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**Development of an Audiological Test Procedure Manual for First Year Au.D. Students**

Patricia I. Carr

Professional Research Project

Submitted to the Faculty of the University of South Florida

In partial fulfillment of the requirements for the degree of

Doctor of Audiology

Raymond M. Hurley, Chair

Theresa Hnath-Chisolm

Jennifer L. Lister

A professional research project submitted in partial fulfillment

of the requirements for the degree of

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(ABSTRACT)

A student manual of audiological procedures with accompanying laboratory assignments does not presently exist at the University of South Florida (USF). In the first year of the four year Au.D. program at USF, students are enrolled in Audiology Laboratory Clinic I, II, and III, in consecutive semesters. Groups of four to six students meet weekly for a 3-½ hour clinical laboratory session to receive training in test instruction, test procedures, test application, and test interpretation. The purpose of the first year Audiology laboratory clinic sessions is to prepare the student for clinical experience in year two of the Au.D program at USF. In preparation for these laboratory sessions, it was discovered that materials related to test procedures are currently scattered throughout a variety of texts, journals, manuals, educational software, videos, and web sites. No one source contains all the needed information on any given test procedure. In addition, specific procedures outlined in documents [American Standards Institute (ANSI) and the American Speech-Language-Hearing Association (ASHA)] are not consistently used by the different sources. Thus, there is no standard procedural manual containing laboratory assignments that lead to the development of appropriate clinical testing skills by a first year Au.D student. A standard test procedural manual for pure tone audiometry, speech audiometry, and immittance testing, with assignments, was developed to assist in the cultivation of the students testing skills. The manual contains test history, purposes, procedures, scoring guidelines, interpretations, and limitations for each test. Laboratory assignments include practice exercises using a computer simulator, classmates, and volunteers. Each assignment is accompanied by discussion questions to enhance and augment student understanding. A reference list is available to obtain further information on each topic area. This manual will be made available to the first year Au.D student as well as to the advanced Au.D student who would benefit from an all-inclusive, updateable source providing the best possible clinical procedures. The final product will be available for a fee in a notebook type format to allow for the inclusion of additional topics and updates as the standards of practice in Audiology change.

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I would like to thank God for giving me the strength, encouragement, and ability to complete this project. I am still in awe as to how my fingers would flow across the keyboard and at how the words just appeared on the screen.

Furthermore, I would like to thank my loving husband, James, and our two wonderful children, James and Becca. They have put up with a lot over the past several years. I did my best to be there at those special moments and times of need, but couldn't be there for all of them. Yet you were all there when I needed the encouragement during the numerous times when I wanted to quit. I will now be able to make up for the time lost with each of you and as a family, which will take the rest of our lives.

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## CHAPTER 1

## PURE TONE AUDIOMETRY

Key Words

Air conduction	Audiometer	Automatic Audiometry
Bone conduction	Hughson-Westlake	Manual pure tone audiometry
Method of limits	Threshold	

History and Background Information

Normative pure tone threshold values have existed since 1951 with the publication of the American Standards Association Document: “Audiometers for General Diagnostic Purposes”. (ASA, 1951). Pure-tone audiometry began after the Bunch and Dean presentation of the “Pitch Range Audiometer” in 1919 before the American Otologic Society (Bunch, 1943). In 1978, the standard procedure for pure-tone threshold testing was established. (ANSI, 1978).

Pure-tone audiometry is part of the basic audiometric evaluation and consists of air conduction (AC) and bone conduction (BC) testing. There are two methods that may be used in the clinical setting. These are manual pure tone audiometry and self tracking automatic audiometry (Bekeesy-type audiometry). The reader is encouraged to refer to the references for further information regarding the Bekeesy-type automatic audiometry. This manual will concentrate on the method known as manual or conventional pure tone audiometry.

Prior to obtaining thresholds, the tester must decide which psychophysical threshold procedure to use with the particular patient. The procedure selected depends on the reason for the evaluation, stimuli available, and the patient. There are a variety of threshold procedures such as single stimuli, counting, forced choice, adjustment, limits, tracking, and staircase that the tester may select to use, either alone, modified, or in combination, in the determination of hearing thresholds. The reader is directed to the references for further detail on each of these

methods. The method discussed here is an ascending technique using a modified method of limits procedure; the modified Hughson-Westlake technique (Carhart & Jerger, 1959).

As a person's hearing sensitivity is being measured in dB HL across frequencies, usually octave intervals of 250 to 8000 Hz, the results are plotted on a graphic audiogram or numerical audiogram for both AC and BC testing. See "Recording and Scoring of Test Results" under Air Conduction and Bone Conduction Testing.

### Definition

Pure-tone audiometry is used to determine the threshold of hearing of the patient and is defined as the lowest hearing level at which the patient responds at least 50% of the time to auditory stimuli. Thresholds are generally obtained for each ear separately. These thresholds are obtained using procedures as recommended by the American Speech-Language-Hearing Association (ASHA) 1977 Guidelines, the American National Standards Institute (ANSI) 1987 and 1992 Guidelines, and the International Standards Organization (ISO) 1982 and 1984 Guidelines. (Wilber, 1999).

### Purpose of the Test

1. To determine the hearing threshold levels for the patient.
2. To determine if a hearing loss is present and if present, the amount of the loss.
3. To determine the type of hearing loss.

### Test Procedure

There are several techniques that may be used by audiologists in the clinical setting. These include the Carhart-Jerger (1959) modification of the Hughson-Westlake (1944) ascending technique, and the ANSI (1978) and ASHA (1978) testing guidelines. The various techniques may also be described by the direction of intensity change (ascending or descending). The ascending approach will be discussed at this time and the reader is directed to the references for information regarding the descending approach. Typically, the auditory stimuli are first presented at supra-threshold levels. For each of the techniques, a tone familiarization process is conducted to determine a dB level near the patient's threshold. From there, the intensity of the stimulus is increased or decreased depending on the patient's response. If the patient responds to

the tone, the intensity of the next tone is decreased in 10 dB steps until the patient ceases to respond. If the patient does not respond to a tone, the intensity of the tone is increased in 5 dB steps until the patient responds. This is known as the “up-5 down-10” technique. This “up-5 down-10” process is repeated until the level at which the patient responds to two out of three presentations or three out of six presentations is determined. Stimuli are presented for one to two seconds with varying time intervals between presentations. The patient indicates that auditory stimuli were heard by responding via handraising, raising a finger, or pushing a button. See for “Step-by-Step Procedures” below for details.

Other procedures may be necessary for children, older patients, and difficult to test patients. The standard procedures for threshold determination will be covered at this time, the reader is directed to the references for further information regarding testing special populations.

## INSTRUMENTATION

### Audiometer

A diagnostic audiometer is capable of producing pure tones at various frequencies as well as broad-bands of noise and narrow-band noise. Another type of audiometer that usually produces pure tones is the screening audiometer. The diagnostic audiometer is the instrument that will be discussed in this manual. The reader is directed to the references for information regarding screening audiometers. The audiometer used in pure tone audiometry must meet the specifications as outlined by the American National Standard Specifications for Audiometers S3.6-1969 (ANSI, 1969). The major components of an audiometer are the oscillator, the attenuator, and the interrupter switch. The oscillator produces pure tones at octave and half-octave frequencies from 125 to 8000 Hz. Some audiometers may have extended high frequency capabilities up to 20,000 Hz. The attenuator controls the intensity level of the pure tones in 5-dB steps and some audiometers are capable of producing 1-or 2-dB steps. The interrupter switch controls the length of time the pure tone is presented to the patient. For other features available on an audiometer, the reader is directed to the manufacturer’s manual that accompanies the audiometer to be used. At the beginning of each test day the tester must perform a biological listening check to ensure that all components are functioning properly. Refer to the listening check procedure used by your testing facility.

**GO TO LABORATORY  
EXERCISE # 1.0**

Calibration

The audiometer used in pure tone testing along with the earphones, insert receivers, and speakers should be calibrated at least annually based on the ANSI S3.6 – 1996 Guidelines (ANSI, 1996). The bone vibrator should be calibrated at least annually based on the ANSI S3.43- 1992 Guidelines (ANSI, 1992) for frontal or mastoid placement.

Test Environment

Pure tone threshold testing should be administered in a sound controlled room to avoid masking by unacceptable noise levels in the room (Wilber, 1999). Appendix A shows the acceptable ambient noise levels, as stated in ANSI S3.1 (ANSI, 1991), that may be present in a room so that thresholds as low as 0 dB HL may be obtained.

AIR CONDUCTION (AC) TEST

Key Words

Acoustical radiations	Azimuth	Bilateral hearing loss
Circumaural earphones	Collapsing ear canal	Conductive hearing loss
False-negative response	False-positive response	Graphic audiogram
Insert receivers	Interaural attenuation	Mixed hearing loss
Numerical audiogram	Peripheral hearing	Pulse-tone
Sensorineural hearing loss	Speakers	Standing waves
Steady tone	Supra-aural earphones	Tactile responses
Transducer	Unilateral hearing loss	Warble tone

Background Information

Hearing thresholds are obtained to determine whether the patient has a peripheral hearing loss: a hearing loss in the external ear, the middle ear, or the cochlea. Air conduction (AC)



thresholds are obtained for a frequency range for each ear and are defined as the lowest hearing level at which the patient responds at least 50% of the time to auditory stimuli.

### Instructions to the Patient

Patient instructions must be clear and explicit. They must be worded in the appropriate language to meet the particular needs of the patient. At various times throughout the testing, instructions may need to be modified depending on the patient's state and the presence of false positives and false negatives. The instructions should include, but are not limited to the following (ASHA, 1990; Gelfand, 1997; Martin, 1998):

- a. Orientation of the patient to the nature of the task;
- b. Specification of the mode of response to the patient;
- c. The type of stimulus that will be heard;
- d. The importance of listening to the faint loudness levels, and then responding at these levels as well.

An example of instructions the tester may use is as follows (Martin, 1998):

*This test is used to find the softest sounds you can hear. I will be putting these earphones over your ears. They will feel somewhat snug. You are going to hear tones, some of which some will sound like beeps, horns, and whistles. Some of those sounds will be loud and others will be soft, so soft that they will be difficult for you to hear. Your job is to raise your hand every time you hear a tone, even when they are very, very soft and you can barely hear it. When you no longer hear the tone, put your hand down. I will test one ear at a time. Do you have any questions?*

## INSTRUMENTATION

### Test Stimuli

The test stimuli used in AC testing are pure tones of different frequencies. Usually the patient's thresholds are determined using the octave frequencies from 250 to 8000 Hz. There are some instances, especially in the monitoring of high frequency hearing loss due to ototoxicity where frequencies above 8000 Hz and up to 20,000 Hz are assessed. Tones used in pure tone audiometry include continuous pure tone, pulsed pure tone, or warble tone.

### Transducer

AC testing may be administered using earphones, insert receivers, or speakers (ANSI, 1996). The selection of the appropriate transducer to use with a patient is usually determined by patient factors.

### Earphones

If earphones are the selected transducers, the tester must place the earphone diaphragm over the opening of the ear canal. To avoid low frequency transmission loss, the earphones must fit snugly over the patient's ears. Loose fitting earphones could be reflected as an erroneous low frequency hearing loss on the audiogram (Wilber, 1999). The tester, however, must be alert to the possibility of a collapsing ear canal in some patients, especially young children and geriatric patients. A collapsing canal is created by the pressure of the earphone on the pinna, which then occludes the ear canal and creates a conductive hearing loss in the presence of a normal tympanogram (Wilber, 1999). To avoid the possibility of collapsing ear canals the tester is advised to routinely use insert receivers (see below). Supra-aural earphones rather than circumaural earphones are the selected earphones for AC testing at this time. Although, the use of circumaural earphones are indicated for extended high frequency (above 8000 Hz) testing. The reader is directed to the references for further information regarding circumaural earphones. Note that the interaural attenuation for earphones is considered to be 40 dB across frequencies (Gelfand, 1997).

### Insert receivers

The advantages of utilizing insert receivers include increased interaural attenuation, increased ambient noise attenuation, elimination of ear canal collapse, and increased patient comfort (Hall & Mueller, 1998; Yacullo, 1996). The interaural attenuation for insert receivers is approximately 60 dB across frequencies (Sanders & Hall, 1999). The tester should not use insert receivers in the presence of atresia, a stenotic ear canal, or a draining ear (Stach, 1998).

In order to receive the best benefit from proper insertion of foam tips, the tester may use the following steps (Yacullo, 1996):

1. Prior to insertion ask the patient if he/she has any jaw problems.
2. Attach the receivers to the patient's clothing, red for right and blue for left.

3. Place the appropriate sized foam tips to the end of the each plastic tubing via the white nubbin.
4. Squeeze the foam tip between your fingers prior to inserting to the patient's ear.
5. Gently pull up and back on the patient's pinna to straighten out the ear canal and then insert the foam tip quickly. The goal is to insert the foam tip so that the outer edge is at the aperture of the patient's ear canal.
6. While the foam tip is conforming to the shape of the patient's ear canal, have the patient open and close their mouth several times as you gently wriggle the pinna.

Insertion of the foam tip is important to the accuracy of test results. The deeper insertions without touching the tympanic membrane offer reduced occlusion effect and greater interaural attenuation values over that of shallow insertions. It is advised that the tester check the tubing for cracks, holes, kinks, and occluding debris on a periodic basis. Check for occlusion if the patient exhibits an unexpected mild conductive hearing loss by removing the insert and then examining the insert for blockage with cerumen. Upon completion of testing, the tester is to properly dispose of the foam tips, making sure that the white nubbin remains attached to the tubing.

### Speakers

Speakers in the soundfield should be used for special testing such as determining functional gain on hearing aids and for patients, especially young children, who refuse to wear earphones. Also, patients who cannot use earphones or insert receivers due to draining ears and excessive cerumen may be tested using speakers. During soundfield testing, the patient is seated, with ears uncovered, at the point to which the speakers were calibrated. Refer to the procedures used by your testing facility. The patient is seated at a certain azimuth that is used to describe the relationship between the patient's head (ears) and the sound source. Zero degree ( $0^{\circ}$ ) azimuth means that the patient is facing the speaker. An azimuth of  $90^{\circ}$ , means that the patient is seated so that the speaker is directed to the right ear. When the patient has her/his back to the speaker that denotes an azimuth of  $180^{\circ}$ . An azimuth of  $270^{\circ}$  means that the patient is seated so that the speaker is directed to the left ear (Wilson & Strouse, 1999).

When testing in the sound field at azimuths of  $0^\circ$  and  $180^\circ$ , stimuli reach both ears at equal intensity and therefore threshold values are not obtained for each ear separately. The resulting threshold could be for the better ear, if the sensitivity of one ear is better than the other, or both ears if the hearing is the same in both ears. The tester does not know which ear is responding. The recommended speaker azimuths are  $90^\circ$  and  $270^\circ$  to take advantage of the 10-15 dB attenuation of the stimulus at one ear (head shadow effect). If responses are bilaterally symmetrical, then ears are of equal sensitivity. If there is a 10-15 dB difference between responses, it is unclear which ear is responding.

Warble tones or pulsed narrow bands of noise must be used when testing in the sound field to avoid the occurrence of standing waves. The warble tone stimulus is the preferred auditory stimulus over the pulsed narrow bands of noise for use in the sound field, especially for patients with high frequency hearing losses (Wilbur, 1999).

### Response Mode

The patient may indicate that auditory stimuli were heard by raising her/his hand, by pushing a button, or by responding verbally. The response mode selected by the tester depends on the needs of the patient. If the patient has limited arm mobility, then the hand raise method is inappropriate. The verbal response mode is inappropriate for patients with a speech, voice, or language disorder. The hand raise or button-pushing responses are preferred because they are clear-cut actions seen by the tester and they are noiseless. Responses made verbally are the least preferred of the three modes for several reasons:

1. Jaw movements may alter the acoustics of the ear canal and may sporadically create a collapsing ear canal (Hall & Mueller, 1998);
2. Test tones may be masked by the patient's voice if they talk at the time a tone is presented (Gelfand, 1997); and
3. Some patients don't limit their responses to "yes", but will add comments thought to be helpful to the tester. This is to be discouraged as it lengthens test time.

During threshold determination, the tester should be aware of false-positive and false-negative responses made by the patient. False-positive responses occur when the patient

responds to a tone that was not presented. False-negative responses occur when the tone was presented at a level above the patient's threshold, but the patient did not respond to the tone.

False-positive responses may occur for the following reasons (Gelfand, 1997):

1. Technical problems such as tactile stimulation and/or acoustical radiations.
2. The patient may experience tinnitus that was confused with the tone.
3. The patient may not have understood the instructions.
4. The patient may not have learned the proper way to respond, or may have lax response criteria.
5. The tester presented tones in a rhythmic pattern, rather than at irregular times intervals.

Reasons for the occurrence of false-negative responses are as follows (Gelfand, 1997):

1. Equipment problems or tester error (e.g., the tone never reached the patient because the incorrect transducer was selected on the audiometer).
1. The patient may experience tinnitus that was confused with the tone.
2. The patient may not have understood the instructions.
3. The patient may not have learned the proper way to respond, or may have very strict response criteria.
4. The patient may present with an unconscious or conscious functional hearing loss.
5. Technical problems such as the occurrence of collapsed ear canals and standing waves.

### Presentation Mode

Stimuli are presented at various interstimulus intervals from one to three seconds apart. Keep in mind that some patients may need longer time intervals in which to produce a response due to the presence of some neurologic dysfunction. (Wilber, 1999). Tones are usually presented for a one to two second duration.

