910.95(g)(3) states that *a technician who operates microprocessor audiometer does not need to be certified*. This is a poor exemption. A technician operating a microprocessor audiometer must know the ins and outs of microprocessor audiometry and of manual audiometry since he or she will be called to perform manual audiometry for those whose audiograms the microprocessor audiometer can't complete. Those who think of a computerized audiometer as an expert system capable of responding to all contingencies clearly have little experience with administering audiograms in an occupational setting.

While all microprocessor audiometers available in the United States employ the modified Hughson-Westlake procedure, no two manufacturers implement the procedure in precisely the same way. Thus, there will be differences between audiograms obtained on audiometers from two different manufacturers. The manufacturers have not been willing to share the code for their testing procedures with anyone, including the American National Standards Institute working group on computerized audiometry (S3/WG76). Thus, it is not possible to determine what and why differences occur between audiometer types.

8.3.4. Test-Retest Reliability and Differences Within and Across Procedures

8.3.4.1. test-retest reliability and differences within methods

Whenever any type of psychometric measurement is made, there will be variation from time to time as the test is readministered. This applies to tests of intelligence as well as to tests of hearing. There are systematic and random error sources in audiometry that affect the results (Hétu 1979). They are:

- audiometer calibration error or drift
- excessive background noise levels in the test room
- interfering signals from the test equipment
- earphone placement
- tester bias and examination procedure bias
- improvement in performance due to familiarity with the examination procedure
- residual temporary threshold shift at the time of the examination
- partial or complete obstruction of the external auditory canal
- presence of tinnitus
- functional hearing loss
- fluctuation in the subjective criterion of audibility by the subject.

Many of these error sources can be minimized by careful control of the testing environment. Careful calibration and day-to-day monitoring of the audiometer, test room, and other equipment can reduce the effects of audiometer miscalibration, excessive background noise, and spurious instrument noises. Errors due to earphone placement inconsistencies can be reduced by having only the tester fit the earphones before the start of each test. Insufficient earphone headband force can be managed by having the tester remove the earphones at the completion of each test and place them on a mounting block that has cups for the earphone cushions; a bioacoustic simulator provides a perfect place for earphones when not used for testing in addition to providing a means of managing the day-to-day calibration check of the audiometer.

Tester bias and improvements in performance due to familiarity with the test procedure can be controlled by the tester. In the first case for manual audiometry, if the tester follows the same protocol test after test, test bias can all but be eliminated. In the second case, if complete test instructions are given at the beginning of each hearing test, no matter how many hearing tests a person has had previously, listeners will always begin at the same point and familiarity should not have an effect on the audiogram.

Instructions also have bearing on the listener's criterion for responding that a tone was heard. Most people, upon being told to signal when they hear a tone will wait until they are sure that they clearly heard a tone; they will have a strict response criterion. A few people will respond whenever they perceive a tone regardless of their certainty level; they have a lax criterion. The instructions presented for each of the test methods later in this chapter (sections 8.8.3.1 through 8.8.3.4) are designed to shift the response criteria to a middle level criterion for those who normally start a hearing test with a strict criterion. The instructions should have little effect on those with a lax criterion and it may be necessary, after testing has begun if there are more than three false positive responses–responses with no signal presented–to advise these listeners to respond only when they are sure that they hear a tone to move them to a moderate criterion.

An alert tester can also reduce error due to tinnitus and obstruction of the ear canal. Listeners should be asked prior to testing if they have ringing in the ears or other head noises that become more audible in quiet. If the listener indicates tinnitus or head noises, the tester should remind the listener that the tones will be pulsed and even presented in triads for microprocessor-controlled audiometry. Adding to the listener's criteria for response the necessity of hearing pulsing tones can help most listeners with tinnitus. A cursory otoscopic examination should precede all hearing tests; thus obstructions can be noted and listeners can even be referred for cerumen removal.

Residual temporary threshold shift is a curse and a blessing for the tester. It is a curse when performing baseline, confirmation, or exit audiometry; for those are the occasions when it is necessary to obtain the best measures of how a person hears. Consequently, care must be taken to ensure that a quiet period (exposure to no loud sounds) of 12 to 14 hours precedes the hearing test. Earmuffs or other forms of hearing protection should not be used to obtain the quiet period. For the annual or periodic audiogram, residual temporary threshold shift is a blessing. It is a blessing if temporary threshold shift is identified during the periodic audiometry, because then interventions can be employed to prevent temporary threshold shift before it becomes permanent threshold shift. Thus, it is recommended that periodic audiometry be performed during and toward the end of work shifts so that any temporary threshold shift due to work place noise can be identified.

The listener with a functional hearing loss, responding only to signal levels that are clearly audible often using a loudness rather than a threshold criterion, presents a difficult challenge.

Most listeners will not conceive of "cheating" on a hearing test by not following the instructions. However, a few of those with something to gain from exaggerated hearing loss may adopt a loudness-based rather than a just-detectable-based criterion for responding. There are many ways to detect such responses and to resolve the functional hearing loss, but they are beyond the scope of this chapter as they involve more than pure-tone air-conduction audiometry.

8.3.4.2. Manual versus Békésy

Manual audiometry will usually provide slightly higher thresholds than Békésy audiometry. This is not because Békésy audiometry is more sensitive than manual. It is related to the range of signal levels presented to the listener. In manual audiometry, the listener is presented signals and responds to those he or she hears. If a person responds, for example, at 10 dB HL and not at 5 dB HL, the threshold will be recorded as 10 dB HL. In Békésy audiometry the listener responds by pressing the response button when the tones are audible and by releasing the response button when the tones become in audible. Given the time it takes to make a decision and respond and the rate of attenuation, the point at which the listener releases the response switch will be a few decibels below the signal level the listener can actually hear. At an attenuation rate of 5 dB/second with a respond latency of 0.5 seconds, the listener will release the response switch when the signal level is at least 2 dB below his or her threshold. The same applies to pressing the response switch in response to hearing the tones. The signal level will be 2 or more decibels above the point of audibility when the response is made. This would seem to even out so that there should be no difference between manual and Békésy methods.

However, given the example of the listener with a 10 dB HL manual threshold, the actual threshold may be 6 dB HL, a level not tested by manual audiometry. So the listener responds by pressing the response button at 9 dB HL, 3 dB above the point of audibility, and by releasing the button at 3 dB HL, 3 dB below threshold, providing a tracing that is 6 dB wide with a mid-point at 6 dB HL. The 6 dB HL threshold would be rounded to the nearest 5 dB and recorded as 5 dB HL, 5 dB less than the 10 dB HL threshold from manual audiometry for the same person. So, in general, Békésy thresholds should be 3 to 4 dB lower than thresholds from manual audiometry. This is consistent with the findings of Harris (1980).

A 6 dB trace width is very good and usually provided only by experienced listeners. Most will provide a wider trace width, pressing the button when they first hear the tones and releasing the button when they are sure they don't hear the tones, thus providing a lower estimate of threshold of hearing than would be obtained with manual audiometry.

8.3.4.3. Manual versus microprocessor

Since the microprocessor-controlled audiometry procedure is an emulation of the modified Hughson-Westlake procedure, there are no apparent reasons for differences between the two procedures. In fact, Jerlvall, Dryselius and Arlinger (1983) and Cook and Creech (1983) have demonstrated that to the extent that the microprocessor method duplicates a manual method, there will be no differences.

8.3.4.4. Differences in Microprocessors

There is no standard method for microprocessor controlled audiometry. As noted above, manufacturers of microprocessor controlled audiometers have not been forthcoming with the

details of their methods and their criteria for threshold assignment. Harris (1980) found that differences of 3.5 dB could be demonstrated just by changing the instructions to the listener. Requiring the listener to press the response button upon hearing the tone and releasing it after the tone was discontinued resulted in higher thresholds than simply requiring the listener to press and release the response button when a tone was thought to have been heard.

8.4. AUDIOMETER CALIBRATION

For audiograms to have any value at all, the audiometers must be in calibration. Thus, it is necessary to check the audiometer calibration no less than daily before use. In addition, records of calibrations must be maintained and dates of calibrations should become part of the permanent audiometric record.

8.4.1. Functional Checks

A functional check is just that, a check to make sure the audiometer's functions are operative. This is often called a listening check because functional checks are performed by listening to the audiometer while checking its functions and state of readiness. The goal of the functional check is to make sure that the audiometer is able to generate tones, gate tones, change levels, switch ears, and work with the response switch without introducing distortions, clicks, and drop outs.

Most audiometer manufacturers will provide a guide for performing a functional check. A suggested procedure follows:

A. Set the audiometer to 70 dB HTL, 1000 Hz, output to right ear.

B. Turn the tone selector to continuous on or, if not possible, for a train of pulses either automatically or by repeated pressing the presentation switch.

C. Listen to the tone; it should sound clear. If pulsing, there should be no noticeable click at the beginning or end of the tone pulse.

D. Wiggle the earphone cords. There should be no noise on the line nor should there be any interruption of the tone. Gently pull on the earphone cords where they enter the earphones and as they come from the back of the audiometer or test room jack panel. There should be no noise on the line nor should there be any interruption of the tone.