### Patient Positioning

In the test room, the patient should be seated in a comfortable chair with armrests. The armrests allow the patient to rest their arm and reduce fatigue that may be experienced from the

hand or finger raising response. Swivel or reclining chairs should be avoided because patients' movements in them are noisy and distracting.

The patient is seated in the test room in one of several directions; facing the tester, with their back to the tester, or facing sideways. Most testers prefer to have the patient facing her/him during testing for several reasons:

1. Allows the tester to monitor the patient's facial expressions and bodily changes, including those that are subtle;
2. Allows the tester to provide the patient with encouragement and retraining through nonverbal reinforcement; and
3. Allows the tester to see the patient's lips and face to make accurate judgements during speech audiometry (Gelfand, 1997).

If the tester selects this seating arrangement, care must be taken that the tester does not provide the patient with cues that stimuli are being presented. Seating the patient away from the tester prevents the patient from "reading" the tester. If the patient is very sensitive to movements made by the tester, it is best to place this patient sideways.

The tester must be cautious that cues are not being provided inadvertently to the patient. If a patient has a "functional" hearing loss, the tester must be extra cautious in the use of advertent and inadvertent cues. For the patient who is apprehensive, the tester may need to provide more cues of encouragement than for a patient who is not apprehensive.

<p style="text-align: center;"><b>GO TO LABORATORY EXERCISE # 1.1</b></p>
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Step-by-Step Procedures for Air Conduction Testing (ASHA, 1990; Margolis, 1997; Hall & Mueller, 1998; Martin, 1998; Stach, 1998; Wilber, 1999):

1. After completion of the case history, otoscopic examination, and acoustic admittance, the patient is seated in a comfortable chair in a sound controlled examining room. The tester instructs the patient as described above.

2. Prior to earphone placement, the patient should remove eyeglasses, earrings, headbands, and hearing aids and the patients' hair should be pushed behind their ears. Place selected transducer on the patient and determine that placement is appropriate. By convention, the red transducer is directed to the right ear and the blue to the left ear. Make sure the diaphragm of the earphone is over the ear canal aperture and adjust the headband.
3. Set up audiometer
  - a. Begin with the patient's better ear or the right ear if a better ear is not indicated.
  - b. Select output for air conduction testing
  - c. Select pulsed tone or warble tone – tones are presented for about one to two seconds in duration and with varying interval lengths between tone presentations.
  - d. Select transducer- earphones, insert receivers, speakers
  - e. Select beginning frequency - 1000 Hz
  - f. Select beginning hearing level – 30 dB HL or at a comfortable intensity level above the patient's estimated threshold. Hall & Mueller (1998) suggest 30 to 40 dB HL for patients with normal hearing and about 70 dB HL for patients with a hearing loss.
  - g. Adjust the “talk-over” and “talk-back” to comfortable levels for the patient and for you.
4. Familiarization Phase:
  - a. This phase allows the tester to determine if the patient understands and is able to perform the task.
  - b. Present the tone at 30 dB HL; if the patient responds proceed to the “Threshold Phase.” If the patient does not respond, increase the tone to 50 dB HL and in 10 dB steps thereafter, if needed, until the patient responds.
5. Threshold Phase using the ascending approach as follows:
  - a. Begin 10 dB below the level obtained in the “Familiarization Phase.”
  - b. Continue descending in 10 dB steps until the patient no longer responds.

- c. Present the stimulus in increments of 5 dB steps until the patient again responds (ascending).
  - d. Once the patient responds, present the stimulus in decrements of 10 dB steps until the patient no longer responds.
  - e. Continue the up in 5 dB steps until the patient responds and the down in 10 dB steps until the patient does not respond, when two out of three or three out of five correct responses are obtained at the lowest ascending test level. This is the patient's threshold and the tester records the dB HL, the frequency, and the ear tested on the audiogram.
6. Repeat step "5" for the remaining frequencies in the following sequence: 2000, 4000, 8000, 500, and 250 Hz.
  - a. The threshold at 1000 Hz is rechecked after 8000 Hz has been tested. If the thresholds are within  $\pm 5$  dB of each other proceed with 500 and 250 Hz. If they are not in agreement, the patient may have become more comfortable with the testing process or the tester may need to reinstruct the patient.
  - b. Thresholds are obtained for the inter-octave frequencies (750, 1500, 3000, 6000 Hz) when a  $\geq 20$  dB difference is present between adjacent octave frequencies (Gelfand, 1997; Margolis, 1997; Wilber, 1999).
  - c. 125 Hz may be tested in cases of low frequency hearing loss.
7. Use masking when indicated. If using earphones, consider reestablishing thresholds if there is a  $\geq 40$  dB difference between ears or between the bone conduction thresholds (500 – 4000 Hz) of the non-test ear and the AC thresholds of the test ear. If using insert receivers, masking is necessary when there is a  $\geq 60$  dB difference between ears or between the bone conduction thresholds (500 – 4000 Hz) of the non-test ear and the AC thresholds of the test ear.
8. Obtain thresholds for the opposite ear by repeating steps 5 through 7.
9. If the patient presents with reduced air conduction thresholds and abnormal admittance results (see Chapter 3 of this manual), bone conduction testing should be completed. Proceed with bone conduction testing as described in the next section. However, if the patient presents with thresholds within normal limits and normal admittance results, proceed with speech audiometry (Chapter 2).



Recording and Scoring of Test Results

At the completion of threshold determination for each frequency, the tester records the ear tested and the dB HL obtained. The tester may record the patient’s threshold in one of two ways; plotted using symbols on a graph or recorded numerically on a table.

Numerical Audiogram

Results are recorded numerically for the right and left ears separately in a table in which the frequencies tested are shown across the top of the table. See Figure 1.0 for sample of a table used in the numerical recording of the patient’s responses. The numerical audiogram allows for rapid recording of responses and, when masking is needed, ease of making calculations (Gelfand, 1997). However, it is difficult for some to visualize the audiometric shape from digital values. When recording “no response”, the tester would record as “NR,” “+,” or “↓” along with the maximum testing level for that frequency. For example “NR70,” “70NR,” “70+,” or “70↓” (Gelfand, 1997).

AIR CONDUCTION

RIGHT

LEFT

250	500	750	1000	1500	2000	3000	4000	6000	8000	250	500	750	1000	1500	2000	3000	4000	6000	8000

BONE CONDUCTION

RIGHT

FOREHEAD

LEFT

500	1000	1500	2000	3000	4000	500	1000	1500	2000	3000	4000	500	1000	1500	2000	3000	4000

**Figure 1.0: Form used for numerical recording of patient’s responses in air and bone conduction pure tone threshold determination.**

Note. From Exercises in audiometry: a laboratory manual (p. 28) by F. N. Martin, 1998, Needham Heights, MA: Allyn and Bacon. Copyright 1998 by Allyn and Bacon. Adapted with permission.

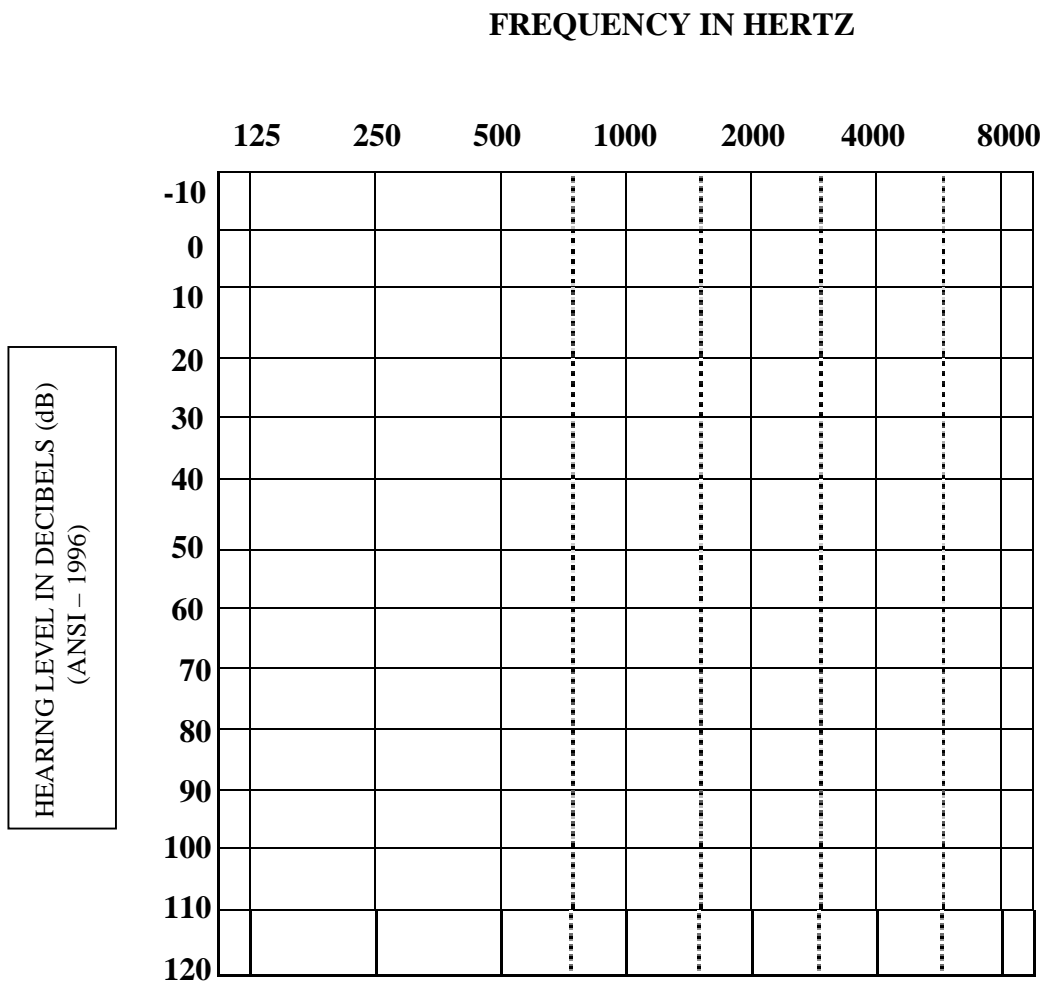
### Graphic Audiogram

Figure 1.1 depicts a sample of a graph in which the tester would insert symbols, indicating thresholds, in the appropriate place on the audiogram. Notice that frequency measured in Hz is shown across the top of the audiogram (250 to 8000 Hz) and that sound intensity measured in dB hearing level (dB HL), from -10 dB at the top to 120 dB at the bottom, is shown on the y-axis. Across the top of the audiogram is the 0-dB HL line, which corresponds to the level of average normal hearing in healthy young adults. The reader is directed to the *ASHA (1990) Guidelines for Audiometric Symbols* for specifics on constructing an audiogram. The tester may record the thresholds for the right ear in red ink and those for the left ear in blue ink, but is not necessary, as the color coding is lost with photocopying. Some facilities plot a separate audiogram for each ear; others plot both ears on the same audiogram. For discussion in this paper, thresholds for both ears will be plotted on the same audiogram.

If the tester utilizes the audiogram to plot the patient's thresholds, he/she must use the appropriate symbol for the transducer used. Because there are several versions of audiometric symbols available, the symbol system used to plot the audiogram is generally placed in a key on the evaluation form. The tester is to keep in mind that the symbols correspond to transducer placement and may not reflect that the sound was even heard in that ear (ASHA, 1990; Gelfand, 1997). Table 1.1 shows the ASHA (1990) suggested audiometric symbol system the tester may use when plotting a patient's audiogram. The tester records the patient's response by drawing the appropriate symbol so that the center of the symbol is on the intersection of the vertical and horizontal axes for the frequency and intensity tested ASHA, (1990). If no response was obtained at the limits of the audiometer, the tester plots the appropriate symbol at the intensity depicting the highest testable level. An arrow is then drawn downward, attached at the bottom of the symbol at a 45-degree angle to the right for the left ear symbol and to the left for the right ear symbol (ASHA, 1990; Gelfand, 1997). Refer to Table 1.1 for the no response symbols. This indicates to the reviewer of the audiogram that testing was attempted at that frequency. Once all of the thresholds have been determined, the tester then connects the air conduction symbols where responses were obtained with a solid line. The lines are drawn so that they do not go

through or touch the symbol. Symbols representing “no response” are not to be connected to each other or to any of the symbols indicating a response (ASHA, 1990).

In some testing facilities, the tester may record thresholds using the numerical audiogram for ease of calculating noise levels needed for masking and then the thresholds are transferred to the graphic audiogram for ease of counseling results to the patient. If a procedure other than the standard procedure for threshold determination was used to determine a patient’s thresholds, the tester must indicate this on the audiogram.



**Figure 1.1: An audiogram with frequency in Hz plotted as a function of intensity in dB HL.**

Note. From Clinical Audiology: an introduction, (p. 201) by B. A. Stach, 1998, San Diego: Singular Publishing Group, Inc. Copyright 1998 by Singular Publishing Group, Inc. Adapted with permission. And from Audiologists’ desk reference, volume 1, (p. 98) by J. W. Hall, & H. G. Mueller, 1997, San Diego: Singular Publishing Group, Inc. Copyright 1997 by Singular Publishing Group, Inc. Adapted with permission.

**Table 1.1: Audiometric symbols used when plotting air and bone conduction thresholds on an audiogram. R – response and NR – no response.**

MODALITY	LEFT EAR RESPONSE		UNSPECIFIED EAR RESPONSE		RIGHT EAR RESPONSE		
	R	NR	R	NR		R	NR
Air Conduction – earphones/inserts	X	X <sub>↓</sub>				O	↙O
Unmasked	□	□ <sub>↓</sub>				Δ	↙Δ
Masked							
Bone Conduction – mastoid							
Unmasked	>	> <sub>↓</sub>	^	↕		<	↙<
Masked	]	] <sub>↓</sub>				[	↙[
Bone Conduction – forehead							
Unmasked			∨	∨ <sub>↓</sub>			
Masked	┌	┌ <sub>↓</sub>				┐	↙┐
Air Conduction - soundfield			S	S <sub>↓</sub>			

Note. From “Guidelines for audiometric symbols,” (pp. 84-86), by ASHA, 1990 in ASHA, 32, (Suppl.). Copyright 1990 by ASHA. Adapted with permission.

Upon completion of the AC thresholds, the tester calculates the pure tone average (PTA) for each ear. This is the mean of the AC thresholds at 500, 1000, and 2000 Hz. The PTAs for each ear are then recorded in the appropriate area of the audiogram so that they may be compared to the Speech Recognition Threshold (SRT) discussed in Chapter Two.

<p style="text-align: center;"><b>GO TO LABORATORY EXERCISE # 1.2</b></p>
---

## TEST INTERPRETATION

### Degree, Shape, Symmetry, and Type

When interpreting the audiogram, the tester will describe the degree of the hearing loss, the shape or configuration of the hearing loss, the interaural symmetry of the hearing loss if present, and the type of hearing loss exhibited by the patient's audiogram. The tester determines the degree of hearing a patient has by comparing the patient's hearing thresholds to a classification chart similar to those shown in Table 1.1 below. The amount of hearing loss is determined as the number of decibels above 0 dB HL that was needed to reach the patient's threshold. It is suggested that the tester check the guidelines of her/his test facility to determine which classification system is used. There are differences noted in the numbers of categories and in the width (in dB HL) of the categories.

The audiometric configuration is another aspect of the patient's audiogram that may need to be described. Stach (1998) provides the following terms with descriptions for defining audiometric configuration:

1. Flat - thresholds are within 20 dB of each other across the frequency range.
2. Rising - thresholds for low frequencies (250 – 500 Hz) are at least 20 dB poorer than for high frequencies.
3. Sloping - thresholds for high frequencies (1000 – 4000 Hz) are at least 20 dB poorer than for low frequencies.

4. Low-frequency – hearing loss is restricted to the low-frequency region (< 1000 Hz) of the audiogram.
5. High-frequency – hearing loss is restricted to the high-frequency region (> 2000 Hz) of the audiogram
6. Precipitous – steeply sloping high frequency hearing loss of at least 20 dB per octave.

**Table 1.1: Depicts several classification systems for the determination of hearing loss.**

Goodman <sup>1</sup> (1965)	Degree of Hearing Loss (in dB HL)	Jerger <sup>2</sup> (1980)	Degree of Hearing Loss (in dB HL)
-10 to 15	Normal hearing	-10 to 20	Normal hearing
16 to 25	Slight hearing loss		
26 to 40	Mild hearing loss	21 to 40	Mild hearing loss
41 to 55	Moderate hearing loss	41 to 55	Moderate hearing loss
56 to 70	Moderately-severe hearing loss	56 to 70	Moderately-severe hearing loss
71 to 90	Severe hearing loss	71 to 90	Severe hearing loss
> 91	Profound hearing loss	> 91	Profound hearing loss

1. Note. From “Reference zero levels for pure-tone audiometer” by A. Goodman, 1965, ASHA, 7, 262-263. Copyright 1965 by ASHA. Adapted with permission.
2. Note. From “Measurement of hearing in adults” (p. 1226), by J. Jerger & S. Jerger, 1980, in Otolaryngology by M. M. Paparella & D. A. Shumrick (Eds.), Philadelphia: W. B. Saunders. Copyright 1980 by W. B. Saunders. Adapted with permission.

In terms of symmetry, the tester may describe that the hearing levels are essentially the same for both ears or that one ear is better than the other. A patient is reported as having a bilateral hearing loss if a hearing loss is present in both ears and a unilateral hearing loss if the hearing loss is present in only one ear. A hearing loss may also be described as asymmetrical when a significant difference is present

between ears. There is no agreed upon definition of asymmetry; however the one commonly used is that an asymmetrical hearing loss is present when a  $\geq 15$  dB difference exists between ears at two or more consecutive octave frequencies.