E. Switch the signal from right to left ear. The tones should be equally as loud.

F. Press the response button. There should be no clicking in the earphone for either the press or release of the button.

G. Change the signal intensity up and then down. There should be no clicking as the level is changed.

H. Change the frequency dial. The tones should start with no clicking noise and the tone should not seem to ramp up or down in frequency.

I. Set the intensity back to 70 dB HTL. Unplug the left earphone and listen through the right while selecting each test frequency. No tones should be audible. Repeat by sending the signal to the unplugged right earphone and listening to the reconnected left earphone.

8.4.2 Acoustic Output Checks

In the United States, OSHA requires a functional check that includes testing the hearing of someone with known hearing (29 CFR 1910.95(h)(5)(i)): *The functional operation of the audiometer shall be checked before each day's use by testing a person with known, stable hearing thresholds, and by listening to the audiometer's output to make sure that the output is free from distorted or unwanted sounds. Deviations of 10 decibels or greater require an acoustic calibration.* For the purposes here, OSHA is describing both a functional and daily threshold check.

8.4.2.1. Daily threshold check

The daily threshold check is a confirmation that the calibration of the audiometer remains unchanged. Each day before use, or each time an audiometer is relocated, a hearing test is administered to a person with known, stable hearing. It is not necessary for the person tested to have normal hearing. While being tested, the listener should also listen for artifacts that might have been missed during the functional check. The person being tested should not be the tester self-administering the hearing test, for response decisions may be made on what is expected rather than on what is heard. Changes of 10 dB or more require the audiometer to be acoustically calibrated before it is used.

8.4.2.2. Bioacoustic simulators

It may not always to be possible to have the same person or persons with known hearing available for the daily threshold check. It is also difficult to perform a daily threshold check on a bank of 8, 10, or 12 audiometers used in a multiple-person test booth. The bioacoustic simulator can take the place of the person with known hearing.

Figure 8.9 displays a typical bioacoustic simulator. The simulator uses acoustic couplers designed to accept the full-size MX41/AR cushion and earphone mounted on the headband. Microphones are located within the couplers. An electronic circuit closes a switch when the signal level exceeds a preset threshold and opens the switch when the signal level is below the threshold, thus simulating a listener. It may be used with any manual audiometer with a response switch and indicator lamp as well as with a Békésy or microprocessor-controlled audiometer . Because the electronic switch responds faster than a listener and doesn't have the signal uncertainty problems of a listener, the Békésy tracings will be very tight, of the order of a couple of decibels. The simulators cannot be used with microprocessor audiometers requiring unusual response patterns such as holding the response switch until the signal stops or counting pulses before responding.

Each simulator has its own characteristic "audiogram," so the same simulator must be used with a given audiometer, day in and day out. Each unit will be set to respond around 65 dB HL for the test frequencies, but as the microphones are not laboratory quality, there can be variations of as much as 15 dB between units and thus each unit is supplied with its own reference audiogram. As with the daily threshold test, changes of 10 dB or more require acoustic calibration of the audiometer before it is used. The nature of the simulator microphones and electronic circuits is such that they work properly or not at all, so they do not require periodic calibration as they will not drift.

Some simulators have circuitry to measure ambient noise levels. Whenever the background

noise levels in the test booth exceed a preset threshold, a lamp associated with the octave-band center frequency lights to alert the tester. Obviously, these lamps will light when there is any activity in the test booth such as giving the listener instructions, but they should not light when the test booth door is closed and testing is underway. While these units may be used to monitor ambient test booth noise, they may not be a substitute for using a sound level meter to measure and document test room ambient noise levels.
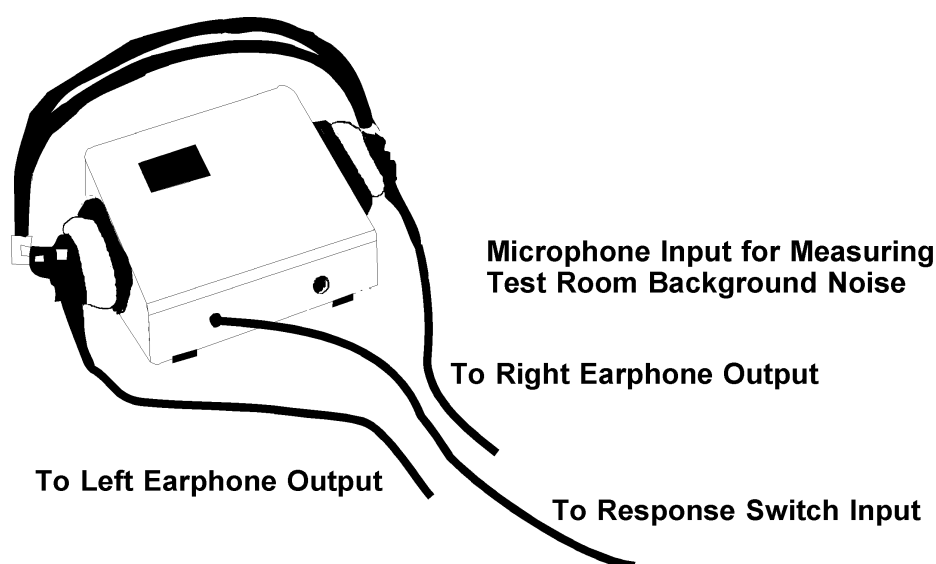

Microphone Input for Measuring Test Room Background Noise

To Right Earphone Output

To Left Earphone Output

To Response Switch Input

Figure 8.9. Bioacoustic simulator.

In the United States the default pre-set simulator criteria levels are those of OSHA's Appendix D, Table D-1 (see Table 8.2) rather than those of ANSI S3.1-1996 for ears covered. One model of simulators (Quest Technologies BA 210-25) may be set to the criteria levels of Appendix D, Table D-1 (see Table 8.2) of the 1981 OSHA Hearing Conservation Amendment (OSHA 1981). These are the same levels as recommended by the National Hearing Conservation Association for mobile test vans (NHCA 1996).

8.4.3. Acoustic and Exhaustive Calibrations

If the daily threshold check shows that there has been a change of 10 dB or more, it is necessary to take the audiometer out of service and use a sound level meter to determine its output levels. The output level will be noted in terms of its deviation from the level specified by the audiometer reference standard. This is referred to as an acoustic calibration check. During an exhaustive calibration, the output levels are actually set to meet those specified by the audiometer standard (e.g., ANSI S3.6-1996).

8.4.3.1. Acoustic calibration check

The acoustic calibration check requires a sound level meter, an acoustic coupler, and a set of octave-band filters. In the United States the meter must meet type II specification re ANSI S1.4-

1983. The coupler must be an NBS-9A or equivalent with an effective volume of 6 ml (the effective volume is the combined actual volume of the coupler and the equivalent volume of the sound level meter microphone and the earphone - the coupler is often referred to as a 6-cc coupler). The earphone in its cushion is placed on the coupler so that the plane of the earphone diaphragm is parallel to the diaphragm of the microphone and so that there are no leaks between the earphone cushion and coupler lip. The earphone is weighted with a 500-gram weight that effectively compresses the earphone cushion to the coupler. Morrill (1986) suggests that with the proper equipment and training the tester can perform the acoustic calibration, thus avoiding having to ship the unit for calibration which alone can have effects on the outcome.

It is important to note that audiometers are calibrated with specific earphones. Replacing the earphones of an audiometer with those of another will result in both audiometers being out of calibration. This is true even when the earphones are the same type and model. The calibration is for the earphones and the audiometer as an integral set. If an audiometer is taken out of service for any reason, the earphones used with that audiometer should also be taken out of service. Likewise, when an audiometer is sent away for calibration, its earphones must be sent with it.

8.4.3.1.1. Coupling the earphone. The goal of this part is to ensure that the earphone is well coupled to the sound level meter and that there are no leaks that would cause inaccurate sound pressure level readings. The earphone and weight should be placed on the coupler. The audiometer should be set to produce a continuous signal at 70 dB HTL at the lowest test frequency (125 Hz on clinical audiometers, 250 or 500 Hz on type 3 or 4 pure-tone air-conduction audiometers). The earphone is then adjusted on the coupler to produce the highest sound pressure level reading on the sound level meter. Then the earphone and weight are removed and the process is repeated. The same reading should be obtained. If so, the earphone should remain on the coupler for the rest of its calibration. If not, the earphone and weight should be removed and the process should be repeated until a sound pressure level reading is duplicated on successive placements and adjustments.

8.4.3.1.2. Measuring output for comparison to the standard. The following steps are adapted from Appendix E of the OSHA Hearing Conservation Amendment (OSHA 1983). The procedures are valid regardless of the earphone or calibration standard used. There are three parts: sound pressure output check, linearity check, and tolerances.