Lastly, the type of hearing loss is included in the interpretation statement of the patient's hearing loss. There are three types of peripheral hearing losses that are considered - conductive, sensorineural, and mixed.

### Conductive Hearing Loss

Conductive hearing losses result from disorders in the external and/or middle ear system. This type of loss is depicted on the audiogram with BC thresholds within the normal range and abnormal AC thresholds. Therefore, the sensorineural portion of the auditory pathways is functioning normally (as indicated by BC thresholds) and the problem lies in the conductive portion of the system.

### Sensorineural Hearing Loss

Sensorineural hearing losses result from disorders in the cochlea or auditory nerve. These losses are generally depicted on the audiogram equally abnormal AC and BC thresholds. This indicates that the conductive part of the auditory system functions normally and the loss is located in the cochlea part of the auditory system. The term "sensorineural" is used because a cochlear (sensory)/VIIIth nerve hearing disorder cannot be separated from an VIIIth nerve (neural) disorder by pure tone audiometry (Gelfand, 1997). If the admittance results (tympanogram, static admittance, and acoustic reflexes) are normal in the presence of reduced AC thresholds, bone conduction testing need not be completed.

### Mixed Hearing Loss

A mixed hearing loss results from disorders in the external and/or middle ear systems as well as the cochlea or the auditory nerve. On the audiogram a mixed hearing loss is shown as reduced sensitivity in both the air and bone conduction thresholds, but the AC thresholds are reduced more than the bone conduction thresholds.

Recall that AC testing evaluates the integrity of the entire auditory system and that BC testing evaluates the sensorineural portion. If there is a difference in the thresholds obtained

between these two tests then a problem is evident in the conductive (outer and/or middle ear) system (Gelfand, 1997). When this difference, AC – BC, is observed at the same frequency, it is known as an air-bone-gap (A-B gap). When there is at least a 10 dB A-B gap, this is considered to be significant and suggests the presence of a conductive component.

#### Factors Affecting Audiometric Interpretation

1. *Standing waves* are suspected if the threshold at 8000 Hz is greatly reduced in comparison to the threshold at 4000 Hz. This phenomenon occurs when earphones are utilized to obtain AC thresholds. Standing waves may also occur at 6000 Hz. The tester can check for the presence of standing waves by reseating the earphone or pulling the earphone slightly away from the ear. If there is an improvement upon re-establishment of the threshold, then standing waves have occurred. The improved threshold is the correct one. The use of insert receivers precludes the incidence of standing waves during pure tone testing, thereby providing another reason to support their routine use.
2. *Tactile responses* occur in patients with very severe to profound hearing losses. They cannot hear the sounds being presented but are able to feel the vibrations produced by the bone vibrator or earphones (Nober, 1970). Tactile responses usually occur at low frequencies (125, 250, and 500 Hz). This type of response creates inaccurate thresholds and gives the impression that the patient has better hearing sensitivity than really exists or hearing where there is none (Gelfand, 1997). In bone conduction testing, a false A-B Gap is created and appears as a mixed hearing loss when it is actually sensorineural (Gelfand, 1997). This type of response can be avoided by asking the patient if the stimulus was heard or felt.
3. *Acoustical radiations* may be depicted on the audiogram as false A-B gaps above 2000 Hz and causes a sensorineural loss to appear mixed (Bell, Goodsell, & Thornton, 1980; Shipton, John, & Robinson, 1980; and Frank & Crandell, 1986). These can be created when the bone vibrator causes sound to be radiated into the air; these radiations then enter the ear canal and are heard by the patient via the air conduction pathway. Acoustical radiations are suspected in the presence of an A-B gap of > 10 dB above 2000 Hz and normal admittance results. The tester may retest those thresholds with earplugs to confirm the influence of radiations (Frank & Crandell, 1986).



4. The presence of *collapsed ear canals* appears on the audiogram as an unexpected high-frequency conductive hearing loss with an A-B gap of 10 to 50 dB (Coles, 1967). This occurs during AC testing when the pressure from the earphones causes the cartilaginous portion of the patient's ear canal to collapse. The elderly population tends to have a higher incidence of collapsed ear canals due to reduced tissue elasticity (Randolf and Schow, 1983). The occurrence of collapsed ear canals can be avoided by the use of insert receivers. If the patient cannot be tested using insert receivers, the earphone can be held loosely over the ear canal to reduce the pressure. Thresholds are retested and if a  $\geq 15$  dB improvement is noted, and then the occurrence of collapsed ear canals is confirmed.

### Test Limitations

1. Accurate thresholds may not be obtained if the earphone is to one side, if the ear canal is collapsed, or if headband pressure is insufficient (Wilber, 1999).
2. Accurate thresholds may not be obtained if the insert receiver is blocked, up against the ear canal, or is not inserted firmly and deeply into the ear canal (Wilber, 1999).
3. Accurate thresholds may not be obtained in the sound field if the patient is not placed properly in the examination room (Wilber, 1999).
4. Test equipment may be out of calibration and result in erroneous thresholds.
5. The patient may be uncooperative or fatigued and inaccurate results may occur (Wilber, 1999).
6. The ventilation and temperature of the examination room may affect the patient and lead to inaccurate results (Wilber, 1999).
7. Transducer jacks may not be inserted securely into the wall panel, which may result in a 20 to 30 dB reduction in signal intensity (Hall & Mueller, 1998).

## BONE CONDUCTION (BC) TEST

### Key Words

Bone vibrator

Compressional bone conduction

Frontal placement

Inertial bone conduction

Mastoid placement

Osseotympanic bone conduction

### History and Background Information

Lybarger (1966) published the Hearing Aid Industry Conference (HAIC) bone conduction (BC) norms in 1966. These were first incorporated in to the ANSI Standard in 1972 and again in 1981 and 1992 (ANSI, 1972, 1992).

BC audiometry is completed following AC testing when any admittance result is abnormal. It is an estimate of sensorineural sensitivity and reflects the integrity of the cochlea and the auditory nerve. During BC testing, auditory stimuli presented through the skull reaches the cochlea in a different way from that of AC testing. The auditory signal, in a sense, bypasses the external and middle ear systems and goes directly to the cochlea. Tonndorf (1966) provides three possible explanations - osseotympanic, inertial, and compressional - of how auditory stimuli are conducted by BC. The reader is directed to the references for more information regarding these explanations. The tester must keep in mind that BC testing only provides as estimate of cochlear hearing sensitivity (cochlear reserve) (Wilber, 1999).

### Definition

BC testing is used to determine the hearing threshold of the patient through the bone vibrator. Thresholds are obtained for octave and ½ octaves between 500 – 4000 Hz for each ear are defined as the lowest hearing level at which the patient responds at least 50% of the time to auditory stimuli.

### Instructions to the Patient

Instructions for BC testing are essentially the same as for AC testing with the exception of the transducer.

An example of instructions the tester may use is as follows (Martin, 1998):

*You will be hearing some more sounds, but this time I will be putting this headband device behind your ear. It will feel somewhat snug and it may slip. Try to sit as still as possible. If the device should move or fall off your head, please let me know. Same as with earphones, I would like for you to raise your hand every time you hear the tones, even when they are very, very soft and you can barely hear them. When you no longer hear the tone, put your hand down. Do you have any questions?*

## INSTRUMENTATION

### Test Stimuli

Same as for AC testing.

### Transducer

The BC vibrator can be placed on the patient's mastoid or forehead. Placement of the bone vibrator on the patient's mastoid is the placement most often used clinically for two reasons:

1. The availability of a wider range of hearing levels over that for frontal placement; and
2. Convenience (Wilber, 1999).

The bone vibrator is placed on the mastoid with a headband type device exerting a force of 5.4 Newtons or 400 grams (ANSI, 1996; Dirks, 1964b). The tester is advised not to hand hold the bone vibrator as the pressure will not be constant and the output of the vibrator may be dampened (Wilber, 1999). It is necessary for the tester to make sure that the bone vibrator does not touch the patient's pinna, that there is very little hair as is possible under the vibrator, and that the disk part of the vibrator sits flatly on the skin of the mastoid process. The patient should remove eyeglasses so that they do not come in contact with the vibrator. Testing will proceed with that placement (Gelfand, 1997). Generally, thresholds are obtained with the opposite ear and the test ear unoccluded.

In forehead placement, the bone vibrator is placed in the center of the forehead. The maximum testable intensity level for forehead placement is less than for mastoid placement (ASHA, 1990; Gelfand, 1997). However, thresholds tend to be more reliable with this placement than for mastoid placement (Dirks, 1964b; Studebaker, 1962). Masking should be completed when obtaining thresholds for each ear.

Note: that the interaural attenuation for BC testing is considered to be 0 dB.

**GO TO LABORATORY  
EXERCISE # 1.3**

Response Mode

Same as for AC testing.

Step-By-Step Procedures (ASHA, 1990)

1. Once AC testing has been completed and acoustic admittance results indicate the presence of a conductive component, thresholds by BC testing should be obtained.
2. Instructions are provided to the patient as described above.
3. The tester will first obtain unoccluded BC thresholds. This will prevent the phenomenon known as the “occlusion effect” from occurring, especially in nonconductive hearing losses, and creating improved low frequency BC thresholds. The reader is encouraged to obtain further information on the occlusion effect using the available references.
4. The bone vibrator is placed on the most prominent part of the mastoid process with the poorer AC thresholds or the right ear if there are no ear differences. No transducer is placed on the contralateral ear at this time.
5. Set up the audiometer:
  - a. Determine the ear in which the patient obtained poorer thresholds by AC, select this ear as the ear to test first.
  - b. Select output for BC testing
  - c. Select pulsed tone or warble tone
  - d. Select transducer- bone vibrator
  - e. Select beginning frequency - 1000 Hz
  - f. Select beginning hearing level – 40 dB HL
6. Follow the same procedures for threshold determination as for AC testing. Only test the following frequencies in the sequence shown – 1000, 2000, 4000, and 500 Hz.
7. Masking is indicated when air-bone gaps of 15 dB or more exist (Gelfand, 1997). If this is the case, it is suggested that the tester obtain bone conduction thresholds with the ear contralateral to the bone vibrator covered by an earphone or insert receiver

### Recording and Scoring of Test Results

As for AC testing, the tester records the ear tested and the dB HL obtained at the completion of threshold determination for each frequency. If the tester chooses to plot patient responses on an audiogram (see Figure 1.1) for the AC thresholds, then the BC thresholds are plotted on the audiogram as well. The tester selects the appropriate unmasked or masked symbol that refers to the ear where the vibrator was placed. See Table 1.1 for the ASHA recommended symbol system. When obtaining unmasked BC thresholds, the tester must keep in mind that the better cochlea will respond to the BC stimuli no matter where the vibrator is placed (Gelfand, 1997). When using the mastoid vibrator placement, the unmasked BC symbols (< and >) refer to the ear where the vibrator is placed and not the ear where the stimuli are heard. The symbols are placed near the frequency grid line rather than on the grid line as in AC. The right ear symbol “<” is placed close to the left of the vertical line for the frequency tested and the left ear symbol “>” is placed close to the right of the vertical line for the frequency tested. If the obtained BC threshold is the same as the AC threshold, the BC symbol is placed adjacent to the AC symbol. Refer to Table 1.1 for symbols used when testing at the forehead. If no responses are obtained for a particular frequency, the tester plots the appropriate symbol at the highest testable level with a downward arrow placed at the bottom of the symbol. Refer to Table 1.1 for the no response symbols for BC. The tester may record the thresholds for the right ear in red ink and those for the left ear in blue ink. The symbols used to designate the BC thresholds are not usually connected or are connected by dashes.

However, if the tester recorded the AC thresholds numerically on a chart, then the BC thresholds are recorded on the same chart. See Figure 1.0 for sample of chart used in the numerical recording of the patient’s responses. If a procedure other than the standard procedure for threshold determination was used to determine a patient’s thresholds, the tester must indicate this on the audiogram.

### Test Interpretation

AC thresholds should be the same as or poorer than the BC thresholds. On occasion a patient exhibits BC thresholds that less sensitive than AC thresholds. This is because BC norms are based on “median” masked values. Thus, it is possible for a patient to have 5 dB or so poorer

BC thresholds. In the presence of an A-B gap, the degree of the patient's hearing loss is based on the AC threshold. Refer to the "Interpretation" section under "Air Conduction Testing."

**GO TO LABORATORY  
EXERCISE # 1.4**

Test Limitations

1. Test equipment may be out of calibration and result in erroneous thresholds.
2. During BC testing, the vibrator may not maintain a stable position on the patient's mastoid, or may contact the pinna; thus producing erroneous thresholds (Wilber, 1999).
3. The pressure of the vibrator on the mastoid may be insufficient and cause incorrect thresholds (Wilber, 1999).
4. The patient may be uncooperative or fatigued and inaccurate results may occur (Wilber, 1999).
5. The ventilation and temperature of the examination room may affect the patient and lead to inaccurate results (Wilber, 1999).

Laboratory Exercises:

**LABORATORY EXERCISE # 1.0**

Goals

1. To understand and manipulate the working components of the audiometer used in pure tone audiometry.
2. To be aware of the intensity versus frequency limits of the audiometer as they pertain to the various transducers.
3. To become familiar with the various pure tone stimuli used in pure tone audiometry.



- |                                    |                             |
|------------------------------------|-----------------------------|
| c. Scenario # 3: Transducer: bone  | Routing: both               |
| Stimulus Intensity: -5 dB          | Stimulus Frequency: 2000 Hz |
| Stimulus Type: recorded            | dB step: 5 dB               |
| Channel: 1                         |                             |
|                                    |                             |
| d. Scenario # 4: Transducer: phone | Routing: right              |
| Stimulus Intensity: 50 dB HL       | Stimulus Frequency: 8000 Hz |
| Stimulus Type: pulsed              | dB step: 2 dB               |
| Channel: 1                         |                             |
|                                    |                             |
| e. Scenario # 5: Transducer: phone | Routing: right              |
| Stimulus Intensity: 50 dB HL       | Stimulus Frequency:         |
| Stimulus Type: mic                 | dB step: 5 dB               |
| Channel: 1                         |                             |

### Questions

1. Review the chart you developed for exercise # 2 above. Discuss the differences noticed in output limits between the transducers. How did frequency range change between transducers?
2. When completing exercise # 3 above, did anything change automatically to any of the settings in Channel 2, if yes, when?

LABORATORY EXERCISE # 1.1
---------------------------

### Goals

1. To properly provide instructions needed for AC pure tone audiometry.
2. To properly place and be comfortable with the placement of earphones and insert receivers.
3. To be aware of proper seating of the patient in the sound treated room for soundfield testing.

### Exercises

1. Practice giving instructions for AC pure tone audiometry on \_\_\_\_ lab mates.



2. Practice placement of each of the following transducers on \_\_\_\_ lab mates. Note: perform otoscopy on each lab mate prior to transducer placement. After insert receiver placement, leave the white nubbin attached to the tubing and dispose the foam insert in the appropriate manner.
  - a. Earphones
  - b. Insert receivers
3. Practice placing \_\_\_\_ lab mates in the sound treated room for soundfield testing in each of the following directions and create a sketch indicating each azimuth:
  - a.  $0^{\circ}$  azimuth
  - b.  $90^{\circ}$  azimuth
  - c.  $180^{\circ}$  azimuth
  - d.  $270^{\circ}$  azimuth

### Questions

1. When giving instructions to your lab mates, did they have any questions regarding your presentation? Did you notice any differences in your presentations, if so what were they?
2. In the transducer exercise, explain any differences noted in transducer placement among your lab mates. Did you experience any difficulties; if so, what were they and how did you solve them?

LABORATORY EXERCISE # 1.2
---------------------------

### Goals

1. To determine thresholds for AC pure tone audiometry using the modified Hughson-Westlake procedure.
2. To be able to record AC thresholds using the numerical audiogram and the graphic audiogram.
3. To use the appropriate AC symbols on the graphic audiogram.

### Exercises

1. Using a computer-simulated program of pure tone audiometry, obtain AC thresholds on \_\_\_ cases. Record half of the cases on a numerical audiogram and half of the cases on a graphic audiogram.
2. Obtain AC thresholds on 12 volunteers using the procedure described in the manual. Perform the testing as follows:
  - a. For 2 of the volunteers, obtain thresholds for each ear using pulse tone stimuli and earphones. Record responses on a numerical audiogram.
  - b. For 2 of the volunteers, obtain thresholds for each ear using warble tone stimuli and insert receivers. Record on a numerical audiogram.
  - c. For 2 of the volunteers, obtain thresholds for each ear using pulse tone stimuli and earphones. Record on a graphic audiogram.
  - d. For 2 of the volunteers, obtain thresholds for each ear using warble tone stimuli and insert receivers. Record on a graphic audiogram.
  - e. For 2 of the volunteers, obtain thresholds in the soundfield using warble tone stimuli and a 90° azimuth. Record on a graphic audiogram.
  - f. For 2 of the volunteers, obtain thresholds in the soundfield using warble tone stimuli and a 0° azimuth. Record on a graphic audiogram.

### Questions

1. You have had the opportunity to record thresholds on the two types of audiograms (numerical and graph), explain which you prefer and why.
2. Explain the benefits of the two types of audiograms and in what situations you would use each one.
3. You have had a chance to obtain thresholds using a variety of transducers and stimuli, discuss differences you noticed with your volunteers. Did you experience any problems, what were they, and what were your solutions? What helpful hints do you have for your lab mates?

LABORATORY EXERCISE # 1.3
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Goals

1. To properly place the bone vibrator on the mastoid process.
2. To understand the differences in thresholds obtained from forehead and mastoid placement of the bone vibrator.
3. To understand the difference of BC thresholds obtained with the contralateral ear unoccluded and occluded.

Exercises

1. Practice placing the bone vibrator on the mastoid process of 5 lab mates.
2. Using the modified Hughson-Westlake method of threshold determination, obtain BC thresholds, unoccluded, with the bone vibrator on the mastoid process and on the forehead of 5 lab mates. Record results on a chart listing results for each placement by frequency.
3. Using the modified Hughson-Westlake method of threshold determination, obtain BC thresholds with the bone vibrator on the mastoid process of 2 lab mates under the following test conditions. Record results on a chart listing results for each test condition by frequency.
  - a. The test ear and contralateral ear is unoccluded.
  - b. Contralateral ear occluded. Note: this means with an earphone over the ear opposite the test ear or the bone vibrator.
  - c. Test ear occluded.
  - d. Both ears occluded.

Questions

1. Review your results obtained for exercise # 2 above. Discuss the differences noticed between the results obtained via forehead placement and those obtained via the mastoid placement. How do you account for those differences?
2. Review your results obtained for exercise # 3 above. Discuss the differences noticed between the results obtained under the various test conditions using the mastoid placement. How do you account for those differences?

3. Review both exercise # 2 and # 3, which test condition do think provides the most accurate results of your lab mates' bone conduction hearing? Why?

LABORATORY EXERCISE # 1.4
---------------------------

### Goals

1. To determine thresholds for BC pure tone audiometry using the modified Hughson-Westlake procedure.
2. To be able to record BC thresholds using the numerical audiogram and the graphic audiogram.
3. To use the appropriate BC symbols on the graphic audiogram.
4. To interpret and describe pure tone audiometric results in terms of degree, type, shape, and symmetry.

### Exercises

1. Using a computer-simulated program of pure tone audiometry, obtain air and bone conduction thresholds on \_\_ cases with normal hearing and \_\_ cases with hearing impairment. Record half of the cases on a numerical audiogram and half of the cases on a graphic audiogram.
2. Obtain air and bone conduction thresholds on 8 volunteers (those using the procedure described in the manual. Perform the testing as follows:
  - a. For 2 of the volunteers, obtain AC thresholds for each ear using pulse tone stimuli and earphones. Then obtain BC thresholds using the unoccluded mastoid placement. Record responses on a numerical audiogram.
  - b. For 2 of the volunteers, obtain thresholds for each ear using warble tone stimuli and insert receivers. Then obtain BC thresholds using the unoccluded mastoid placement. Record on a numerical audiogram.
  - c. For 2 of the volunteers, obtain thresholds for each ear using pulse tone stimuli and earphones. Then obtain BC thresholds using the unoccluded mastoid placement. Record on a graphic audiogram.

- d. For 2 of the volunteers, obtain thresholds for each ear using warble tone stimuli and insert receivers. Then obtain BC thresholds using the unoccluded mastoid placement. Record on a graphic audiogram.
3. Describe the degree, shape, type, and symmetry of the results you obtained for each of the simulated-computer cases and of the 8 volunteers in exercises # 1 and # 2.

### Questions

1. Review the results obtained in all the cases for exercises # 1 and # 2, based on the limited knowledge regarding masking up to this point, is masking needed for any of them? Indicate the cases. Then for each case where masking is indicated state whether masking is needed for AC, BC, or both.
2. When you were describing your pure tone audiometric test results did you experience any difficulties? If so, indicate the case(s) and state the problem(s).

## CHAPTER 2

## SPEECH AUDIOMETRY

Key Words

Speech awareness threshold	
Speech detection threshold	Phonetically balanced
Speech recognition threshold	Monitored live voice
Speech recognition tests	Word recognition tests

History and Background Information:

The development of speech stimuli and speech tests progressed from whispered messages measured at a number of distances from the listener to nonsense syllables for the telephone (Campbell, 1910), to phonographic recordings of digits (Fletcher & Steinberg, 1929), and to recorded monosyllabic words (Hirsh, 1952). In the 1940's and 1950's, hearing loss for speech was found to be correlated with the pure tone audiogram (Carhart, 1946). Further, it was found that hearing loss for speech could be predicted from calculating the patient's pure tone average (Fletcher, 1959). People involved in the research and development of speech audiometry over the years came from many disciplines including psychoacoustics, speech science, telecommunications, military, and clinical audiology.

Speech audiometric measurements are a routine part of the audiologic evaluation. These measurements may include:

1. The patient's threshold for speech, the lowest level at which the patient detects or recognizes speech, known as the speech awareness threshold (SAT) or the speech detection threshold (SDT).
2. The lowest level at which the patient is able to identify speech serves as a crosscheck of pure tone thresholds. This is known as the speech recognition threshold (SRT).
3. The patient's ability to process and understand speech at suprathreshold levels is the word recognition score (WRS).

These three speech measurements will be discussed in the following sections.

Features common to all speech audiometric tests (differences particular to each test will be discussed under that test):

### Audiometer

As per ASHA, 1988 suggested guidelines, “speech audiometry shall be accomplished with a speech audiometer capable of transducing speech as defined and calibrated according to the American National Standard Specifications for Audiometers (ANSI S3.6-1969)”. A two-channel audiometer is needed to administer speech audiometric testing so that the tester may present speech stimuli to the patient in a variety of ways depending on the particular speech measurement being administered. The possibilities are as follows:

1. The tester may present speech stimuli to both ears;
2. The tester may present speech stimuli to one ear and speech masking to the other ear;
3. The tester may present speech stimuli to one ear and speech masking to the same ear;
4. The tester may present speech stimuli and speech masking to both ears.

When performing speech audiometric testing, the speech mode/channel of the audiometer is selected. The tester then selects a means of presenting stimuli to the patient such as recorded material or microphone for live voice testing. If recorded material is selected, the tester selects Compact Disc (CD) player or tape deck. An attenuator is needed so that the tester may control the level of the speech material presented to the patient. Lastly, the tester selects the desired output transducer in order to deliver the stimuli to the patient – earphones, insert receiver, sound field, or bone oscillator.

### Test Environment

Same as for pure tone audiometry. See the first part of this manual.

### Presentation mode

Although, speech materials may be prerecorded materials or the monitored live voice (MLV) mode, prerecorded materials are preferred. The use of prerecorded materials offers better

control over the level and quality of the speech signals presented to each patient, as well as allowing for standardization from test to test. Standardization of test procedures is critical to the quality of care to the patient; therefore, the tester must attempt to utilize prerecorded materials as much as possible (ASHA, 1988, Mendel & Danhauer, 1997, Gelfand, 1997, and Wilson & Margolis, 1999). Table 2.0 provides the tester with a number of reasons why recorded materials should be used during speech audiometric testing and MLV testing should be avoided. However, according to ASHA (1988) administration of the SRT and SDT by MLV may be needed when testing very young children or the difficult-to-test patient. In the MLV mode, the tester presents the spoken word into a microphone while monitoring her/his voice on the audiometer’s VU meter. A disadvantage of MLV testing is that of maintaining vocal quality and intensity within the test session and between patients.

**Table 2.0: Seven reasons why you shouldn’t routinely use the monitored-live-voice (MLV) method for presentation of word recognition materials.**

1.	Word recognition scores obtained for different talkers are not equivalent.
2.	Word recognition scores for the same talker at different times are not equivalent.
3.	“Each speaker of word recognition materials constitutes a different test that may produce different psychometric articulation functions (percent correct performance as a function of presentation level)” (Wiley et al., 1994, p. 29).
4.	With MLV presentation, the acoustic characteristics of the signal are highly variable, just as Jennifer’s voice is distinctly different from Jay’s, and Gus has totally different vocal characteristics than both of them (e.g., pitch, articulation, rate of speech, dialect).
5.	With MLV presentation, the difficulty of the items (single words) is dependent, in part, on who’s talking.
6.	Most testers today are not sitting in a sound-treated control room. Background sounds reaching the patient through the open microphone may confuse the patient and influence test results.



7.	With current CD recorded speech audiometry materials, and progressive presentation techniques (e.g., patient control of the rate of words), you need not sacrifice quality, reliability, and validity to obtain speed. A variety of word recognition test materials are commercially available in compact disc (CD), digital audio tape (DAT), and, of course, cassette tape recording formats.
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Note. From Audiologists' Desk Reference: Volume 1 diagnostic audiology principles, procedures, and practices (p. 133), by J. W. Hall III & H. G. Mueller III, 1997, San Diego, CA: Singular Publishing Group, Inc. Copyright 1997 by Singular Publishing Group. Adapted with permission.

#### Calibration of recorded speech materials

The calibration of prerecorded speech material (CD or other recorded media) needs to be completed daily and prior to the presentation of recorded speech materials (ANSI S3.6-1996). Recalibration of recorded speech materials will be necessary whenever the tester changes recorded materials. From this point on, we will refer to speech materials formatted on CDs.

On most CDs, there is a track that contains the recorded reference/calibration tone used in the calibration of the CD for use during speech audiometric assessment. For instance, Auditec<sup>TM</sup> recordings on the CD containing CID W-1, CID W-22, and NU-6 word lists, the calibration tone is on "track one". To determine the location of the calibration tone on a CD, the tester is encouraged to read the manual that accompanied the test materials. Further, the volume (VU) meter must have ballistic characteristics that conform to the ANSI, C16.5-1954 standard for VU meters.

#### Perform the calibration for recorded materials as follows

1. Select *Tape 1, External A, or Tape A in Channel 1*.
2. Press the interrupt switch to the constantly "on" position.
3. Select the track containing the calibration tone on the CD player and press play.

4. While the calibration tone is playing, adjust the control knob for the VU meter until the level of the calibration tone is at 0 dB on the VU meter.
5. Repeat the above steps for Tape 2 or Tape B in Channel 1.
6. Repeat the above steps for Tape 1 or Tape A in Channel 2.
7. Repeat the above steps for Tape 2 or Tape B in Channel 2.

#### Calibration for live-voice testing

When the live-voice test mode has been selected as the medium in which to present speech stimuli for SDT or SRT when testing very young children or difficult-to-test patients the following steps are used to calibrate the tester's voice through the audiometer:

1. Select microphone as the input source of the presentation of speech material.
2. Press the interrupt switch to the constantly "on" position.
3. The tester is to speak naturally into the microphone, meanwhile adjust the control knob for the VU meter until his speech is "peaking" at 0 dB on the VU meter.

<b>GO TO LABORATORY EXERCISE # 2.0</b>
--

NOTE: Of the various tests utilizing speech materials, only speech detection threshold (SDT), speech recognition threshold (SRT), and word recognition testing (WRT) will be covered in this manual.

#### SPEECH DETECTION THRESHOLD (SDT)

##### Definition

The SDT is an index of the lowest level at which the listener detects the presence of speech 50% of the time. The patient does not need to identify the speech stimuli but simply indicate in some way that speech was heard. The SDT has also been referred to as SAT but the term preferred is SDT.

### Purpose of the Test

The SDT is often obtained when the speech recognition threshold is unable to be determined. The following are some situations the tester may encounter for which the SDT may need to be obtained:

1. Patients with a profound hearing loss.
2. Patients who have lost language function due to some neurologic insult.
3. Patients with language disorders.
4. Children who are hard of hearing.
5. Patients diagnosed as profound mentally handicapped.
6. The evaluation of very young children.

In these instances, the SDT is obtained by presenting a variety of speech stimuli using the monitored live-voice test mode. The SDT is often the first test administered to very young children, as they tend to respond better to speech materials than to pure tones. The SDT obtained provides guidance to the tester in the establishment of pure tone thresholds.

### Instructions to the Patient

Instructions for determination of the SDT are the same as for pure tone stimuli except that speech material will be used instead of pure tone stimuli.

## INSTRUMENTATION

### Test Stimuli

A variety of speech stimuli may be used in the determination of the SDT. Speech materials may include the following:

- a. Continuous discourse;
- b. Spondees, see Appendices B, C, and D;
- c. The child's name;
- d. CV syllables ("bye-bye", "uh-oh");
- e. Short phrases ("hey, pretty girl");
- f. Words familiar to the child; and
- g. Individual speech sounds (/m/, /sh/, /ah/).

### Transducer

The SDT may be obtained using earphones, insert receivers, loudspeakers, or the bone vibrator. Earphones, insert receivers, and the bone vibrator may be used depending on the acceptance level of the patient. If the patient does not accept earphones or insert receivers, the tester must resort to soundfield testing. In these instances, the better ear responses will be obtained rather than separate ear measures.

### Response mode

A number of response modes may be used to obtain the SDT; usually, they are nonverbal in nature. Some examples of response modes are hand raising or button pushing.

### Step-by-Step Procedures

1. The tester first instructs the patient or the caregiver of the patient if the patient is unable to understand directions.
2. The tester selects speech stimuli that are appropriate for the patient. Keep in mind that several of the speech stimuli listed above may need to be used by the tester in order to obtain reliable responses from the patient.
3. The tester selects the transducer most readily accepted by the patient. Try insert receivers first, then earphones. As a last resort, use loudspeakers if the patient will not tolerate the insert receivers or headphones. Attempt use of the bone oscillator when needed to determine the type of hearing loss (conductive or sensorineural).
4. The tester then determines the SDT using the same test technique as for pure tone threshold estimation. If insert receivers or earphones are the accepted transducers, the tester attempts to obtain the SDT for each ear. If the tester needs to resort to loudspeakers, then an SDT in the soundfield will be obtained.
5. Masking should be applied when indicated.

### Recording and Scoring of Test Results

When the SDT is established; the following should be recorded on the audiogram:

1. If the tester obtained the SDT with insert receivers or earphones the results are recorded in dB HL for each ear separately. If the SDT was obtained in the soundfield, record in dB HL under soundfield findings.

2. Record the type of response observed to obtain the SDT. Types of responses may include handraise, button push, eye widening, head turn, smile, and cessation of activity.
3. Record the type of stimulus used to obtain the SDT (i.e. continuous discourse, spondees, and Ling 6 sounds).

### Test Interpretation

The SDT often relates to the best single pure tone threshold in the 250 – 4000 Hz range, but is most closely related to the average of 250 and 500 Hz (Olsen & Matkin, 1979; Rintelmann, 1991). The average SDT is approximately 7-9 dB lower than the average SRT. Others have reported great variation between the SDT and the SRT by as much as 2 dB or even 16 dB (Thurlow, Silverman, Davis, & Walsh, 1948; Chaiklin, 1959; Martin, 1986; and Rintelmann, 1991).

### Test Limitations

1. The SDT often reflects the best single pure tone threshold in the 250 – 4000 Hz range and thus does not provide a representation of the configuration or degree of hearing loss at the various frequencies.
2. The SDT indicates the lowest loudness level in which a patient can detect speech, but does not provide information of how that patient hears speech above threshold.

<p style="text-align: center;"><b>GO TO LABORATORY EXERCISE # 2.1</b></p>
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## SPEECH RECOGNITION THRESHOLD (SRT)

### Definition

The Speech Recognition Threshold (SRT) is the lowest hearing level at which a patient can hear and understand two syllable words. It is the lowest level in which the patient can correctly repeat or identify the two syllable words 50% of the time. The SRT has also been referred to as the speech reception threshold or speech threshold (ST). In order to improve

interclinician and interclinic comparison of test results, it is suggested that the tester follow a standard procedure (ASHA, 1988).

### Purpose of the Test

1. SRTs may be obtained to confirm pure tone results;
2. The SRT may be used as the reference point for setting appropriate levels at which to administer supra-threshold speech recognition tests;
3. The SRT may be used to determine hearing sensitivity for young children and others who are difficult to test; and
4. The SRT may be useful in the assessment of patients suspected of pseudohypacusis.

### Instructions to the Patient

When instructing the patient, the instructions must be worded in the appropriate language to meet the particular needs of the patient. The instructions should include, but are not limited to the following:

1. Orient the patient to the nature of the task;
2. Specify the response mode to the patient;
3. Inform the patient that the test material is speech and that the patient should respond using words from the test list shown to them; and
4. Strongly state the importance of the patient listening to the faint loudness levels, responding at these levels and provide encouragement to the patient to guess.

An example of instructions the tester may use is as follows:

*This test is used to find the softest speech you can hear and repeat back. You are going to hear a man say some two-syllable words like cowboy, toothbrush. At first the words will be somewhat loud and then the words will get softer and softer, so soft that they will be difficult for you to hear. Your job is to repeat the words the best that you can and guess if you need to. Do you have any questions?*

### Familiarization of the Spondaic Word List

Once the tester has completed the instructions to the patient, the tester familiarizes the patient with the spondaic words in the word list. The purpose of the familiarization process “is

to ensure that the patient knows the test vocabulary and is able to recognize each word auditorily, and that the clinician can accurately interpret the patient's responses" (ASHA, 1988, p. 100). Tilman and Jerger (1959) reported that using non-familiarization, the average SRT was about 4 to 5 dB poorer than when the patients were familiarized with the word list.

The tester may familiarize the patient with the word list in one of several ways. They may either read the alphabetized word list (See Appendix B) to the patient in a face-to-face situation, or present the test list through the microphone circuit of the audiometer at a comfortable level for the patient. The patient is to repeat the word to demonstrate recognition of each word on the list. If the patient responds incorrectly or does not respond to any of the words, the tester should eliminate those words from the list. Also, any word that the tester has any difficulty understanding should be eliminated from the test list. In situations where the tester is certain that the patient would have no difficulty understanding the words, give the patient the alphabetized list to read to themselves prior to test administration.

## INSTRUMENTATION

### Test Stimuli

When determining the SRT, typically, the test stimuli consist of at least 12 spondaic (two syllable words in which each syllable is presented with equal stress) words that were found to be appropriate for adults. See Appendix C for this list. This spondaic word list, which is a revision of the CID W-1/W-2 list, is recommended by ASHA (1988) as the standard test materials for determination of the speech recognition threshold.