Sound pressure output check

    A.   Place the earphone on the coupler as described in Section 8.4.3.1.1.
    B.   Set the audiometer's hearing threshold level (HTL) dial to 70 dB.
    C.   Measure the sound pressure level of the tones at each test frequency from 500 Hz through 8000 Hz for each earphone.
    D.   At each frequency the readout on the sound level meter should correspond to the levels in Table 8.5 for the type of earphone, in the column entitled "sound level meter reading." There is a debate as to whether or not the Telephonics TDH 39 earphone had a calibration artifact at 6000 Hz. Many advocate making a correction for the artifact, others do not. In the United States, OSHA has not addressed the matter.

Table 8.5 Reference threshold levels for Telephonics -TDH-39/49

Frequency (Hz)	Reference threshold for TDH-39 earphones	Sound level meter reading at 70 dB HTL for TDH-39 earphones	Reference threshold for TDH-49/51 earphones	Sound level meter reading at 70 dB HTL for TDH-49/51 earphones
500	11.5	81.5	13.5	83.5
1000	7	77	7.5	77.5
2000	9	79	11	81
3000	10	80	9.5	79.5
4000	9.5	79.5	10.5	80.5
6000	15.5	85.5	13.5	83.5
8000	13	83	13	83

Linearity check

A.   With the earphone still in place on the coupler, set the audiometer frequency to 1000 Hz, the HTL dial on the audiometer to 70 dB and the frequency band on the sound level meter octave band filter to 1000 Hz.

B.   Measure the sound levels in the coupler at each 10 dB decrement from 70 dB to 10 dB, noting the sound level meter reading at each setting.

C.   For each 10 dB decrement on the audiometer the sound level meter should indicate a corresponding 10 dB decrease.

D.   Alternatively, this measurement may be made electrically with a voltmeter connected to the earphone terminals. The dynamic earphone is also a very efficient microphone and care must be taken when performing electrical measurements that the signal being measured is from the audiometer, not from the earphone that is picking up environmental sounds.

Tolerances. When any of the measured sound levels deviate from the levels in 8.5 by + or - 3 dB at any test frequency between 500 and 3000 Hz, 4 dB at 4000 Hz, or 5 dB at 6000 and 8000 Hz, an exhaustive calibration is advised. ANSI S3.6-1996 requires that each change of 5 dB in HTL have a corresponding change in sound pressure level of ± 1.5 dB.

8.4.3.2. Exhaustive calibration

An exhaustive calibration requires the use of a sound level meter, octave band filters, an acoustic coupler and other instrumentation. Exhaustive audiometer calibrations should be performed by trained personnel who are familiar with the operations of audiometers, who have the necessary equipment, and who may adjust the audiometer to bring it back into calibration where necessary. Thus, it is often necessary to send the audiometer away for exhaustive calibration. If such is the

case, an acoustic calibration should be performed upon its return. Also, if a bioacoustic simulator is used for daily threshold checks, it is important to perform a simulator test with the newly calibrated audiometer to obtain new reference levels.

NIOSH recommends and OSHA requires that audiometers receive an exhaustive calibration every two years in accordance with relevant sections of ANSI S3.6-1996. These include measuring output levels and output frequencies with comparison to tolerances of the standard, evaluating distortion of the test signals, checking for channel crosstalk and any other unwanted sounds in the earphone, and measuring duty cycle and rise/fall time of the signal when gated on and off. If the measurements for the audiometer are outside of specified tolerances, repairs or adjustment in calibration must be made before the audiometer may be placed back into service.

Since every audiometer will receive an exhaustive calibration at least every two years (more frequently if a substantial problem arises), it is important that instructions for resetting the output level of the audiometer be given to the technician performing the exhaustive calibration. Over time, the output levels of audiometers may drift away from the specified levels, but will remain within the tolerance range. If this is the case, it is important to tell the calibrating technician to not adjust the output level to bring it back to the exact specified level. Resetting the output level back to the exact specified level in the standard every two years will introduce a new source of variability into the hearing conservation database (see Section 8.3.4) and may result in a sudden increase in the number of workers identified as having a significant threshold shift.

There are not universal standards for certifying calibration technicians. In the United States, only Texas licenses audiometer calibration technicians who are required to pass an examination. Massachusetts requires that all audiometers used in the public schools to screen school children be sent to the state facility every summer for calibration. In the absence of calibration technician certification standards, it is best to have an audiometer calibrated by the firm that sold it or by a firm that is recognized by the manufacturer as an authorized repair facility for its audiometers. A few audiometers must be sent to the manufacturer for calibration and, except for damage that may be encountered during shipment, the likelihood that correct procedures will be used is good.

8.4.4. Calibration Records

At a minimum, calibration records should be kept with the audiometer as long as it is in service. A better practice would be to maintain the audiometer calibration records as long as there are persons currently receiving hearing tests who were tested at any time in the past with the audiometer in question. Ambient test-booth noise levels should be recorded on the audiograms and maintained separately for as long as the booth is in service. These records are important when workers' compensation claims are filed and when regulatory agencies are reviewing the hearing loss prevention program.

It is also important to place the biological or functional calibration and the exhaustive calibration dates on the audiogram. In the United States, state compensation claims for hearing loss are often filed at the termination of employment or at retirement (Gasaway 1985). When the employer cannot produce records of ambient noise levels and audiometer calibrations, there is very little protection level against the claim if it should reach litigation.

8.5. THRESHOLD SHIFT

In the United States, OSHA and the Mine Safety and Health Administration (MSHA), presently have definitions different from NIOSH of the amount of change in hearing indicated by repeat

audiometry that should trigger additional audiometric testing and related follow up. OSHA and MSHA use the term Standard Threshold Shift (STS) to describe and average change in hearing from the baseline levels of 10 dB or more at the frequencies 2000, 3000, and 4000 Hz. Upon finding OSHA/MSHA STS, certain actions are mandated including retest, evaluation of the adequacy of hearing protectors or requiring their use if not used prior to the STS event, and revision of the baseline audiogram. NIOSH uses the term Significant Threshold Shift to describe a change from baseline levels of 15 dB or more at any single test frequency 500 through 6000 Hz that is also present on an retest for the same ear-frequency condition. The NIOSH Significant Threshold Shift, called the 15 dB twice, same-ear, same-frequency method, can only be calculated and subsequently employed if the baseline audiogram is available for comparison at the time of the annual audiometric test. OSHA and MSHA do not require immediate check for Standard Threshold Shift. As a result, it may be days, weeks, or even months before the Standard Threshold Shift is documented and subsequent follow-up actions commence.

8.6. TYPES OF AUDIOGRAMS

Audiometric monitoring is critical to the success of a hearing loss prevention program in that it is the only way to determine whether occupational hearing loss is being prevented. When the comparison of audiograms shows temporary threshold shift (a temporary hearing loss due to noise exposure), early permanent threshold shift, or progressive hearing loss, it is time to take swift action to halt the hearing loss before additional deterioration occurs. Because occupational hearing loss occurs insidiously and is not accompanied by pain or other symptoms, the affected worker will not notice the change until a large threshold shift has accumulated. The results of audiometric tests can trigger changes in the hearing loss prevention program more promptly, initiating protective measures before the hearing loss becomes handicapping, and motivating employees to prevent further hearing loss.

8.6.1. Baseline Audiogram

The baseline audiogram is the audiogram obtained when someone is initially hired to work in a situation where potentially hazardous noise exists. NIOSH recommends that the baseline audiogram be obtained prior to employment or placement into hazardous noise. In order for the baseline to represent the best hearing that a person has prior to noise exposure, it is important that the period of time prior to the hearing test be free from exposure to high-level noise. If the person has not been exposed to high-level noise(defined as noise above 80 dB(A), occupational and non-occupational) for between 12 to 14 hours prior to the test, then the baseline audiogram should represent best hearing (i.e., be uncontaminated by temporary threshold shift). This is analogous to requiring a fasting period before tests are made of blood cholesterol levels. The goal is the same, baseline levels with no prior activity that would raise levels. (While OSHA requires a 14-hour pretest quiet period, NIOSH recommends 12 hours since the amount of recovery from temporary threshold shift for 12 versus 14 hours is negligible. A 12-hour is easier to manage for those employees with compressed work schedules such as four 10-hour days)

Many have suggested that in lieu of actual quiet, hearing protectors may be used prior to the baseline audiogram to achieve the pretest quiet period. While this makes management easier for the employer, it does not guarantee that the worker has actually had a quiet period. Research has shown that the noise reduction labels for hearing protectors over-predict the amount of actual

noise reduction by as much as 2000% (Berger, Franks, and Lindgren 1996). Thus, an audiogram that at face value is supposed to provide best hearing levels may, in fact, have a temporary threshold shift overlay. The best approach is to keep the employee from all known occupational noise exposures and to provide advice on how to avoid non-occupational hazardous noise. The following advice may be used as a practical guideline for helping the employee to know when noise is too loud: *if talking with someone in a background of noise requires raising one's voice to be heard at a distance of 1 m, the noise may be hazardous and should be avoided*. This same advice should also be given to a person to be seen for a baseline audiogram as part of a pre-employment evaluation.