### Transducer

Headphones, insert receivers, bone vibrator, or speakers may be used to obtain the SRT. Typically, headphones or insert receivers will be the transducer of choice.

### Response Mode

When obtaining the SRT, the usual patient response is a verbal repetition of the stimulus item heard. At times, other response modes may be necessary such as signing, visual scanning,

or picture pointing. The tester must select the response mode most appropriate for the patient and instruct the patient accordingly.

### Step-by-Step Procedures

The test procedure selected by the tester in the determination of the SRT depends on the patient's behavior and pure tone thresholds. While there is no single SRT technique in universal use, all are an adaptation of ascending and descending techniques. The descending approaches begin with the presentation of spondees above the patient's estimated SRT with subsequent blocks of spondees presented at progressively lower hearing levels. The ascending approaches start at presentation levels below the patient's estimated SRT with subsequent spondees presented at higher hearing levels. Wall, Davis, and Myers (1984) and Jahner, Schlauch, and Doyle (1994) found that the differences between the ascending and descending approaches were clinically insignificant. The procedure discussed here is the guidelines suggested by ASHA (1988). The steps in determination of the SRT consists of two phases, and are as follows:

#### 1<sup>st</sup> Phase: Establish Starting Level

1. Set the hearing level to 30-40 dB above the estimated speech recognition threshold and present one spondaic word to the client. A lower starting level may be required in certain cases of sensorineural hearing loss where tolerance problems may exist.
2. If the patient does not respond correctly to the first spondaic word at the first level, then increase the level in 20 dB steps until a correct response is obtained.
3. If the response is correct, then descend in 10 dB steps, presenting one spondaic word at each level until the patient responds incorrectly.
4. When one word is missed, present a second spondaic word at the same level. Continue this process of descending in 10 dB steps until a level is reached at which two consecutive words are missed at the same hearing level.
5. Add 10 dB to the level at which the two words were missed. This is considered to be the ***STARTING LEVEL***.



2<sup>nd</sup> Phase: Test Phase

1. Present two spondaic words at the *STARTING LEVEL* and at each successive 2 dB decrement. An acceptable alternative is to present five words in 5 dB steps.
2. Continue this process if five out of the first six words are repeated correctly. If this criterion is not met, increase the starting level by 4-10 dB.
3. The descending series is terminated when the patient responds incorrectly to five of the last six words presented. If five words are presented in 5 dB steps, then the descending series is terminated when all words at a single intensity are not correctly recognized.
4. Threshold is calculated by subtracting the total number of correct responses from the starting level and adding a correction factor of 1. For the presentation in 5 dB steps, the correction factor is +2 dB. This is the dB hearing level that is recorded on the audiogram.
  - a. Thus,  $SRT = \text{starting level} - \# \text{ correct} + \text{correction factor}$ .
  - b. To assist the tester in keeping track of the patient's responses use the tally sheet as shown in Fig. 2.0 when determining the SRT.
5. Masking should be applied when indicated.

Speech Level (dB HL)	Word Number					Speech Level (dB HL)	Word Number				
	1	2	3	4	5		1	2	3	4	5
<i>Starting level</i>						50	✓	✓	✓	✓	✓
						45	✓	✓	✗	✓	✓
						40	✗	✓	✗	✗	✗
						35	✗	✗	✗	✗	✗

**Figure 2.0: Tally sheet used when determining the SRT using the ASHA (1988) method. The right side shows an example of how to use the tally sheet. Count the number of correct words from the starting level to the stopping level. In this case there were 10 correct responses. The number of correct responses is then subtracted from the starting dB level**

**(50 dB HL – 10= 40). Then a 2 dB correction factor is added to that total to arrive at an SRT of 42 dB HL.**

Note. From Essentials of Audiology (p. 260), by S. A. Gelfand, 1997, New York: Thieme Medical Publishers, Inc. Copyright 1997 by Thieme Medical Publishers, Inc. Adapted with permission.

Another procedure known as the “Martin and Dowdy Spondee Threshold Procedure” (1986), based on the Hughson-Westlake pure tone procedure, may be used to obtain the SRT. The steps ( Hurley, 1999) are as follows:

1. Familiarize the patient with the spondee list. Use 10-12 spondaic words: “The 13 Most Homogeneous Spondaic Words (See Appendix C)”.
2. Start level at 30 dB HL. Present one spondee. If a correct response is obtained decrease presentation level by 10 dB. If there is no correct response, raise the presentation level in 10 dB steps, presenting one spondee at each increment until a correct response is obtained or the limits of the equipment is reached.
3. After a correct response is obtained, lower the presentation level in 10 dB steps until an incorrect response is given.
4. When an incorrect response is given, raise the presentation level 5 dB and present one spondee. If a correct response is given, lower the intensity 10 dB. If an incorrect response is given, continue raising the intensity in 5 dB steps until a correct response is obtained.
5. Intensity is increased in 5 dB steps after an incorrect response and decreased in 10 dB steps after a correct response. In short, up by 5 dB and down by 10 dB until three correct responses have been obtained at a given presentation level. Same process as for pure tone threshold estimation.
6. Threshold is defined as the lowest level at which three correct responses were obtained.

Recording And Scoring of Test Results

Once the SRT values have been determined for the patient, the tester needs to record them in dB HL on the audiogram. Also, if materials other than spondaic words were used to obtain the SRTs, the alternative materials used need to be recorded on the audiogram. See Fig. 2.1, the sample audiogram, which shows the SRT values obtained for the patient. Proceed with the SDT if the SRT cannot be obtained. There may be some instances in which the SRT may not be determined; these are indicated as follows:

1. Patients presenting with a profound hearing loss;
2. Patients who do not have the language competency to identify spondaic words;
3. Patients who lost language function due to a neurologic insult; and
4. Patients who may hear the spondaic words but are unable to identify them.

SPEECH AUDIOMETRY

Procedure	RE	LE	BC	SF	SF AIDED
PURE TONE AVERAGE (AC)					
SPEECH RECOGNITION THRESHOLD (SRT) dB HL	0	5			
SPEECH DETECTION THRESHOLD (SDT) dB HL					
WORD RECOGNITION SCORE (WRS) <u>40</u> dB HL	96%	100%			
_____ dB HL					
MOST COMFORTABLE LOUDNESS (MCL)					
UNCOMFORTABLE LOUDNESS LEVEL (UCL)					

Word Recognition List NU-6 Tape CD MLV # of test items 25

(Circle one)

**Figure 2.1: Depicts what the speech audiometry section may look like on the patient's audiogram.**

### Test Interpretation

Once the SRT is obtained, it is compared to the best pure tone average (PTA) for the respective ear. Hall and Mueller (1997) report that the calculated SRT should be within  $\pm 7$  dB of the best PTA. In order to obtain the best SRT-PTA agreement, the tester must consider the following factors in the selection of the most appropriate PTA formula:

1. Generally the “three frequency pure-tone average” is utilized in the determination of SRT/PTA agreement. The thresholds for 500, 1000, and 2000 Hz are averaged for each ear (Fletcher, 1929). This works best for flat and gently sloping hearing losses.
2. When the shape of the puretone audiogram slopes sharply or when there is more than a 20 dB difference between two of the three frequencies a “two-frequency pure-tone average” is often used. The best two of the three frequencies (500, 1000, and 2000 Hz) are used to calculate the PTA. (Fletcher, 1950).
3. Carhart (1971) suggests a formula of averaging puretone thresholds at 500 and 1000 Hz and then subtracting 2 dB in cases of sloping hearing loss.
4. When the shape of the puretone audiogram slopes precipitously, it is often necessary to compare the SRT to the one frequency that has the best threshold. The best threshold is often at 500 Hz and may even be 250 Hz. (Gelfand & Silman, 1985, 1993; Silman & Silverman, 1991).

If there is lack of agreement upon comparison in the SRT-PTA values, the tester must stop testing and determine the possible cause of the inconsistency. The tester may search for examiner error, equipment problems, and suspected functional hearing loss. After the tester has investigated these three areas, he/she may need to reinstruct, and retest the patient's hearing in attempt to obtain of the SRT-PTA values. In cases when the SRT is lower (better) than the PTA, psuedohypacusis is suspected.

### Test Limitations

1. The spondees are not representative of the speech that the patient uses when communicating on a daily basis.

2. There continues to be no standardization in the use of spondees or in methods used to obtain speech recognition thresholds from clinic to clinic (Wiley, Stoppenbach, Feldhake, Moss, and Thordardottir, 1994).
3. Hall and Mueller (1997) suggest “spondees aren’t a good reference for determining a level for presentation of word recognition test material, (i.e., sensation level) because the two tests utilize different stimuli”.
4. Hurley (1999) suggests that the SRT be used as part of the diagnostic test battery and not as a stand-alone test.

<b>GO TO LABORATORY EXERCISE # 2.2</b>
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## WORD RECOGNITION TEST

### Definition

The word recognition score (WRS) is the percentage of words correctly identified at some specified level above threshold. The WRS is also known as “the speech recognition score”, “the speech discrimination score”, or “PB scores”. However, the term “word recognition score (WRS)”, has become the accepted term when nonsense syllables and monosyllabic words are the test materials and will be used in this portion of the manual.

### Purpose of the Test

1. To provide an estimate of the patient’s ability to recognize single words at suprathreshold levels;
2. To describe the extent of the hearing impairment in terms of how it affects speech understanding; and
3. To assist in the differential diagnosis of auditory disorders.

### Instructions to the patient

When the tester is instructing the patient, the instructions for determining the WRSs should be phrased in language appropriate to the patient and shall indicate:

1. That the patient will hear a word at a comfortable loudness level;

2. The patient is to repeat the word or the last word of the sentence heard;
3. The patient is encouraged to guess as some of the items may be difficult to understand;
4. Each ear is to be tested separately.

An example of instructions the tester may use is as follows:

*You are going to hear a person telling you to say some words. The words will be presented at a level comfortable for you. They will remain at the same level and will not get louder or softer. For example, if you hear "Say the word GIRL," just repeat "GIRL." If you are unsure of a word, repeat what you think you heard. Do you have any questions?*

## INSTRUMENTATION

### Test Stimuli

There are a number of variables the tester may need to take into consideration in the selection of appropriate speech test materials for the determination of word recognition scores. These include:

1. Test materials
2. Number of test items
3. Recorded or monitored live voice presentation
4. Open-set vs. closed-set test format
5. Stimulus type
6. Word familiarity
7. Communication mode of the patient

### Test Materials

The tester may select from a variety of test materials depending on the purpose of the speech recognition task. When determining the WRSs for adults, the most commonly used tests include the CID W-22, the NU-6, and the PB-50 word lists. See Appendices E and F.

### Number of test items

The standard word lists, CID-W22, NU-6, and PB-50, used during speech recognition testing consist of 50 monosyllabic words. During administration of the word lists, the tester may

present 10, 25 or, 50 words per ears depending on the number of errors made by the patient. If the patient responds correctly to all ten words, testing stops. Otherwise, continue presenting the next 15 words for a total of 25 words. If there are more than four errors at the completion of the 25 words, a full 50-word list should be administered. Consider presenting a 10 word-screening test when the patient presents with normal hearing or a conductive hearing loss.

The tester is alerted to the variability in WRSs that occurs in relation to the number of test items presented (Raffin and Thornton 1980). The standard deviation of the test score which is used to define its variability, is dependent upon the percent correct score and the number of test items administered. The difference between two speech recognition scores are seen as significant within the confidence limits of 95%. For further details, the reader is directed to Raffin and Thornton (1980) or to the discussion by Gelfand (1993).

#### Recorded versus monitored live voice presentation

See discussion above. Recorded presentation is preferred over that of MLV for validity and reliability purposes.

#### Stimulus Type

The tester may select nonsense syllables or monosyllabic words as stimuli to obtain the WRS. Monosyllabic words will be the only stimulus type discussed at this time, as they are the most commonly used test stimuli for assessing word recognition.

#### Transducer

The tester may select to use insert receivers, headphones, or loudspeakers to obtain the WRSs.

#### Response Mode

The response mode typically used during word recognition testing is a verbal response from the patient. In some instances, the patient may need to write or sign their response such as when the patient is apraxic, dysarthric, a laryngectomee, severely hoarse, has a profound hearing loss, or the tester has a hearing loss that interferes with her/his ability to monitor the patient's responses.

### Presentation Mode

Speech materials are presented to the patient through a compact disc (CD) player with the audiometer set up on the player so the patient avoids hearing the introduction to the test stimuli.

### Presentation Level

The speech recognition test is typically administered at 30-40 dB above the patient's SRT. Typically, WRS is obtained at the presentation level of 40 dB SL re: patient's SRT. It is now more common to administer a word recognition test at a second higher SL such as 90 dB HL (Wilson & Strouse, 1999; Gelfand, 1997) as a screening to differentiate between cochlear and retrocochlear dysfunction. WR testing at the patient's most comfortable loudness level (MCL) is not recommended as this is a range and not a level (Wilson & Strouse, 1999; Gelfand, 1997). Dirks & Morgan (1983) found the highest WRSs occur at SLs higher than the patient's MCL.

### Step-by-Step Procedures

1. Prepare the audiometer for use of recorded speech materials. Set up the recording so that the patient only hears the test items and not the identifying components of the test stimuli.
2. Select the most appropriate speech material to be used to obtain the word recognition scores. CID W-22, NU-6, or PB-50.
3. Select the transducer preferred.
4. Select the better ear or the right ear if better ear is not indicated.
5. Set the presentation level 40 dB above the SRT for that ear. (40 dB SL, re: patient's SRT for the ear tested.).
6. Begin presenting test stimuli and keep track of the number of test items the patient correctly identifies.
7. A percent correct score is obtained for each ear separately.
8. Use masking when appropriate.



### Recording and scoring of test results

Test items for WR testing are based on the whole-word method. The test item is scored correct if the patient repeats all the phonemes in the test item correctly. If any or all of the phonemes of the test item are repeated incorrectly or not repeated at all, the test item is scored as incorrect. See Figure 2.1 for an example of recording WRSs.

### Test Interpretation

The WR score suggests the approximate degree of difficulty the patient experiences understanding speech for each ear in quiet. When interpreting WR scores, consider the following:

1. For patients with normal hearing, the speech recognition score is expected to be above 92% correct (Gelfand, 1997; Wilson & Strouse, 1999).
2. For most patients with a conductive hearing loss, the speech recognition score is typically between 80% and 100%. The speech recognition score has been found to be as low as 60% in cases of glomus tumor (Gelfand, 1997). Stach (1998) reports that the WR scores should not be effected by the presence of a conductive hearing loss due to a middle ear disorder.
3. For patients with cochlear hearing loss, the speech recognition score is usually consistent with the degree of hearing loss. The greater the hearing loss, the poorer the score. The speech recognition score may range from 0% to 100% depending on the etiology and degree of hearing loss. (Bess, 1983; Gelfand, 1997; Wilson & Strouse, 1999). Stach (1998) states that WR scores will be poorer than expected in relation to the degree of hearing loss in cases of endolymphatic hydrops or Meniere's disease
4. For patients with lesions beyond the cochlea, the speech recognition score will be poorer than expected for the amount of hearing loss. Scores will appear to be "abnormally low".

The tester, upon completion the word lists for WR testing then determines if there is a significant difference in the test scores between ears by referring to the Thornton & Raffin data shown in Appendix G. When word recognition scores are abnormally low, be cautious when interpreting the scores. It is possible that the presentation level was not high enough and the

tester must retest at a higher hearing level. The tester then refers to Table 2.1 to determine how the degree of hearing loss affects the word recognition score.

**Table 2.1: How degree of hearing loss affects speech recognition (Tye-Murray, 1998).**

Hearing Loss	Effect on Word Recognition
Mild (PTA = 26-40 dB HL)	In quiet situations, speech recognition will be fairly unaffected. In the presence of noise, speech recognition may decrease to 50% words correct if the PTA is 40 dB HL. Consonants are most likely to be missed, especially if the hearing loss involves primarily the high frequencies.
Mild-to-Moderate (PTA = 41-55 dB HL)	Will understand much of the speech signal if it is presented in a quiet environment face-to-face, and if the topic of conversation is known and the vocabulary is constrained. If a hearing aid is not used, the individual may miss up to 50-75% of a spoken message if the PTA is 40 dB and 80-100% if the PTA is 50 dB.
Moderate (PTA = 56-70 dB HL)	If the individual does not use a hearing aid, he or she may miss most or all of the message, even if talking face-to-face. Will have great difficulty conversing in group situations.
Severe (PTA = 71-90 dB HL)	May not even hear voices, unless speech is loud. Without amplification, the individual probably will not recognize any speech in an audition-only condition. With amplification, her or she may recognize some speech, and detect environmental sounds.
Profound (PTA = 90 dB HL or greater)	May perceive sounds as vibrations. An individual will rely on vision as the primary sense for speech recognition. May not be able to detect the presence of even loud sound without amplification.

Note. From Foundations of Aural Rehabilitation: Children, Adults, and Their Family Members (p. 97), by N. Tye-Murray, 1998, San Diego, CA: Singular Publishing Group, Inc. Copyright by

Singular Publishing Group, Inc. Adapted with permission. The author of the table is C. Flexor, 1994, Facilitating hearing and listening in young children. San Diego, CA: Singular Publishing Group.