8.6.2. Periodic-annual audiogram

In the United States, OSHA requires annual hearing testing for those exposed to noise levels equal or greater than 50% of the permissible exposure limit of 90 dB(A) eight-hour time-weighted average (TWA$_8$). The TWA$_8$ is based on a 5 dB exchange rate, so workers with exposures of 85 dB(A) TWA$_8$ are enrolled in the hearing conservation program and receive annual hearing testing. NIOSH, on the other hand, recommends that all employees exposed at or above the recommended exposure limit of 85 dB(A) $L_{Aeq,8h}$ receive annual hearing testing. NIOSH further recommends that the hearing tests be administered from the middle to the end of the work shift so that those employees who are experiencing temporary threshold shift may be identified. OSHA has no similar requirement or recommendation.

Editors' note: Appropiate procedures for baseline and periodic audiograms should be adopted in line with national practice and guidance. But one should have in mind that practising different procedures for baseline and periodic audiograms as expressed in this chapter has its implications, e.g. identification of the temporary threshold shift depends on the execution of a strict timetable related to the immediate daily noise impact, which is for various reasons impossible to manage properly in most cases.

For many companies that must use an outside provider of hearing tests, such as mobile audiometry testing services, it is most effective to test the hearing of all workers once a year over a few-day period. For companies that have on-site facilities for hearing testing, it is often convenient to test an employee at the same time every year, such as on a birthday or anniversary of employment. It is not always possible to ensure that all workers are tested exactly on the anniversary of the previous audiogram, so an acceptable window of time would be from 9 months to 15 months after the previous audiogram.

Noise-induced hearing loss can develop rapidly in workers exposed to relatively high noise levels on a daily basis. For example, the most susceptible 3 percent of a population exposed to average unprotected noise levels of 100 dB(A) $L_{Aeq,8h}$ could be expected to develop significant hearing threshold shifts before the end of one year (ANSI S3.44-1997). Thus, it may be good practice to provide audiometry twice a year to workers exposed to noise levels that equal or exceed 100 dB(A) $L_{Aeq,8h}$.

8.6.3. Immediate Retest Audiogram

In order to determine if a significant threshold shift exists, it is necessary to have access to the baseline audiogram. If the audiometry is done remotely from where the hearing loss prevention program's records are kept, it will not be possible to do the determination at the time of the periodic audiogram while the worker is still accessible to the tester and test facility. When this

is the case, a confirmation audiogram must be rescheduled for every worker with a significant threshold shift.

However, when the baseline audiograms are immediately accessible, a check for significant threshold shift may be made as soon as the hearing test is complete. If the condition for significant threshold shift is met, the worker can be reinstructed, the earphones can be refitted, and the hearing test may be administered again. Experience of some vendors finds that as many as 70% of those showing significant threshold shift on the periodic audiogram will not substantiate the shift on the immediate retest.

There are many reasons for this, the most common reason being familiarization with the threshold task of responding to low-level signals after a portion of the test has been completed, lack of concentration on the first test, or poor placement of earphones. When instructions are given again and the earphones are refitted, all of these situations may resolve and the immediate retest audiogram will show hearing levels not significantly different from those of the baseline audiogram.

8.6.4. Confirmation Audiogram

The confirmation audiogram is scheduled for all persons whose periodic audiogram or immediate retest audiogram indicated significant threshold shift. Those audiograms are considered to show pending significant threshold shift. If no confirmation audiogram were scheduled, those audiograms would automatically become confirmed significant threshold shift and thus the new reference audiogram (revised baseline audiogram) at the time of the next periodic audiogram.

As with the baseline audiogram, the confirmation audiogram should be preceded by at least a 12 to 14-hour quiet period, a period with no exposure to high-level occupational or non-occupational noise. As with the baseline audiogram, hearing protection should not be used to achieve the quiet. If the confirmation audiogram affirms the significant threshold shift, some follow-up actions are necessary. The first action involves assessing the worker's noise exposure, the adequacy of the worker's hearing protection and his or her ability to wear them correctly, and the training the worker has received about noise effects on hearing, protector use, and avoidance of hazardous noise at and away from work. The second action involves a determination that the threshold shift was not due to a factor other than exposure to noise. While this determination is not the purview of the occupational hearing conservationist, there are guidelines for making referrals to physicians for the purpose of establishing threshold etiologies (AAO 1983). More often than not, exposure to noise will be the default etiology in the absence of any other explanation. A third action might be recording the standard threshold shift as an occupational hearing loss on the OSHA Form 300 log or similar form.

If the confirmation audiogram fails to confirm the significant threshold shift and, if an immediate retest audiogram were performed, then the shift can be considered as a temporary threshold shift. OSHA gives no guidance regarding the management of those with temporary threshold shift. NIOSH recommends that the same actions be followed as for the worker with a confirmed threshold shift, other than referring the worker for a medical evaluation. In fact, this is a case where intervention with a better selection of hearing protectors and further training in recognizing noise hazards for best self-protective behaviors has a chance at preventing a permanent threshold shift. Successful intervention for the worker with temporary threshold shift makes the periodic audiometry program a tool for hearing loss prevention instead of a tool for hearing loss documentation.

8.6.5. Exit Audiogram

It is good practice to obtain an audiogram for those workers leaving a place or position with exposure to hazardous noise, whether because of transfer, cessation of employment, or retirement. The exit audiogram should be preceded by a period of quiet just as the baseline and confirmation audiograms. The audiogram will provide the best estimate of the worker's hearing at the termination of exposure to workplace noise for this employment situation.

The exit audiogram has more value for the employer than the employee, because it specifies the amount of hearing loss incurred while employed in this situation. In states where employers pay workers' compensation for only the amount of hearing loss acquired while the worker was on the payroll, the exit audiogram can limit employer liability.

8.6.6. Considerations for All Audiograms

Adherence to the following practices will ensure the best possible quality of audiograms:

- The audiograms should be administered using properly calibrated audiometers in a sound-treated room with acceptable ambient noise levels during testing. Circumaural earphone enclosures (earphones inside earmuffs), which are purported to reduce external noise, should not be substituted for a sound-treated room, and generally should not be used because of inherent problems with calibration and earphone placement.

- The same type of audiometer (and preferably the same instrument) should be used from year to year. This may help prevent measurement variations caused by subtle differences among instrument models/types or by the type of responses required from the person being tested.

- The training of audiometric technicians should meet as a minimum, in the United States and Canada, the current requirements of the Council for Accreditation in Occupational Hearing Conservation and any state requirements for audiometrists. Use of microprocessor-controlled or computer-based audiometric equipment should not exempt a technician from receiving training.

- All audiometric technicians should use the same testing methods for all of the company's employees.

- All testing should be done under the supervision of an audiologist or a physician knowledgeable about hearing loss prevention.

8.7. TRAINING AND SUPERVISION OF AUDIOMETRIC TESTING PERSONNEL

There is a tendency for the training of audiometric testing personnel to be dismissed as not really important. After all, this is only a pure-tone audiogram, not a diagnostic clinical test. In fact, the importance of the test itself is often diminished by referring to it as a "screening test." So, it is not uncommon to encounter the attitude that "anyone can do a hearing test."

In reality, the well administered pure-tone audiogram is the tool that signals the need for

intervention by identifying temporary threshold shift so that interventions can be employed to prevent permanent threshold shift. Thus, technicians must be well trained and be responsible to an audiologist or physician knowledgeable in the prevention of occupational hearing loss. *(See Editors' note in section 8.6.2)*

8.7.1. Occupational Hearing Conservationists

In the United States, certification of audiometric technicians dates back to 1965 when the Intersociety Committee was started by the American Association of Industrial Health Nurses, the American Industrial Hygiene Association, the Industrial Medicine Association, and the American Speech and Hearing Association. In 1966 the Intersociety Committee published the Guide for the Training of Industrial Audiometry Technicians (Intersociety Committee on Industrial Audiometric Technician Training 1966).

In 1972, the Intersociety changed its name to the Council for Accreditation in Occupational Hearing Conservation (CAOHC) and added additional representatives from the American Council for Otolaryngology, the Academy of Occupational and environmental Medicine, the National Safety Council, and the National Hearing Conservation Association as well as from the founding organizations and their successors. CAOHC is the only professional group involved in the development, review, and approval of course work that leads to a recognized certification. Each course director, who must be separately certified by CAOHC, must submit an occupational hearing conservation training course outline and faculty list to CAOHC before the course is taught and must use approved training materials. Those technicians completing the course are eligible for a five-year certificate in Occupational Hearing Conservation. The certificate may be renewed by taking a refresher course every five years.

The American Speech-Language-Hearing Association (ASHA), the certification body for audiologists in the United States, does not certify audiometric technicians or hearing conservationists. ASHA is one of the professional organizations with representation in CAOHC and so has influence in its certification processes and standards. Some states that licence audiologists are now beginning to require that audiometric technicians be registered by the state and supervised by an audiologist licensed by the state. This has resulted in situations where a national hearing testing company may have to allay with a local audiologist licensed by the state and register the company's technicians as under the supervision of that audiologist. Presently, California, Indiana, New York, and Ohio have such requirements.

8.7.2. Audiologist and Physicians

OSHA requires an audiologist, otolaryngologist, or a physician, to perform or supervise hearing testing and to provide general program overview including the supervision of audiometric technicians.