### Test Limitations

1. The SL of 40 dB re: SRT may not be the best presentation level during WR testing and results may lead to misdiagnosis and mismanagement of the patient (Hall & Mueller, 1997).
2. Wilson & Strouse (1997, p. 26) report “ adding a fixed sensation level to the SRT, however, will not always result in a valid maximum word recognition score, especially for patients with sensorineural hearing loss. The level at which scores are obtained differs substantially among patients.”
3. The CID W-22 and NU-6 are the least sensitive to differences in hearing loss among patients (Hall & Mueller, 1997).
4. Utilizing a single presentation level in sensorineural hearing loss may not differentiate cochlear from retrocochlear pathology ( Wilson & Strouse, 1997; Stach, 1998; Gelfand, 1997).
5. Shortening of the number of test items on some word lists may invalidate the test (Wiley, et al., 1994; Gelfand, 1997).
6. Word recognition testing as described here does not assess how the patient performs in the presence of noise. Some patients may perform differently in noise than in quiet (Wilson & Strouse, 1997).
7. Whole-word scoring does not provide information regarding how the patient utilizes the acoustical cues of speech (Gelfand, 1997).
8. Tye-Murray (1998, p. 105) reports “use of word stimuli may not reflect very well how an individual performs in everyday listening situations because we typically listen to connected discourse”.

### Laboratory Exercises

Laboratory Exercise # 2.0
---------------------------

### Goals

1. To be able to set up the audiometer and the CD player for speech audiometry, including the use of all transducers.
2. To be able to set up the audiometer for monitored live voice testing, including the use of all transducers.
3. To be able to calibrate the audiometer using the CD player.
4. To be able to calibrate the audiometer using the tester's own voice.
5. To be familiar with the functioning of the CD player and manipulate it during testing in a timely manner.

### Exercises

1. Practice setting up the audiometer in the following scenarios, include calibrating with the calibration tone:
  - a. Input: Channel 1, Tape B, recorded speech/Channel 2, speech noise  
Output: Channel 1, insert receiver, right ear/Channel 2, insert receiver, left ear  
Stimulus: Channel 1, children's spondees located on a CD such as that formatted by Auditec/Channel 2, speech noise
  - b. Input: Channel 1, Tape A, recorded speech/Channel 2, Tape B, recorded speech  
Output: Channel 1, headphone, left ear/Channel 2, headphone, right ear  
Stimulus: Channel 1, NU-6 word list located on a CD such as that formatted by Auditec or the Veteran's Administration/Channel 2, speech babble located on the same CD as the word list.
  - c. Input: Channel 1, Tape A, recorded speech/Channel 2, speech noise  
Output: Channel 1, insert receiver, right ear/Channel 2, insert receiver, right ear  
Stimulus: Channel 1, PAL PB-50 word list located in a CD such as formatted by Auditec or the Veteran's Administration/Channel 2, speech noise.
  - d. Input: Channel 1, headphone, recorded speech/Channel 2, headphone, speech noise  
Output: Channel 1, headphone, left/right/Channel 2, headphone, left/right  
Stimulus: Channel 1, CID W-22 word list/Channel 2, speech noise
2. Practice using the monitored live-voice mode of the audiometer for speech. Set up the audiometer for monitored live-voice testing using Channel 1 as your primary channel. Select

microphone as the input source of the presentation of speech material to the patient. Then select a transducer through which the speech signal will be transmitted to the patient. Press the interrupt button to the constantly “on” position. Locate the VU adjustment knob on the audiometer panel. While speaking at a natural rate into the microphone manipulate the knob until your speech is “peaking” at 0 dB VU meter. Then present the following speech stimuli at a natural rate, with equal stress while attempting to peak at 0 dB on the VU meter. Keep your eyes on the VU meter and record your observations:

- a. Select a single syllable word and repeat it five times
- b. Select seven different single syllable words and repeat
- c. Select seven two syllable words and repeat
- d. Select seven sentences of five to seven words in length and repeat.

### Questions

1. Review exercise #1 above and determine two other possible scenarios, taking into consideration the transducers and other options on the audiometer you have available to you.
2. For exercise #2 above, summarize your observations and discuss how this may or may not effect your test results. Utilize references if needed to support your arguments.
3. Based on these two exercises you have completed and literature that you have read, which presentation mode (recorded or MLV) is preferred? Why?

## Laboratory Exercise # 2.1

### Goals

1. To be able to obtain speech recognition thresholds using the ascending and descending approaches as suggested by the ASHA 1988 guidelines.
2. To be able to obtain speech recognition thresholds using 2 dB and 5 dB steps.
3. To be able to determine the PTA utilizing the most appropriate formula based on the configuration of the patient’s hearing loss and then comparing to the SRT to determine SRT/PTA agreement.

### Exercises

1. Gather \_\_\_\_\_ classmates and/or volunteers and determine their SRT as described in the ASHA (1988) guidelines. Prior to determining SRTs, obtain AC thresholds for both ears. Set up the audiometer for speech audiometric testing, via insert receivers, in the CD mode using the spondee word list. Remember to familiarize your volunteer with the alphabetized spondee word list prior to SRT determination. Use the attached tally sheet to assist you in keeping track of volunteer responses. Once you have obtained the SRTs for your volunteer under the following test conditions, record results and test condition on a piece of paper, calculate the PTA, and determine SRT/PTA agreement. Test conditions are as follows:
  - a. Descending approach in 2 dB steps
  - b. Descending approach in 5 dB steps
  - c. Ascending approach in 2 dB steps
  - d. Ascending approach in 5 dB steps

### Questions

1. Review the exercise completed above.
  - a. Did you notice any differences in the SRT when you utilized the descending approach versus the ascending approach? If so how much?
  - b. Did you notice any differences in the SRT when you utilized 2 dB steps versus 5 dB steps? If so, how much?
  - c. Were there any differences in the SRT/PTA agreement between the test conditions? If so, which test condition provided the best SRT/PTA agreement?
2. Review the article, *A comparison of American Speech-Language Hearing Association Guidelines for Obtaining Speech-Recognition Thresholds*. Ear & Hearing 1994, 15, 324-329. Discuss the results of the study and any impact the study has on clinical practice.

LABORATORY EXERCISE # 2.2
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### Goals

1. To be able to administer word recognition tests using a variety of word lists.

2. To be able to determine when to use the 10, 25, or 50-item word lists when obtaining the word recognition scores.
3. To be able to interpret the word recognition score in comparison to the audiogram.
4. To be aware of other types of speech stimuli used to obtain the word recognition score.

### Exercises

1. Obtain the recorded word recognition score at 40 dB SL re: SRT on \_\_\_\_\_ volunteers for both ears using the CID W-22 word lists:
  - a. Present the first 10 words, note the length of time needed to complete each ear.
  - b. Present the first 25 words, note the length of time needed to complete each ear.
  - c. Present the full 50 words, note the length of time needed to complete each ear.
2. Obtain the recorded word recognition score at 40 dB SL re: SRT on \_\_\_\_\_ volunteers for both ears using the NU-6 half lists:
  - a. Present the first 10 words, note the length of time needed to complete each ear.
  - b. Present the first 25 words, note the length of time needed to complete each ear.
  - c. Presenting the full 50 words, note the length of time needed to complete each ear.
3. Obtain the recorded word recognition score at 40 dB SL re: SRT on \_\_\_\_\_ volunteers for both ears (50 words per ear) using the PB-50 word list, note the length of time needed to complete each ear.
4. Obtain the recorded word recognition score on \_\_\_\_\_ volunteers using the first 25 words of the CID W-22 word List 1 for the right ear and List 2 for the left ear presented at 50 dB HL and 80 dB HL.
5. Utilize references available to you, review and record using other speech stimulus types that are available for word recognition testing. Include some examples of each and in what situations you would utilize them.

### Questions

1. Review the results you obtained for exercise 1 above. Compare and contrast the 10, 25, and 50 item presentations of the test.
2. Review the results you obtained for exercise 2 above. Compare and contrast the 10, 25, and 50 item presentations of the test.

3. Review the results you obtained from exercises 1 and 2, compare and contrast the CID W-22 and the NU-6 word lists.
4. Review the word recognition scores obtained when 50 words were presented for the CID W-22, the NU-6, and the PB-50 word lists. Discuss any similarities and differences noted.

### Chapter 3

#### ACOUSTIC IMMITTANCE AUDIOMETRY

##### Key Words:

Acoustic admittance	Acoustic impedance	Acoustic reactance
Acoustic resistance	Acoustic reflex threshold	Conductance
Hermetic seal	Immittance	Manometer
mmhos	Static admittance	Susceptance
Tympanometry	Vanhuyse model	

##### History and Background Information

The study of the clinical application of immittance measurements was begun in 1939 by Otto Metz in Copenhagen, Denmark. He developed the “theory of acoustic impedance of the ear” (Margolis and Hunter, 1999) and published his findings based on normal and abnormal ears using the Schuster device in the 1940s. In the 1960s and 1970s, research revealed a variety of tympanometric patterns for different ages, different probe frequencies, and for different ear diseases. A group of physicists at the University of Antwerp investigated the relationship between the various tympanometric patterns and the physics of the middle ear. They developed the *Vanhuyse model*, which provides “the basis for clinical interpretation of tympanograms and a tool for experimental studies of pathology on middle ear function” (Margolis & Hunter, 1999).



Some of the other significant contributors to this research include Bekesy, Zwislocki, Jerger, Colletti, and Van Camp. In 1970, Jerger published the results of his study on the clinical application of immittance measurements of over 400 subjects titled “*Clinical experience with impedance audiometry.*”

Administration of the complete immittance test battery provides a quick and relatively inexpensive objective assessment of the status of the middle ear, cochlea, VIIth and VIIIth nerves, and lower brainstem. Immittance audiometry, which typically consists of tympanometry, static immittance, and ipsilateral and contralateral acoustic reflexes, is usually completed before pure tone and speech audiometry. The immittance test battery is much more sensitive to middle ear disorders than the determination of air-bone gaps. (Stach, 1998). If the results on all the subtests are within normal limits in the presence of a hearing loss, the hearing loss is sensorineural in nature, and BC testing does not need to be performed. (Stach, 1998).

Before discussing the clinical application of the immittance test battery, it is important for the tester to understand some of the basic concepts of acoustic immittance. This will assist the tester in understanding the relationship between the patterns of results and middle ear disorders. For an expanded discussion of acoustic immittance, the reader is directed to the references. Margolis and Hunter (1999) state that “the acoustic immittance measurement is a method for analyzing the responses of acoustic systems to sound” and “the acoustic immittance measured in the ear canal is a result of the combined effects of the air volume in the canal and the characteristics of the middle ear” (p. 91). Stach (1998) describes immittance audiometry as a way of assessing the manner in which energy flows through the outer and middle ears to the cochlea (p. 262).

Acoustic immittance is a general term that encompasses the components of acoustic impedance and acoustic admittance (Gelfand, 1997; Wiley & Fowler, 1997). Acoustic impedance ( $Z_a$ ) refers to the opposition to the transfer or flow of acoustic energy that is measured in ohms. The reciprocal of acoustic impedance, acoustic admittance ( $Y_a$ ), refers to the ease with which acoustic energy flows as a result of air pressure changes. The measurement of acoustic admittance is expressed in millimhos (mmhos). Therefore, in the human ear, as the flow of

acoustic energy increases through the middle ear, the acoustic admittance will increase and the resulting acoustic impedance will decrease. The opposite will occur when the flow of acoustic energy decreases through the system as the impedance of the system increases. Acoustic impedance and acoustic admittance are comprised of the following components (Gelfand, 1997; Wiley & Fowler, 1997; Margolis & Hunter, 1999):

### Acoustic Impedance

1. The friction component, acoustic resistance ( $R_a$ ), is measured in acoustic ohms.
2. The stiffness component, negative acoustic reactance ( $-X_a$ ), is measured in acoustic ohms.
3. The mass component, positive acoustic reactance ( $X_a$ ), is measured in acoustic ohms.

### Acoustic Admittance

1. The frictional component, acoustic conductance ( $G_a$ ), is measured in acoustic mmhos.
2. The stiffness or compliant component, acoustic susceptance ( $B_a$ ), is measured in acoustic mmhos.
3. The mass component, negative acoustic susceptance ( $-B_a$ ), is measured in acoustic mmhos.

The immittance of the ear is influenced by the sources of mass, friction, and stiffness. The ossicles, the pars flaccida of the eardrum, and the perilymph influence the mass components. The friction components respond to changes presented by the perilymph, the mucous membrane linings of the middle spaces, the narrow passages between the middle ear and mastoid air cavities, the tympanic membrane, and the various middle ear tendons and ligaments. The stiffness components react to the volumes of air in the spaces of outer ear and middle ears, the tympanic membrane, and tendons and ligaments of the ossicles. Gelfand (1997) also reports that the contraction of the middle ear muscles and the presence of various middle ear pathologies affect the immittance of the middle ear.

For the most part, in the clinical setting, the tester will utilize immittance measures pertaining to acoustic admittance. Wiley and Fowler (1997) state that the mathematic and engineering principles are easier with acoustic admittance measures than with acoustic impedance measures. From this point on the term acoustic admittance will be used to discuss immittance. The equipment available for clinic use is based on acoustic admittance measures.

A review of the history and background information reveals the following. Research has demonstrated that with an understanding of some basic physical principles and the use of a device, which makes admittance measurements of the middle ear possible, the tester is able to diagnose ear disease and its effects on middle ear function. (Margolis & Hunter, 1999).

### Instrumentation

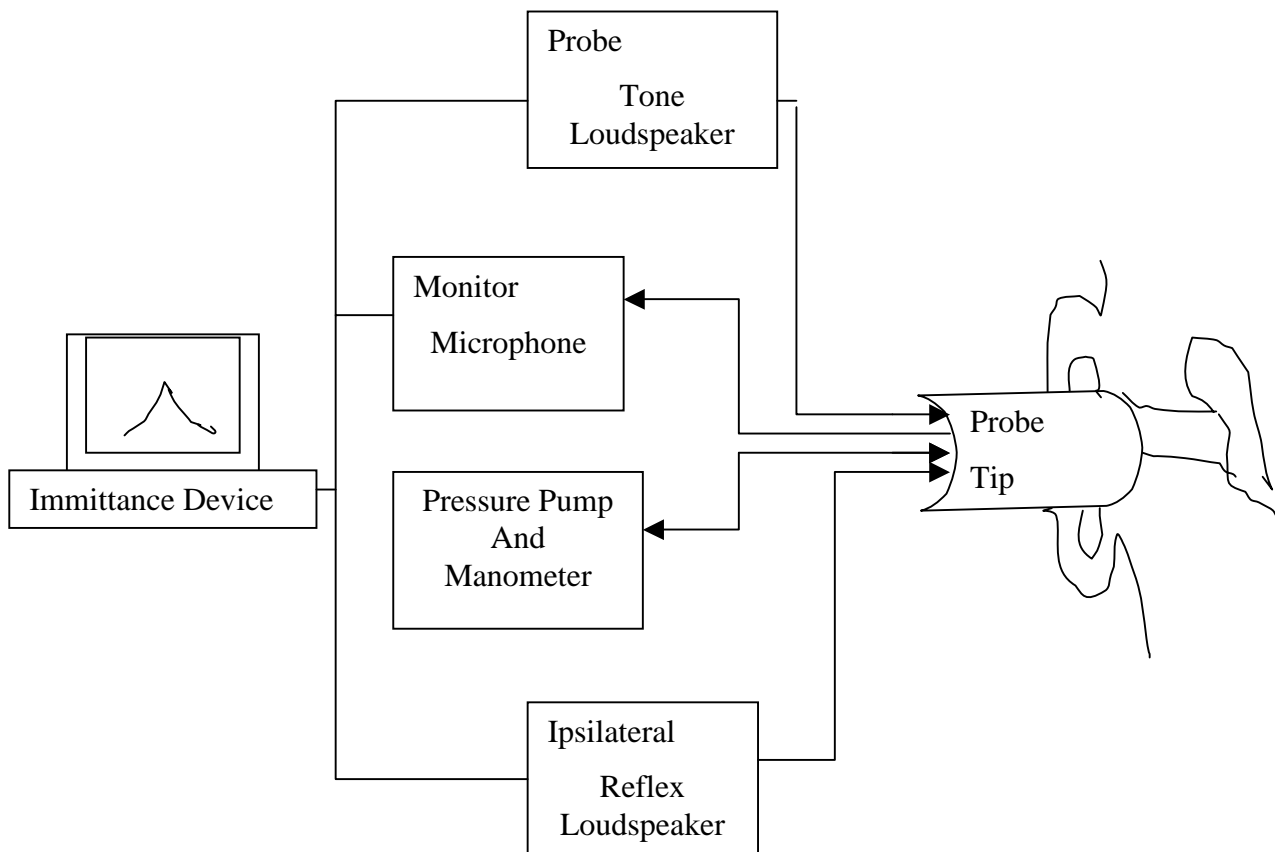
The acoustic admittance measurements are made utilizing a device which consists of a probe assembly, headphone or insert receiver, analysis system, and display. The devices used are developed and calibrated according to the ANSI 1987 specifications. See Figure 3.0 of a block diagram displaying the major components of a clinical acoustic admittance device.

The probe assembly is comprised of four components: the probe tone speaker (receiver), which delivers the probe tone to the ear canal; the monitor microphone, which monitors the probe tone within the ear canal; the air pressure pump and manometer, which controls the air pressure in the ear canal; and a second loudspeaker, which delivers stimuli used in ipsilateral acoustic reflex testing. A removable soft cuff surrounds the probe tip, which is available in a number of sizes to accommodate the ear canal size openings across patients. This cuff, when is of the size appropriate for the patient, allows for the creation of an hermetic seal in the ear canal required for the completion of acoustic admittance measurements.