Audiologists are universally certified by ASHA once they have obtained the necessary academic and clinical training and pass a nationally administered examination. Those states that license audiologists have standards that are very similar to those of ASHA. In some states a person must be a licenced audiologist, hearing aid dispenser, or physician to even perform a hearing test. If an audiometric technician, one must be working under the direct supervision of an audiologist or physician licensed in the state. The definition of supervision varies from state to state.

Otolaryngologists are physicians who specialize in the practice of otology (ear diseases),

and laryngology (throat disease). Most often the otolaryngologist's practice will focus on the diagnosis, evaluation, and treatment of ear disease, while relying upon the audiologist to perform the hearing testing and assessment. However, some otolaryngologists who are particularly interested in occupational hearing loss may perform the actual testing as well as the training and supervision of technicians.

There is no mandated course of training for audiologists or otolaryngologists in the area of occupational hearing loss prevention. While a few graduate training programs have formal course work in occupational hearing loss prevention, most don't. The situation is similar for the otolaryngologists. Thus, those who work in the area do so because of interest, opportunity, or both. They are members of organizations such as the National Hearing Conservation Association where they meet with others of similar interest to exchange information. ASHA may eventually offer speciality certification in occupational hearing loss prevention.

8.8. PREPARING EMPLOYEES FOR AUDIOMETRIC TESTING

The most important part of an audiometric test is its beginning. If employees are not sure of the importance of the audiogram they are not likely to work as hard as they need to during the audiogram. Employees should be told that the hearing test is "hard work" and requires a measure of concentration and effort on their part. If there is no care as to the placement of the earphones prior to the test, there is great likelihood that there will be unsupportable threshold shift. If excellent instructions about how to listen and respond during the test are not given, the results may be inconsistent, frequency to frequency, ear to ear.

An example of the worst case scenario is one where employees are told that the purpose of the hearing test is to have a hearing test and their instructions run something like, "Put the blue phone on your left ear, and the red on your right, press the button when you hear the tone."

8.8.1. Pre-Test Information for Employees for Valid Tests

The employee needs to be informed of the purpose of the hearing test. If it is the baseline audiogram, its importance as the reference against which all future audiograms will be compared should be explained. If it is the periodic audiogram, it is important in identifying temporary threshold shift or confirming no change in hearing and thus needs explanation. The immediate retest needs to be explained in the light of substantiating a threshold shift. If the shift is not substantiated, the employee should be told that a vast majority of retests actually confirm the better hearing of the baseline. Similarly, the importance of the confirmation audiogram and the need for a 12 to 14-hour quiet period before the test should be explained. When exit audiograms are given, their importance in documenting the employees' hearing at the end of their exposure to potentially hazardous noise requires explanation. *(See Editors' note in section 8.6.2.)*

8.8.2. Earphone Placement

Figure 8.10 depicts the technician placing the earphones on the employee. This is critical. The audiometric earphone, cushion, and headband were not designed for comfort. If the employee places the earphones for most comfortable fitting, it will most likely not be the correct placement for audiometry. The correct placement is for the opening of the ear canal to be centered under the cutout in the earphone cushion for the earphone diaphragm. There should be no hair under the earphone cushion and eyeglasses and earrings need to be removed for testing.

Figure 8.10. Technician placing earphones on listener in an audiometric test booth

Care must be taken to place the left earphone over the left ear and the right earphone over the right ear. In many occupational settings, the earphone case will have a colored plastic cap, blue for left and red for right. Nonetheless, reversing the earphones is the most common mistake made in testing hearing, whether for occupational or clinical purposes.

On occasion the earphone placement will cause the tragus to close over the ear canal opening or cause the pinna to shift so that the ear canal collapses, thus closing off the path to the eardrum and raising hearing thresholds in the higher frequencies. When this happens, the technician has several options. The most common remedy is to place an otoscope specula or an insert tube specifically designed for that purpose in the ear canal and then gently place the earphone over it. In some cases, insert earphones are available for use in cases such as collapsed ear canals.

8.8.3. Instructions

The pure-tone hearing test, as stated at the beginning of this chapter, is an unusual test. The employee encounters nothing similar in his daily life. Therefore, good instructions are essential for getting good results. Good instructions should resolve all uncertainties about the test, doing everything possible to make the test easy for the employee up to the point of pressing the response button.

8.8.3.1. Manual audiometry

A suggested instruction set for manual audiometry follows:

Do you hear better out of one ear than the other? (If yes, ask which ear. If no, then start with the right ear.) You will be hearing some faint tones, first in your <better or right> ear and then in your <other or left> ear. The tones will be pulsing so that you will hear a chain of beeps and then silence. Listen for the beeps and when you hear them <press this button or raise your hand> to signal that, -Yes, I hear them. The beeps will generally get fainter and fainter each time they are presented. <Press this button or raise your hand> whenever you think you hear the beeps. The pitch of the tones will change, first going lower in pitch and then going higher in pitch. The test of your <other or left> ear will not begin until your <better or right> ear has been tested for all of the frequencies. If you are certain that you hear the beeps, you don't have to wait for the beeping to stop to <press this button or raise your hand>. And, you don't have to <hold the button down or hold your hand up> for as long as you hear the beeps. A simple <press and release or hand raise and fall> will do. So, if you haven't any questions, I will put the earphones on and we can start the test. (Answer any questions.) Please wait for me to remove the earphones when the test is over.

8.8.3.2. Self-recording audiometry

A suggested instruction set for self-recording (automatic) follows:

Do you hear better out of one ear than the other? (If yes, ask which ear. If no, then start with the right ear.) You will be hearing some faint tones, first in your <better or right> ear and then in your <other or left> ear. The tones will be pulsing so that you will hear a beep-beep-beep-beep sequence. Listen for the beeps and when you hear them press and hold down this button. Press this button as soon as you think you hear the beeping. As you hold the button, the beeps will get fainter and fainter until you can no longer hear them. Hold the button down for as long as you hear the beeping and then release it as soon as you think that you can no longer hear the beeping. You will be pressing the button when you hear the beeps and releasing the button when you don't hear the beeps. After about one-half minute the pitch of the tones will change, first going to a lower-pitched tone and then going higher pitched tones. Once your <better or right> ear has been tested for all of the frequencies, the test of your <worse or left> ear will begin. So, if you haven't any questions, I will put the earphones on and we can start the test.(Answer any questions.) Please wait for me to remove the earphones when the test is over.

8.8.3.3. Microprocessor-controlled audiometry

A suggested instruction set for microprocessor-controlled audiometry follows:

Do you hear better out of one ear than the other? (If yes, ask which ear. If no, then start with the right ear.) You will be hearing some faint tones, first in your <better or right> ear and then in your <other or left> ear. The tones will be pulsing so that you will hear three beeps and then silence. Listen for the beeps and when you hear them press this button to signal that, -Yes, I hear them. The beeps will get fainter and fainter each time they are presented until you don't hear them and then they will increase so that you can just hear them. They will never get very loud. Press this button whenever you think you hear the

beeps. The pitch of the tones will change, first going to a lower tone and then going to higher and higher tones. The test of your <other or left> ear will not begin until your <better or right> ear has been tested for all of the frequencies. If you are certain that you hear the beeps, you don't have to wait for all three to press this button. And, you don't have to hold the button down for as long as you hear the beeps. A simple press and release will do. So, if you haven't any questions, I will put the earphones on and we can start the test. (Answer any questions.) Please wait for me to remove the earphones when the test is over.

8.8.4. Employees with Testing Problems

Various problems may be encountered during audiometric testing. The following is adapted from Morrill (1986).

8.8.4.1. Physiological Problems

A. Tinnitus (head noises) that become more noticeable in the quiet test environment when earphones are worn. In some cases the tinnitus may be confused with the test tones. In rare cases, test tones can initiate tinnitus, even beeping tinnitus. Persons with tinnitus that interferes with testing should be referred for clinical testing.

B. Ear-hand coordination (latency in the response such as pressing the response button) may make the administration of self-recording or microprocessor-controlled audiometry impossible. An technician experienced with manual audiometry will know to allow adequate time for the person to respond after a tone sequence is presented.

C. Fatigue that causes the listener to fall asleep in the quiet and darkened test booth. If often helps to have the listener take a walk before retesting.

D. Ear disease and or wax impaction will complicate testing hearing. Ear disease may have accompanying drainage, which will not be a hygiene problem if disposable polypropylene earphone covers are used. While the tympanic membrane may not be visible due to obstruction by wax, as long as there is the smallest airway, hearing thresholds should not be affected.

E. Existing hearing loss may make the start of audiometry more difficult because the listener will require a higher initial signal level. It may also happen that the listener is not able to hear signals at some frequencies at the maximum output levels of the audiometer.

F. Unilateral hearing loss may be sufficient that it is not possible to know without contralateral masking if the thresholds for the worse ear are actually valid or if the crossover signal was heard in the better ear. In some settings insert earphones will be available, increasing the interaural attenuation from the 40 dB for earphones to as much as 60 dB or more, allowing a better assessment of the hearing in the poorer ear. In any case, when a unilateral hearing loss is observed for the first time, the employee should be referred to a clinical a setting for a complete hearing test.