During admittance testing, a probe tone is introduced into the ear canal and the SPL of the signal is measured. The microphone located in the probe assembly monitors the decreases or increases in the level of this tone. These decreases and increases in the level of the probe tone are due to the various admittance properties of the ear. Generally, an 85 dB SPL, 226 Hz probe tone is used for most admittance measures. The reader is directed to the references for more information regarding the selection of the 226 and the 660-678 Hz probe tone frequencies. Other probe frequencies, such as 800 and 1000 Hz, may be available depending on the instrument. These higher frequencies tend to be more sensitive to certain middle disorders than the lower frequencies. For discussion at this time only the 226 Hz probe tone will be considered. See Table 3.0 for a brief list of definitions provided by the 1987 ANSI guidelines. (Margolis & Hunter, 1999).

### Calibration

The acoustic immittance instrument must be calibrated on an annual basis. The features that need to be calibrated include the probe assembly and the measurement/analysis system. The 226 Hz probe tone must be in agreement with standards by 3%, in another words between 219 and 233 Hz, and the sound pressure level must be  $\leq 90$  dB measured in a  $2 \text{ cm}^3$  (HA-1) coupler. (Margolis & Hunter 1999).



**Figure 3.0: A block diagram displaying the major components of a clinical acoustic immittance device.**

Note. From Essentials of Audiology (p. 218), by S. A. Gelfand, 1997, New York, NY: Thieme Medical Publishers, Inc. Copyright 1997 by Thieme Medical Publishers, Inc. Adapted with permission.

**Table 3.0: Terms used in acoustic immittance measurements provided by the 1987 ANSI guidelines.**

<b>Term</b>	<b>ANSI 1987 Definition</b>
<i>Acoustic immittance</i>	Refers collectively to acoustic impedance, acoustic admittance, and all of their components
<i>Acoustic compliance</i>	The reciprocal of acoustic stiffness, is the ratio of a change in volume displacement to a change in sound pressure. Compliance is a characteristic of spring. The correct unit of measure is the millimho (mmho).
<i>Compensated static acoustic immittance</i>	The immittance that has been compensated (or corrected) for the acoustic immittance of the ear canal. This value represents the acoustic immittance of the middle ear at the tympanic membrane.
<i>Peak compensated static acoustic immittance</i>	The static immittance obtained with the ear canal air pressure adjusted to produce a peak in the measured immittance. This is frequently referred to as the static admittance or the peak admittance.
<i>Measurement-plane Tympanometry</i>	A measurement of acoustic immittance at the probe tip and represents the combined acoustic immittance of the ear canal and middle ear.
<i>Compensated Tympanometry</i>	A measurement of acoustic immittance that has been compensated (or corrected) for the acoustic immittance of the ear canal.

Note. Table was adapted by P. Carr, 2001, utilizing information from Contemporary perspectives in hearing assessment (p. 100-101), by R. H. Margolis & L. L. Hunter, 1999, Needham Heights, MA: Allyn & Bacon. Adapted with permission.

The tester should routinely perform a calibration check of the instrument on a daily basis by using a device provided by the manufacturer containing three calibration cavities with volume

of 0.5, 2.0, and 5.0 cm<sup>3</sup>. (Margolis & Hunter, 1999). The tester should also perform the test battery on herself/himself to ensure proper functioning of the instrument.

### Test Limitations

The following are general test limitations of the admittance test battery. Limitations specific to each measurement (tympanometry, static admittance, and acoustic reflex threshold) will be mentioned under that measurement.

1. Acoustic admittance measures may vary depending upon on the depth of probe insertion (Wiley & Fowler, 1997).
2. Acoustic admittance measurements are affected by the differences in ear canals among patients (Wiley & Fowler, 1997).
3. A hermetic seal necessary for completion of the immittance test battery may not be able to be obtained or maintained for every patient.

## TYMPANOMETRY

### Key Words

Decapascals (daPa)	Equivalent ear canal volume	
Single-frequency tympanometry	Static Admittance	Tympanogram
Tympanometric peak pressure	Tympanometric Shape	
Vector tympanometry		

### Background Information

Definition: The ANSI, S3.39-1987 guidelines define tympanometry as the dynamic measurement of acoustic immittance in the external ear canal as a function of changes in air pressure in the ear canal. It can also be described as the measurement of the acoustic admittance of the ear using various amounts of air pressure in the ear canal. There are several tympanometric measurements that may be obtained such as single-frequency/ single-component tympanometry and multi-frequency/multi-component tympanometry. At this point in time, the

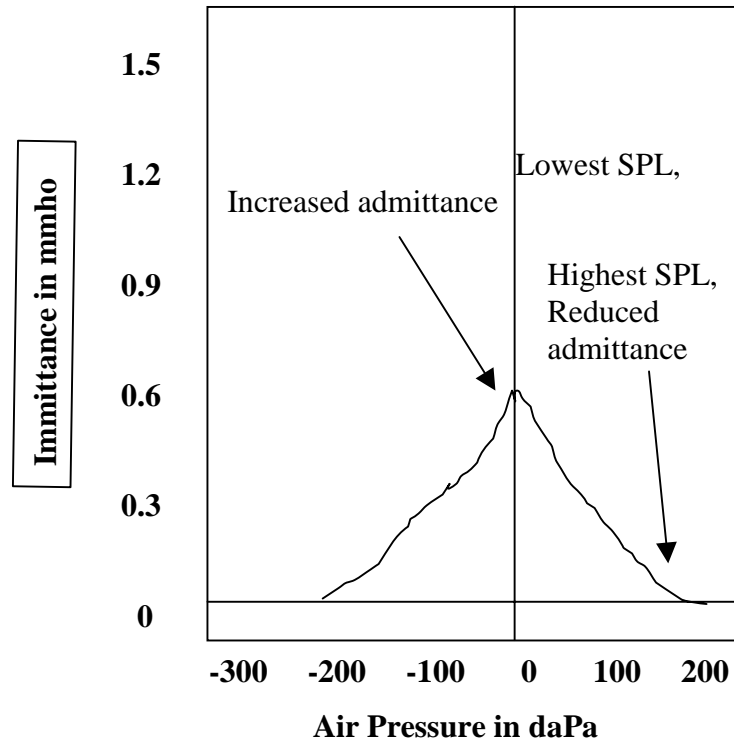
most common method of evaluating the middle ear, single frequency/component tympanometry also known as vector tympanometry, will be discussed.

The measurement of tympanometry: In single-frequency tympanometry, tympanograms are measured at a single probe tone frequency of 226 Hz while the ear canal pressure, measured in dekapascals (daPa), is varied from a positive pressure of 200 daPa to a negative pressure of 300 daPa. (Wiley & Fowler, 1997). The changes in acoustic admittance are measured and plotted as a tympanogram. Admittance in mmhos, in equivalent volume of air ( $\text{cm}^3$ ), or ml is shown on the y-axis and air pressure in daPa or mm H<sub>2</sub>O is shown on the x-axis (Gelfand, 1997; Margolis & Hunter, 1999). See Figure 3.1.

Maximal sound transmission through the middle ear system occurs when the air pressure in the ear canal is the same as the air pressure in the middle ear space. This is seen in Figure 3.1 at the peak of the tympanogram. When the air pressure in the ear canal is more (positive pressure) than or less (negative pressure) than the air pressure in the middle ear space, the transmission of sound through the middle ear is significantly reduced. This is depicted at the tails (200 and -200 daPa) of the tympanogram as shown in Figure 3.1. As the air pressure is varied from 200 daPa to the point of maximal sound transmission (at or around 0 daPa), the sound pressure level in the ear canal decreases. Then, as the air pressure is varied from at or around 0 daPa to -300 daPa, the sound pressure level in the ear canal increases. The tympanogram depicted in Figure 3.1 is typically seen in the absence of middle ear pathology. The presence of middle ear disorders alters the tympanogram in predictable ways so that the various middle ear pathologies correspond to various tympanometric shapes. These will be discussed in the interpretation section of this manual.

### Purpose of the Test

Tympanometry is performed on both ears of a patient to enable the tester to determine the presence of a middle ear disorder and its possible cause. (Wiley & Fowler, 1997; Margolis & Hunter, 1999).



**Figure 3.1:** This figure depicts the admittance measured in mmho on the y-axis and air pressure in daPa on the x-axis. It also shows that as the pressure is varied above and below the point of maximum transmission, the sound pressure level of the probe tone in the ear canal increases, reflecting a reduction in sound transmission through the middle ear mechanism.

### Instructions to the patient

The tester instructs the patient prior to administration of the immittance test battery. It is suggested that the tester face the patient when providing instructions in a clear audible voice. If the patient utilizes amplification, instruct the patient prior to hearing aid removal. Instructions should include information regarding what you are about to do, what you expect them to do, what they might hear, and that they should inform you when intolerable pain or intense discomfort is experienced so that the test may be terminated.

An example of instructions the tester may provide to the patient:

*Now we are going to do a test that tells us how well your eardrum, the bones in your middle ear, and the muscles in your middle ear work. I will put a headphone on one ear and a*



*probe tip in the opening of your other ear. You will feel some pressure in your ear similar to when you go up in an elevator. Also, you will hear a humming sound. From time to time you will hear some loud beeps, you do not need to tell me when you hear the beeps. Please try to sit very still and try not to talk, as any movement or sound can affect the test results. If you should feel any intolerable pain or too much discomfort, please tell me and I will stop the test. Do you have any questions?*

Note: Make sure that the patient removes any gum or candy he or she may have in his or her mouth prior to testing.

## INSTRUMENTATION

### Test set up

Acoustic immittance instrument is set up to perform tympanometry, review manufacturer's manual for specifics.

### Test stimuli

The test stimulus will consist of a probe tone frequency of 226- Hz. The probe tone sound pressure level is 85 dB SPL. The air pressure will sweep from a positive (200 daPa) to a negative pressure (-400 daPa).

### Transducer

Probe tip assembly to one ear and headphone or insert to the opposite ear.

### Response Mode

As the acoustic immittance test battery is an objective test, the patient is not required to respond. The patient however must sit quietly and avoid talking throughout the test battery as any movement or sound made by the patient will interfere with the test.

### Step-by-Step Procedures

The following are suggested procedures for obtaining tympanometric measures:

1. The tester is to perform an otoscopic examination to determine the following:
  - a. External ear canal pathologies;
  - b. Perforated tympanic membrane;

- c. Pressure equalization (PE) or ventilation tube(s); and
- d. Shape of the ear canal.

NOTE: If there is drainage, blood, excessive amounts of cerumen, or the presence of foreign object(s) in the ear canal DO NOT PROCEED with the admittance testing, this will interfere with the functioning of your instrument and puts you and your patients at risk for infectious diseases. Refer the patient for otologic examination.

2. Upon completion of the otoscopic examination the tester is to document findings and consider possible tympanometric findings
3. Instruct patients as stated above.
4. The tester is to select the appropriate size clean probe-tip and place it snugly on the probe assembly.
5. Begin with the right ear. In order to create a hermetic seal, the tester gently pulls up and back on the pinna to straighten the ear canal and inserts the probe tip into the opening of the ear canal. The tester proceeds by directing the probe tip towards the tympanic membrane with a slight twisting motion. Verify that the probe tip is well within the ear canal and filling the meatus. If the probe tip entered the ear canal relatively easily, the tip size may be too small and a larger probe tip is needed. A smaller probe tip may be needed if most of the cuff of the tip visualized.
6. The tester is now ready to perform the test. If positive pressure cannot be maintained, either reseal the probe tip or select a larger or smaller probe tip. If a different probe tip size doesn't solve the problem, consider the following troubleshooting tips:
  - a. The tester places her/his finger over the end of the probe tip to build up pressure. If the pressure is not maintained, there could be a technical problem with the instrument or the probe. The instrument is in need of repair;
  - b. Check that all three tubes are connected to the instrument and the probe assembly and that there are no leaks;
  - c. Check to see that the probe tip is attached snugly to the probe assembly;
  - d. Repeat the otoscopic exam to determine the presence of hair, moles, oddities in the canal, a perforated tympanic membrane or recent placement of pressure equalization (PE) or ventilation tube;

- e. If you are unable to visualize the presence of perforated tympanic membrane or pressure equalization tubes by otoscopic exam prior to testing, question the patient regarding those concerns; and
  - f. Do not take excessive amounts of time or alienate the patient in attempts to obtain a seal. Terminate the admittance measurements and proceed with the remainder of your test session.
7. Once a hermetic seal as been obtained, press the appropriate button(s) on the instrument to obtain the tympanogram beginning with air pressure of 200 daPa. This corresponds to the admittance of the ear canal. The pressure then varies from 200 daPa to -300 daPa. Consult the manufacturer for operating procedures regarding the specific instrument you utilize.
  8. Review the results obtained; note the ear canal volume, the peak amplitude of the tympanogram, and the pressure point of the peak.
  9. Interpret the tympanogram as normal or abnormal.
  10. If the tester has found the test results to be abnormal consider the following:
    - a. Consider the possible middle ear pathologies that could be related to the tympanometric results obtained;
    - b. Based on the tympanometric results obtained, consider the possible audiometric patterns you might obtain;
    - c. Performing bone conduction testing following AC testing; and
    - d. Consider an otologic referral.
  11. Repeat the steps 4 through 10 for the left ear.
  12. If performing other admittance testing, continuing administering those. If tympanometry is the only admittance measure being performed on the patient, remove the used probe tip and dispose of it according to the procedures adopted by your facility.
  13. If tympanometry is the only immittance test being performed, either print the tympanograms or save them to a computer. Make sure that the patient's name, test date, and the test ear are recorded on the tympanograms.
  14. Record the tympanometric results onto the audiogram

Note. From Audiologists' desk reference: diagnostic audiology principles, procedures, and practices (p. 190-191), by J.H. Hall & H. G. Mueller, 1998, San Diego, CA: Singular Publishing Group, Inc. Copyright 1997 by Singular Publishing Group, Inc. Adapted with permission.

<p style="text-align: center;"><b>GO TO LABORATORY</b> <b>EXERCISE # 3.0</b></p>
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### Recording and Scoring of Test Results

Results are either printed out in a variety of ways (strip chart, directly onto an audiogram, or 8 X11" paper) depending on the manufacturer, or saved to a computer. Many clinics record the data manually to help keep paper use down.

### Test Interpretation

When interpreting the tympanograms of a patient, the tester must review the tympanometric shape, the amplitude of the tympanogram, the static admittance, equivalent ear canal volume, and tympanometric peak pressure. Interpretation of tympanograms may be based on a qualitative (tympanometric shape) or quantitative approach (static admittance, tympanometric peak pressure, and equivalent ear canal volume).

Tympanometric Shapes: Liden (Liden, 1969; Liden et al., 1974) and Jerger (1970) provide qualitative classifications of tympanograms based on the height and location of the tympanometric peak. See Table 3.1 depicting a qualitative classification system for tympanometric shape.

Static Admittance: Static admittance, also known as the peak compensated static acoustic admittance, is sensitive to many middle ear conditions. These may include otitis media with effusion, some chronic otitis media sequelae such as cholesteatoma, ossicular adhesions, ossicular discontinuity, eardrum perforation, and ear canal occlusion. Also, space-occupying lesions of the middle ear that are in contact with the eardrum or ossicular chain such as glomus tumors affect static admittance measurements. (Margolis & Hunter, 1999). Static admittance is

an estimate of the admittance at the lateral surface of the tympanic membrane, excluding the effects of the ear canal volume. (VA, 1997). Norms are shown in Table 3.2. See the section following tympanometry for more discussion on static admittance.

**Table 3.1: Tympanometric shape classification system by Jerger (1970) and Liden (1969).**

Tympanometric Shape	Description
Type A	Has a normal peak height and location of the tympanometric peak on the pressure axis. Associated with normal middle ear function.
Type B	Flat or slightly rounded. Associated with otitis media with effusion, cholesteatoma, tympanic membrane perforations, impacted cerumen.
Type C	The peak is displaced toward negative pressure. Associated with Eustachian tube dysfunction, otitis media with effusion.
Type A <sub>d</sub>	High peaked Type A pattern, deep. Associated with ossicular discontinuity, scarred tympanic membranes
Type A <sub>s</sub>	Low-peaked Type A pattern, shallow. Associated with otosclerosis, otitis media

Note. Table was designed by P. Carr, 2001, utilizing information from Acoustic immittance measures in clinical audiology: a primer (52-54), by T. L. Wiley & C. G. Fowler, 1997, San Diego, CA: Singular Publishing Group, Inc. and from Essentials of audiology (223-224), by S. A. Gelfand, 1997, New York, NY: Thieme Medical Publishers, Inc.

**Table 3.2:** Norms for static admittance (Y), and equivalent ear canal volume (V<sub>ea</sub>)

<b>Age Group</b>		<b>Y</b>	<b>(V<sub>ea</sub>)</b>
		<b>(mmho)</b>	<b>(cm<sup>3</sup>)</b>
Children (3-10 years)	Mean	0.52	0.58
	90% Range	(0.25-1.05)	(0.3-0.9)
Adults (≥ 18 years)	Mean	0.79	1.36
	90% Range	(0.30-1.70)	(0.9-2.0)

Note. From Contemporary Perspectives in Hearing Assessment (p. 104), by R. H. Margolis and L. L. Hunter, 1999, Needham, Heights, MA: Allyn & Bacon. Copyright 1999 by Allyn & Bacon. Adapted with permission.