8.8.4.2. Response problems

A.   Intelligence and comprehension may have an effect on the employee's ability to respond appropriately to the test signals. Arrangements should be made to provide detailed test instructions in a language other than English, if the employees do not have a functional ability to understand English. Do not, however, assume that written instructions in English or another language will suffice, since many persons may not be literate in the language in which they converse.

B.   Persons under the influence of prescription or non-prescription drugs or alcohol may often be drowsy, have drug-induced tinnitus, and may have problems following instructions. If a reliable audiogram can't be obtained, then referral for clinical testing may be necessary.

C.   Anxiety, fear, or confusion can make taking a hearing test very difficult. Some employees may have test anxiety. Be aware also that some employees may have claustrophobia that prevents them from remaining in a test booth for the duration of the hearing test. Referral to a clinical facility with a larger test booth may help alleviate claustrophobia.

8.8.4.3. Malicious Intent

A.   Labor relations problems.

B.   Malingering to either inflate or deflate thresholds. It is just as common to find an employee trying to hide a hearing loss as it is to find an employee trying to fake a hearing loss.

C.   Clowning behavior that makes administration of the test difficult and is especially disruptive of group hearing testing environments.

D.   Compensation problems may make the employee hesitant to provide adequate historic information.

8.9. SUPPORTIVE INFORMATION

An audiogram or a collection of audiograms is of diminished value in the absence of collateral supportive information. While audiograms alone are sufficient for calculation of threshold shift, they are insufficient when it comes to planning interventions for employees with threshold shift or for understanding employees who don't experience threshold shift. Similarly, without collateral information it is difficult to substantiate test results for workers' compensation or litiginous cases.

8.9.1. Employee Demographics

Figure 8.11 displays an audiometric and identification information form. This form presents the minimum data that should be collected for an employee. It supports recording the audiogram and has a place for recording the baseline audiogram as well. This audiogram can be partially filled out prior to testing, such as recording identification information and the baseline audiogram if

Audiometric and Identification Information

Name _____

Soc. Sec. # _____ -__-_____   Birth Date __/__/__   Gender M F (Circle)

Empl No: _____   Job Code _____   Dept No _____

Test Date __/__/__ Time __:__   Test Type _____   Time since last exposure _____ h

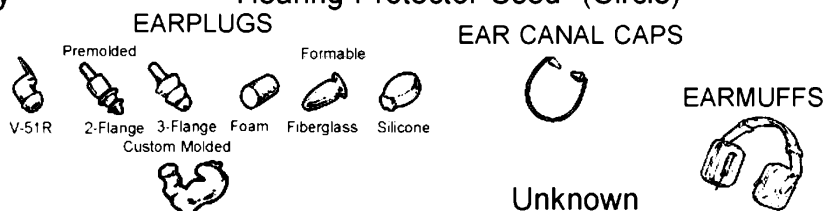Exposure Level ___ dBA

Hearing Protector Activity

Yes _____ No _____

Issue _____

Reissue _____

Training _____

Retraining _____

Hearing Protector Used (Circle)

EARPLUGS

Premolded   Formable

V-51R   2-Flange 3-Flange Foam Fiberglass Silicone
         Custom Molded

EAR CANAL CAPS

EARMUFFS

Unknown

Self-Reported Employee Histories

(Y/N) Medical History   (Y/N) Hobby & Military History   (Y/N) Additional Information
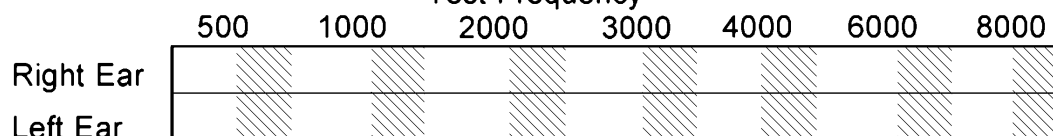
_____ Diabetes   _____ Hunt/Shoot   _____ Noisy 2nd Job
_____ Ear Surgery   _____ Car racing   _____ Noisy Past Job
_____ Head Injury   _____ Motorcycles   _____ Exposure to Solvents
_____ High Fever   _____ Other Loud Vehicles   _____ Exposure to Metals
_____ Measles   _____ Loud Music/Band   _____ Difficulty Hearing
_____ Mumps   _____ Power Tools   _____ Hearing Aid
_____ Hypertension   _____ Other Noisy Hobbies   _____ Recent Change in Hearing
_____ Ringing in Ears   _____ Military Service   _____ See Physician About Ears
_____ Ear Infection   _____ Fire Weapon   _____ See Prior Histories
_____ Other   _____ Other   _____ Other

Audiogram

Baseline Thresholds

Test Frequency

	500	1000	2000	3000	4000	6000	8000
Right Ear							
Left Ear							

Audiometer _____   Serial Number _____
Exhaustive Cal. Date __/__/__   Biological Cal. Date __/__/__
Tester Identificaiton ___-__-____   Test Reliability (Good, Fair, Poor) __
Review Identification ___-__-____   Audiogram Classification Code __ __ __

Comments

Figure 8.11. Sample audiogram and collateral information form

one exists, and then be completed at the time of the hearing test. It can also be used to counsel the employee at the end of the test.

The top of the form collects personal information such as name, identification number, birth date, gender, job code, department number, test date, test time, test type, time since last exposure to occupational noise, and occupational noise exposure level. The baseline audiogram values can be placed in the grey boxes. This is very basic information, but more than many hearing conservation programs collect. In the United States, information about race is either not collected or its provision is optional at the discretion of the employee, but it is useful information to have if possible as expected hearing levels vary by race.

8.9.2. Employee Hearing Protector Use History

This form contains information about whether hearing protection is used at work, whether it is issued or reissued at the time of the hearing test, and whether or not training or retraining has occurred. The form provides sketches of various types of earplugs, ear canal caps, and earmuffs, asking that the type used be circled. In the ideal hearing loss prevention program, the style, make, and model of the hearing protector used would be provided and the attenuation actually received by the worker would be tested and recorded.

8.9.3. Hearing and Related Health

There are conditions of the ear and overall health that are positively correlated with hearing loss or susceptibility to noise-induced hearing loss. Previous studies have shown that persons with histories of diabetes, head injury resulting in concussion, prolonged high fevers, post adolescent measles and mumps, and hypertension are at greater risk of noise-induced hearing loss (Franks, Davis, and Krieg 1989). Other ear conditions such as prior ear surgery, ringing in the ears, and ear infection can cause hearing loss independent of noise exposure. Interestingly, hearing losses due to middle ear disorders are protective against noise-induced hearing loss.

8.9.4 Noisy Hobbies and Military History

Not all exposure to noise comes at work. People may have non-occupational activities that expose them to hazardous noise such as hunting or shooting, using power and hand tools, riding snowmobiles or motorcycles, and listening to loud music. NIOSH has determined that personal stereos are capable of delivering music levels that are just as potentially hazardous to hearing as many occupational noises (Tubbs, Sizemore, and Franks 1997). As well, many persons, particularly males, will have been in the military and may have been exposed to weapons fire, artillery, or heavy equipment noises. These exposures, if they occurred in the past, may account for hearing loss that pre-dated employment; or, if the exposures are continuing into the present, may combine with noises at work to increase the employee's daily noise burden.

8.9.5. Additional Information

There are other instances that can contribute to hearing loss that is observed in a hearing loss prevention program. Persons with noisy past jobs may have pre-existing hearing loss. Some people may have a noisy second job, a job that is as noisy or noisier than the present job which contributes to their noise-induced hearing loss. Research has shown that exposures to solvents

such as toluene and styrene and metals such as lead and mercury can cause hearing loss and, that when there are combined solvent-noise or metal-noise exposures, the risk of hearing loss is higher than for exposures to the agents alone (Morata and Franks 1996, 1997).

8.10. REVIEW AND TREATMENT OF AUDIOGRAMS

An audiogram is a medical record, regardless of the conditions under which it was obtained. The pure-tone air-conduction audiogram obtained as part of an occupational hearing conservation program is no less a medical record than a complete audiogram obtained in a hospital, clinic, or private practice office. As such it should be treated as any other medical record, including a quick interpretation, development of successive management strategies, and the protection of the privacy of the person.

Unfortunately in the United States, audiograms are often treated as if they were tax forms with handling avoided until the last possible moment. As much as a year may go by before the employee is advised through his employer about the results of the last test, how they related to the previous test, and whether any additional hearing protective actions need to be taken. Workers may assume falsely that if they receive no information about their hearing test, there is not a problem.

Each audiogram should be compared to the baseline audiogram to determine if there has been a significant threshold shift. *Even when there has not been a shift*, the worker should be told so and given positive reinforcement that present hearing protective measures are working. If there has been a shift, actions should be taken to discover why and appropriate interventions should be initiated with the informed worker as the centerpiece.

8.10.1. Definition of Problem Audiograms

Sometimes circumstances make it difficult to have an audiologist or physician review every hearing test. This may be true whether testing is done on-site by the company at its health station or by a mobile occupational health testing service. Therefore, some rules need to be developed that will identify those audiograms that must be seen by a professional from those that may be reviewed by the tester.

8.10.1.1. Hearing impairment

Figure 8.12 displays both a graphic and tabular audiogram. The lightest shaded area of the graphic audiogram in Figure 8.12 is the range of normal hearing. In most cases, when the hearing level at any frequency for either ear is 25 dB HTL or greater, hearing at the frequency is considered to be impaired. The first frequency to cross the 25 dB HTL fence for most noise-exposed people will be 4000 or 6000 Hz. For the audiogram to indicate that a person is hearing-impaired; however, the average hearing loss for a set of adjacent frequencies must exceed 25 dB HTL. NIOSH recommends that those frequencies be 1000, 2000, 3000, and 4000 Hz and that the binaural average equal or exceed 25 dB HTL.
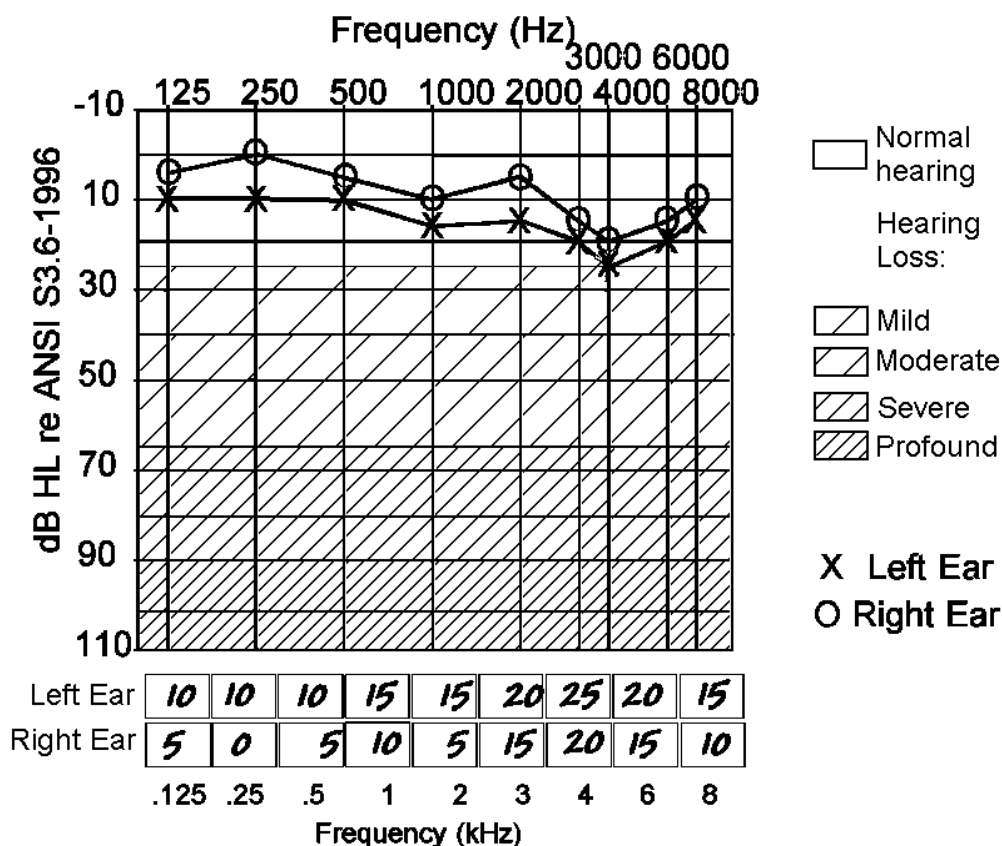
Figure 8.12. Graphic audiogram showing ranges of hearing from normal to profound hearing loss. Normal audiogram is plotted and values are entered in table below audiogram as well.

The first time an employee's audiogram shows impaired hearing, it should be seen by a professional reviewer. Many workers with prior noise exposure at other facilities will show impaired hearing on the baseline audiogram. It is necessary for the reviewer to determine if the hearing loss is noise-induced or possibly due ear disease or some other factor such as systemic infection, physical trauma, or familial tendency to develop early-onset age-related hearing loss. Often this will require that arrangements be made for an evaluation by an audiologist, a physician, or both.

Any time a periodic audiogram shows hearing thresholds that are poor enough to meet the definition of impaired hearing, the audiogram should be seen by the reviewing professional. It is possible that a person's hearing will worsen to the point where it is described as impaired, but not sufficiently to qualify for a significant threshold shift, especially for the worker whose baseline hearing thresholds are at the upper boundary of normal hearing.

Once a person with hearing-impairment is identified and a probable etiology is established, it will usually not be necessary for subsequent review and referrals if the hearing stays the same on subsequent tests. Of course, the reviewing professional may wish to see all future hearing tests for that person; the managing audiologist or physician may wish to actually conduct the subsequent examinations as well.

It is tester's role to identify hearing impairment according to established criteria set by the professional reviewer. It is also the tester's role to compare the current audiogram to the baseline audiogram to identify significant threshold shift. Threshold shift is not related to hearing impairment. A threshold that shifts from 0 to 15 dB is as important as one that shifts from 35 to 50 dB and should evoke the same subsequent actions.

8.10.1.2. Interaural difference

Sometimes the audiogram will document a difference between the hearing sensitivity of left and right ears. It is not normal to have exactly the same hearing threshold levels in both ears at all test frequencies. However, in the absence of ear disease or other insult, the differences between the two ears will be small, typically 15 dB or less. The reviewing professional should set rules for when the interaural difference is sufficient to require referral for professional review.

Figure 8.13 displays a graphic and tabular audiogram showing normal hearing for the right ear and a hearing loss for the left. When the difference between left and right hearing thresholds
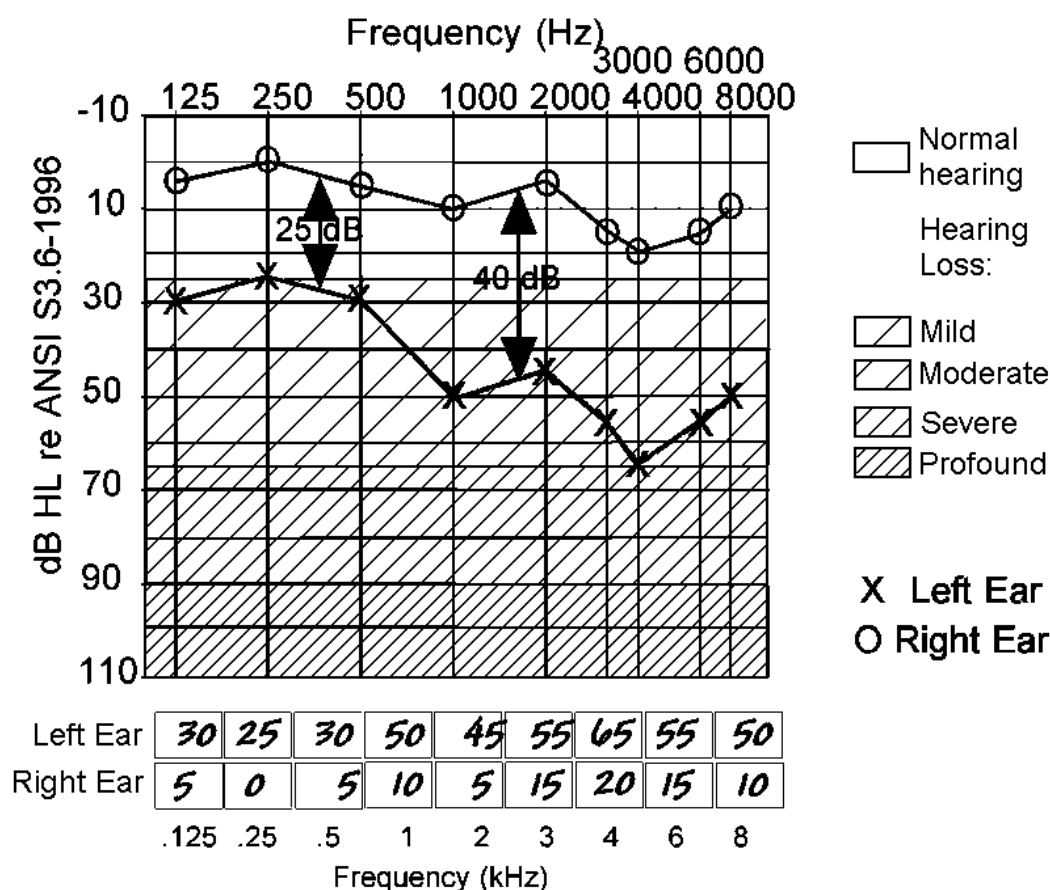
	.125	.25	.5	1	2	3	4	6	8
Left Ear	30	25	30	50	45	55	65	55	50
Right Ear	5	0	5	10	5	15	20	15	10

Figure 8.13. Maximum differences between ears for reliable air-conduction thresholds. Shown are hearing thresholds for right an left ears (values also shown in table) to demonstrate maximum frequency-dependent interaural differences. The right ear shows a 4000-Hz notch, but normal hearing sensitivity, while the left ear shows a moderate high-frequency loss with 4000-Hz notch.

equals or exceeds 25 dB in the lower frequencies (500 Hz or less) there is the possibility that the apparent thresholds for the poorer ear actually represent crossover responses for the non-test ear. Crossover thresholds may occur for frequencies at or above 1000 Hz when the interaural difference is 40 dB or more.

The only sure way to determine the hearing thresholds for the poorer ear is to use masking noise for the better ear while testing the poorer ear. Masking is usually not available with audiometers used for testing in occupational hearing loss prevention programs and most testers are not trained to obtain masked thresholds.

Figure 8.14 displays audiometric results for which there is an interaural difference, but where the difference is not greater than 25 dB at 500 Hz and below nor greater than 40 dB at 1000 Hz or above. Instead, the shape of the audiogram, the audiometric contour, is not the same for both ears. The right ear has a notch at 4000 Hz and recovery at 8000 Hz such as would be expected for a person exposed to noise. The left ear also has impaired hearing at 4000 Hz, but the hearing does not recover at 8000 Hz as it does for the right ear. This type of asymmetry of contour may be medically significant and is another reason for the audiogram to be referred to the reviewing professional.

8.10.1.3. Change since last hearing test

Just as no person's left ear will have exactly the same hearing levels at the same frequencies as the right, no person's audiogram will be exactly the same for each successive hearing test. There will be variations due to placement of the earphones, time of day, fatigue level of the person, and other factors. The problem, then, is how much change between successive audiograms should be attributed to normal variation and how much change should trigger referring the audiogram to the reviewing professional.

In many cases in the United States, the criteria for change sufficient to trigger referral is the same as the definition of OSHA Standard Threshold Shift; an average change of 10 dB or more for the frequencies 2000, 3000, and 4000 Hz in either ear compared to the baseline audiogram. Following this rule might trigger an audiogram for review if the hearing at all three frequencies worsened by 10 dB (which is within the scope of normal test-retest variation). However, at the other extreme, the hearing at 4000 Hz can worsen by 30 dB while the hearing at 2000 and 3000 Hz remains unchanged (or more than 30 dB at 4000 Hz if the hearing at either 2000 or 3000 Hz improves by 5 dB). Royster (1996) recommends that the OSHA Standard Threshold Shift not be used as the sole criteria for change sufficient to trigger referral to the reviewing professional. She suggests that "sub-OSHA" threshold shifts also be used to identify a person before a Standard Threshold Shift occurs.
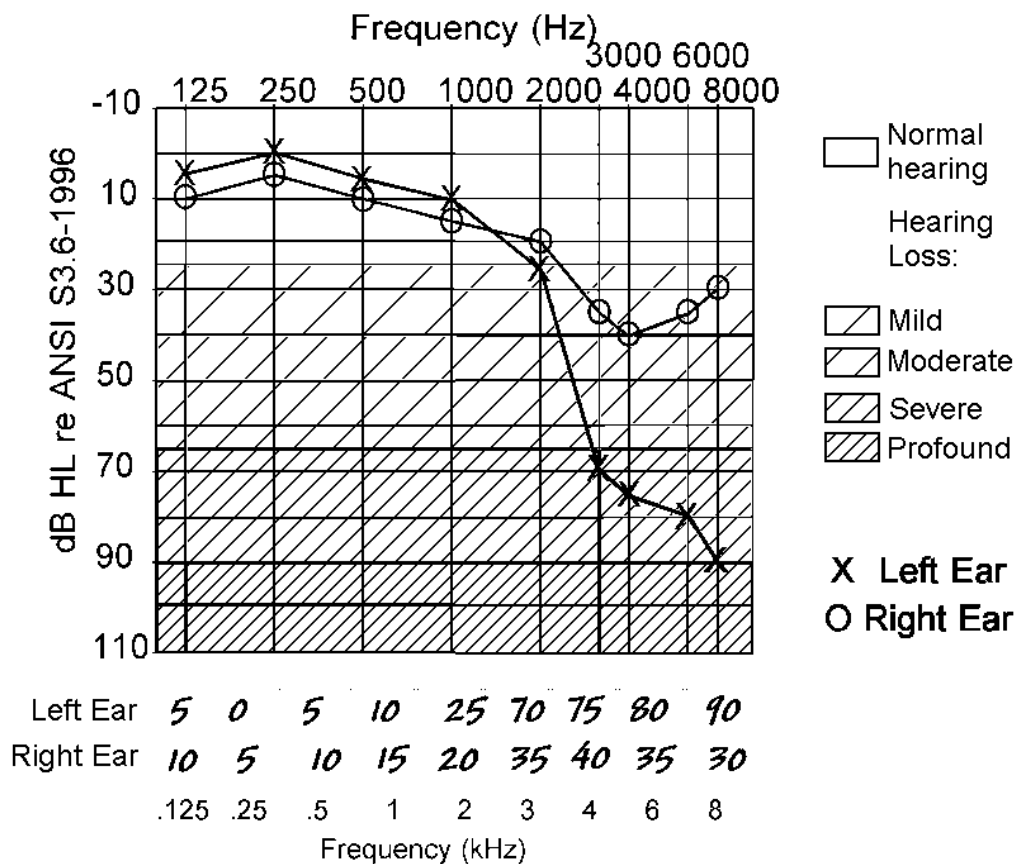
Figure 8.14. Audiogram asymmetric depicting high-frequency hearing loss. The right ear shows a mild high-frequency loss with notch at 4000 Hz. The left ear shows a severe-to-profound high-frequency hearing loss with no notch. Audiograms showing this type of asymmetry usually trigger a referral for clinical evaluation.

NIOSH defines a significant threshold shift as a change in hearing of 15 dB or more as compared to the baseline audiogram at any single frequency, 500 through 6000 Hz. The NIOSH recommendation takes into account that normal time-to-time variations in hearing thresholds may be as large as 10 dB, thus reducing the likelihood of referring an audiogram for review that is just showing normal variation. In order for the threshold shift to be significant, the 15 dB or more change must appear on a subsequent audiogram for the same ear and the same frequency. If that subsequent audiogram is the immediate retest, the shift is considered to be pending and a confirmation audiogram should be scheduled. The confirmation audiogram is preceded by a quiet period of 12 to 14 hours. If the confirmation audiogram affirms the 15 dB or greater threshold shift for the same ear and frequency, the shift is considered to be confirmed.

A pending threshold shift that is not confirmed is most likely to be a temporary threshold shift that resolved when the person had an adequate time away from the noise. It is important that the events that led to the temporary threshold shift be identified so that the person will experience no further temporary shifts as he or she continues to work in hazardous noise. Except in cases of acoustic trauma, where hearing loss is caused by one event such as blast overpressure, permanent threshold shifts may be preceded by hundreds or thousands of temporary threshold shifts. Preventing temporary threshold shift prevents permanent threshold shifts.

A pending threshold shift that is confirmed also requires actions to make sure that the

person's hearing does not further degrade. In addition, the confirmation audiogram also becomes the revised baseline audiogram to which all future subsequent hearing tests are compared. Thus, subsequent referral of a person's audiogram for review would not occur unless and until the criteria for significant threshold shift were met again.

8.11. SUMMARY

A very common occurrence in occupational hearing loss prevention programs is the underestimation of the difficulty inherent in the measurement of hearing in the occupational setting. There must be a continuous quality assurance process in place to assure that each audiogram reflects to the extent possible, the worker's hearing at the time of the test. Without continuous quality assurance, unreliable, unrepeatable audiograms become part of the record. NIOSH has analyzed large audiometric databases for the purpose of identifying invalid audiograms. In many cases, only a few audiograms were found to be invalid. However, in other cases, almost half of the hearing tests were invalid (Franks 1996, 1997). It becomes impossible to evaluate the program's success in preventing hearing loss when it becomes impossible to track accurately the progress of each individual worker in the program. The quality assurance steps should involve the evaluation of each audiogram in light of those audiograms that preceded it with acceptance of the new audiogram once all changes in hearing have been assigned a reason.

Morrill (1986) lists testing problems such as excessive ambient noise levels in the test booth, poor instructions, poor testing techniques, instrument calibration errors, employee response problems, inappropriate hearing protection, and medically referable conditions as other reasons for test variability (see Section 8.8.4). A quality assurance program should identify these and have established steps to be taken in case of each of these.

Workers enrolled in an effective hearing loss prevention program should be able to complete their careers without incurring an occupational hearing loss. Accurate audiometry is the key to spotting and responding to temporary threshold shifts in order to prevent workers from developing permanent threshold shifts and eventually handicapping noise-induced hearing loss.

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INTERNATIONAL STANDARDS

Titles of the following standards related to or referred to in this chapter one will find together with information on availibility in chapter 12:

ISO 389, ISO 645, ISO1999, ISO 6189, ISO 8253
IEC 60651, IEC 60804

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