Tympanometric Peak Pressure: The tympanometric peak pressure (TPP) is the ear canal air pressure at which the peak of the tympanogram occurs. The TPP is the point at which the same pressure is present on both sides of the tympanic membrane. Margolis and Hunter (1999) report that TPP is an indicator of the pressure in the middle ear space, but tends to overestimate the actual ear pressure of the middle ear. Therefore, the tester should take caution when using this value in isolation (Cantekin, Doyle, Phillips, & Bluestone, 1980; Magnuson, 1981, 1983; Ostfeld & Silberberg, 1992). Margolis and Hunter (1999) reveal that, in the absence of other tympanometric, audiometric, or otoscopic abnormality, negative middle ear pressure alone is not an indication of a significant middle ear disorder. For example, Margolis and Nelson (1992) reported that positive pressure (≥ 50 daPa) has been observed in patients with acute otitis media. Positive peak pressure has also been associated with nonpathologic causes such as rapid elevator rides, crying, or nose blowing. (Harford, 1980). According to Gelfand (1997), abnormally negative tympanometric peak pressures are associated with eustachian tube disorders that can occur either with or without the presence of middle ear fluid. See Table 3.2 for norms.

**Equivalent Ear Canal Volume:** In the presence of a flat tympanogram, an estimate of the volume of air in front of the probe can be useful for detecting eardrum perforations, evaluating the patency of tympanostomy tubes, and evaluating the effects of cerumen in the ear canal. When flat tympanograms are obtained, it is necessary for the tester to review the ear canal volume measurements to determine the presence of various middle ear conditions. The ear canal volume values may be abnormally large, abnormally small, or within normal limits. In the case of a tympanic membrane perforation, the equivalent ear canal volume is an abnormally large estimate of the middle ear space, contiguous mastoid air cells, and ear canal volume (Margolis & Hunter, 1999). Abnormally large ear canal volume/flat tympanogram may be attributed to:

1. A perforated tympanic membrane;
2. In the presence of a tympanostomy tube, a patent tube; or
3. The absence of a hermetic seal, especially if the ear canal volume measurements exceed 2.0 mmhos in children and 2.5 mmhos in adults. (Van Camp et al, 1986; Silman & Silverman, 1991).

If the ear canal volume measurements are unusually small (at or close to 0 mmhos), the flat tympanogram could be attributed to:

1. A clogged probe tip;
2. A probe tip that is pushed against the ear canal wall;
3. Impacted cerumen or another obstruction in the ear canal;
4. In the presence of a tympanostomy tube, a clogged tube (Gelfand, 1997); or
5. In the presence of a flat tympanogram, normal or near normal ear canal volume measurements may be indicative of a fluid filled or tissue-filled middle ear cavity.

The tester must keep in mind, however, that a normal ear canal equivalent volume does not always rule out perforation (Margolis & Hunter, 1999). Shanks & Lily (1981) report that when maximum pressure is presented to the ear canal using a 226 Hz probe tone, the eardrum and ear canal walls are not perfectly rigid. Therefore, the resulting equivalent ear canal volume overestimates the ear canal volume by about 25 % in adults. The average tympanometrically measured equivalent ear canal volume is about 0.3 cm<sup>3</sup> in 4-month infants (Holte, Margolis, & Cavanaugh, 1991), 0.75 cm<sup>3</sup> in preschool-aged children (Margolis & Heller, 1987) and 1.0 to 1.4 cm<sup>3</sup> in adults (Margolis & Heller, 1987; Wiley, Cruikshanks, Nondahl, Tweed, Klein, & Klein,

1996). The tester should practice caution when reviewing ear canal volumes as a normal volume does not rule out an eardrum perforation.

When interpreting flat tympanograms, the tester should consider the following as ears with past or present middle ear disease have smaller middle ear/mastoid volumes than normal ears for several reasons:

1. An ear with active disease may contain fluid, inflammation, granulation, fibrosis, and cholesteatoma that reduce middle ear/mastoid volume.
2. Ears with active disease may have obstructions of the mastoid air cell system reducing the total mastoid volume
3. When chronic disease occurs in infancy, there is an interruption of the pneumatization process resulting in a smaller air-filled space (Palva & Palva, 1966).
4. Chronic disease is more prevalent in ears with poorly pneumatized mastoids (Diamant et al., 1958).
5. Ears with perforations have abnormally large volumes when they are free of active disease. However, when perforations occurred in the presence of active disease, the equivalent ear canal volume was often normal (Shanks, 1985).
6. Progressively larger equivalent ear canal volume following tube insertion is an indication of recovery from otitis media. However, when the equivalent ear canal volume remains small, it is an indication of persistent disease (Takasaka, Hozawa, Shoji, Takahashi, Jingu, Adachi, & Kobayashi, 1996).
7. Ears with equivalent ear canal volumes of 1.5 cc or less should be followed more closely for recurrent otitis media (Margolis & Hunter, 1999).

### Test Limitations

1. When utilizing only the 226 Hz probe tone, some middle ear disorders that are affected by high frequencies will be missed (Wiley & Fowler, 1977).
2. There is no agreed upon cutoff value that determines abnormally negative tympanometric peak pressure. Jerger (1970), Fiellau-Nikolajsen (1983), and Silman et al (1992) recommend a cutoff value of -100 daPa. Renvall and Liden (1978) and



- Davies, John, Jones, and Stephens (1988) suggest using  $-150$  daPa as the cutoff value. Brooks (1969) reported the use of  $-170$  daPa.
3. There is no one particular cutoff value for tympanometric peak pressure that reliably distinguishes between the presence and absence of middle ear effusion (Gelfand, 1997).
  4. The tester needs to practice caution when reviewing equivalent ear canal volumes as perforation may be present with normal volume measurements.
  5. The tester must review tympanometric results along with case history and other audiometric findings as these results cannot be interpreted alone.
  6. It is difficult to determine the presence or absence of middle ear disorder by the static admittance results alone. Jerger (1970) and Feldman (1976) demonstrated that the range of static admittance values found with various types of middle ear disorders overlaps values considered to be in the normal range.
  7. Norms do not always specify recording parameters such as recording speed, direction of pressure change, and number of tympanograms measured sequentially. All of these parameters affect test interpretation (Wiley & Fowler, 1997).

### Laboratory Exercises

Laboratory Exercise # 3.0
---------------------------

#### Goals

1. To be able to select the appropriate size probe tip and obtain a hermetic seal.
2. To be able to troubleshoot when a hermetic seal is unable to be obtained and maintained.
3. To be able to set up the acoustic immittance instrument and perform tympanometric measurements.

#### Exercises

1. Practice calibrating the immittance instrument using the device containing the 0.5, 2.0, and  $5.0 \text{ cm}^3$  cavities.

- a. Place the probe tip assembly in the 0.5 cm<sup>3</sup> cavity and run a tympanogram by selecting the appropriate buttons as specified in manufacturer directions. Repeat tympanograms for the 2.0 and 5.0 cm<sup>3</sup> cavities.
  - b. Determine that the results are within ANSI 1987 specifications.
  - c. If the facility has a daily calibration log, record completion of calibration in the log.
2. Practice performing tympanometry on \_\_\_\_\_ volunteers for both ears. Make sure the instrument is set for the 226 Hz probe tone frequency, the Y mode, pump speed of 200 daPa/sec, and the pressure direction from 200 daPa to -400 daPa.
- a. Perform otoscopic exam and record findings on the audiogram
  - b. Begin with the right ear and determine the appropriate probe tip size. Obtain a tympanogram.
  - c. Repeat for the left ear.
  - d. Repeat the tympanograms for both ears using a pump speed of 50 daPa/second.
  - e. Repeat the tympanograms for both ears using the pressure direction from -400 daPa to 200 daPa and pump speed of 200 daPa/second.
  - f. Repeat the tympanograms for both ears using the pressure direction from -400 daPa to 200 daPa, pump speed of 50 daPa/second.

### Questions

1. Review the tympanometric peak pressure (TPP), static admittance, and equivalent ear canal volume (EECV) results obtained for the second exercise above.
  - a. Were there any differences between the three measurements when the pump speed was varied?
  - b. Were there any differences between the three measurements when the direction of pressure change was varied?

Laboratory Exercise # 3.1
---------------------------

### Goals

1. To be able to determine if tympanometric results are normal or abnormal.

- To be able to predict the possible pure tone results and condition of the middle ear based upon the TPP, the static admittance, and EECV results.

Exercises

- Following are some cases depicting TPP, static admittance, and EECV results. Review the results, state the tympanometric shape (A, A<sub>d</sub>, A<sub>s</sub>, B, C), whether the results are normal or abnormal, and speculate the possible condition based on the results.

Case # 1:

TPP → -50 daPa

Static admittance → 0.4 cm<sup>3</sup>

EECV → 0.7 cm<sup>3</sup>

Normal/Abnormal (circle one)                      Shape\_\_\_\_\_

Indicative of what condition? \_\_\_\_\_

Case # 2:

TPP → no pressure reading

Static admittance → no peak reading

EECV → 0.5 cm<sup>3</sup>

Normal/Abnormal (circle one)                      Shape\_\_\_\_\_

Indicative of what condition?  
\_\_\_\_\_

Case # 3:

TPP → no pressure reading

Static admittance → no peak reading

EECV → 0.1 cm<sup>3</sup>

Normal/Abnormal (circle one)                      Shape\_\_\_\_\_

Indicative of what condition?  
\_\_\_\_\_

Case # 4:

TPP → no pressure reading

Static admittance → no peak reading

EECV → 3.1 cm<sup>3</sup>

Normal/Abnormal (circle one)                      Shape\_\_\_\_\_

Indicative of what condition? \_\_\_\_\_

Case # 5:

TPP → -350 daPa

Static admittance → 0.4 cm<sup>3</sup>

EECV → 0.6 cm<sup>3</sup>

Normal/Abnormal (circle one)                      Shape\_\_\_\_\_

Indicative of what condition? \_\_\_\_\_

Case # 6:

TPP → 5 daPa

Static admittance → 0.3 cm<sup>3</sup>

EECV → 0.5 cm<sup>3</sup>

Normal/Abnormal (circle one)                      Shape\_\_\_\_\_

Indicative of what condition? \_\_\_\_\_

Case # 7:

TPP → -15 daPa

Static admittance → 2.1 cm<sup>3</sup>

EECV → 0.7 cm<sup>3</sup>

Normal/Abnormal (circle one)                      Shape\_\_\_\_\_

Indicative of what condition? \_\_\_\_\_

2. Select 10 cases on a simulated program. For each case:
  - a. Complete the tympanometric measurements
  - b. Interpret the results as normal/abnormal

- c. Determine tympanometric shape
- d. State possible middle ear condition and why the condition was selected
- e. Determine possible pure tone findings and state why.

### Questions

1. Upon completion of the two exercises, describe any patterns noted between pure tone results and tympanometric measurements.
2. As a tester, do the tympanometric results alone provide you with enough information to comfortably formulate a diagnosis? Why or why not? If additional information is needed in formulating your diagnosis, what is it and why?

## STATIC ACOUSTIC IMMITTANCE (SAI)

### Key Words

Acoustic mmhos (a mmhos)

Compensated static acoustic admittance

Total immittance

Tympanometric peak

### Background Information

Definition: Wiley and Fowler (1997) define compensated static acoustic immittance or static acoustic immittance (SAI) as the amplitude of the tympanogram (the height of the tympanometric peak) measured at the plane of the tympanic membrane. The measurement estimates the acoustic admittance at the plane of the tympanic membrane and the middle ear system combined, excluding the ear canal value.

Total immittance measurements are based on the SPL reading at the probe tip and reflect the acoustic immittance of the ear at that point of the measurement. The total immittance measurements are the combined effects of the ear canal, the tympanic membrane, the middle ear system, and the coupling of the ossicular chain to the cochlea. Our focus is on the acoustic immittance of the middle ear, which is measured at the plane of the tympanic membrane. In order to do this we need to subtract out the effects of the ear canal from the total immittance.

This is done by first measuring the total acoustic admittance of the ear at either atmospheric pressure (0 daPa) or ambient ear canal pressure, or at the peak of the tympanogram. Wiley and Fowler (1997) report that the tympanometric peak value is the preferred measurement for use in the clinic for several reasons:

1. It is the most stable of the two methods of measuring the SAI as it is unaffected by small, normal fluctuations caused by swallowing and respiration.
2. It provides an estimate of the best possible function of the middle ear system.

Once the total acoustic immittance value is determined, a high amount of pressure (negative or positive) is presented to the ear canal. This creates a stiffened tympanic membrane so that essentially no flow of acoustic energy passes through to the middle ear and a measurement of the ear canal is obtained. These measurements may be taken from the positive or negative tails of the tympanogram. Most norms are based upon measurement taken from the positive tail. Shanks and Lily (1981) report that measurements taken from the negative tail, which are higher in peak value than those taken from the positive tail, provide a more accurate estimate of ear canal volume. This value (the ear canal volume) is subtracted from the total acoustic admittance to arrive at an estimate of the middle ear acoustic admittance at the lateral surface or plane of the tympanic membrane, the SAI. (Gelfand, 1997; Wiley & Fowler, 1997). The final SAI values usually represent the calculations automatically determined by the instrument's analysis system.

<p style="text-align: center;"><b>GO TO LABORATORY</b> <b>EXERCISE # 3.2</b></p>
--

#### Purpose of the Test

SAI values are used to predict the presence of middle ear pathology.

#### Instructions to the Patient

None are given, as this is part of the tympanometric measurement.

Instrumentation, test set-up, test stimuli, transducer, response mode, step-by-step procedures

SAI is part of the tympanometric measurement, therefore follow for tympanometry.

Recording and Scoring of Test Results

Results are either printed out in a variety of ways (strip, directly onto an audiogram, or 8 X11" paper) depending on the manufacturer or saved to a computer. SAI results may be designated as SC (static compliance) or tympanometric peak measured in a mmhos or  $\text{cm}^3$  depending on the manufacturer. Many clinics record the data manually to keep paper down.

Test Interpretation

The SAI, the tympanometric peak, values obtained are then compared to the norms. There are no universally accepted norms for the SAI. When interpreting SAI values and comparing to the norms, the tester must take into consideration the pump speed utilized during the procedure and whether measurements were taken from the positive or negative tails. Fast pump speeds are often used during immittance screening procedures. See Table 3.3 depicting several sets of norms. The SAI values may be interpreted in the following ways:

Normal: if the SAI results fall within the range of normal

Below Normal: if the SAI results fall below the normal range. This is often seen as a low peak on the tympanogram and corresponds to abnormally low admittance. Reduced SAI values can occur due to stiffening conditions such as otosclerosis, cholesteatoma, and middle ear fluid. While SAI values at or near 0 mmhos are usually seen in cases where the middle ear is filled with fluid, ears impacted with cerumen or perforated tympanic membranes exhibit SAI values that are at or near 0 mmhos. (Gelfand, 1997; Wiley & Fowler, 1997).

Above Normal: if the SAI values fall above the normal range. This is usually depicted as a very high peak on the tympanogram and corresponds to abnormally high admittance. Increased SAI values are seen in middle ear pathologies that add mass to the middle ear system. Conditions such as ossicular discontinuity and ear drum pathology such as external otitis, or cerumen or water adhering to the surface of the tympanic membrane present themselves with increased SAI values. (Gelfand, 1997; Wiley & Fowler, 1997).

**Table 3.3:** Depicts various norms for static acoustic admittance at the 90% range in a mmhos.

References	Adults	Children	Infants
ASHA (1990) <sup>1</sup>	0.30 - 1.40	0.20 - 0.90	
Gelfand (1997) <sup>2</sup>	0.37 – 1.66 (Wiley, 1989)	0.35 – 1.25 (Silman, Silverman, & Arik, 1992)	0.26 – 0.92 (Margolis & Popelka, 1975)
Gelfand (1997) <sup>3</sup>	0.57 – 2.00 @ pump speed of 200 daPa/sec 0.50 – 1.75 @ pump speed of ≤ 50 daPa/sec (Wilson, Shanks, & Kaplon, 1984)	0.40 – 1.03 @ pump speed of 200 daPa/sec 0.35 – 0.90 @ pump speed of ≤ 50 daPa/sec (Koebsell & Margolis, 1986)	
Hurely (1999) <sup>4</sup>	0.40 – 1.60	0.22 – 0.90	0.11 – 0.92
Margolis & Hunter (1997)	0.30 – 1.70	0.25 – 1.05	

1. Note. From “Guidelines for screening for hearing impairment and middle-ear disorders,” by American Speech-Language-Hearing Association, 1990, ASHA, 32 (Suppl. 2) p. Copyright 1990 by the American Speech-Language-Hearing Association. Adapted with permission.

2 & 3. Note. From Essentials of Audiology (p. 225), by S. A. Gelfand, 1997, New York, NY: Thieme Medical Publishers, Inc. Copyright 1997 by Thieme Medical Publishers, Inc. Adapted with permission.



4. Note. From Manual of Tests Procedures: these materials were prepared for use in COMD 6203: “Advanced Diagnosis in Audiology,” Spring Term, 1999, 1999, by R. M. Hurley.

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5. Note. From Contemporary Perspectives in Hearing Assessment (p. 104), by R. H. Margolis and L. L. Hunter, 1999, Needham, Heights, MA: Allyn & Bacon. Copyright 1999 by Allyn & Bacon. Adapted with permission.

**GO TO LABORATORY  
EXERCISE # 3.3**

### Limitations

1. There is variability of norms due to differences among researchers in terms of measurement and recording parameters.
  - a. Some norms determine the static admittance measurement from the positive tail of the tympanogram and others from the negative tail of the tympanogram. The measurements taken from the positive tail are smaller than those taken from the negative tale (Gelfand, 1997; Wiley & Fowler, 1997) and may possibly be less accurate although it is unlikely to have a significant clinical effect.
2. There is an overlap of SAI values obtained from normal ears and ears with middle ear pathology making it difficult to separate the normal ears from the abnormal ears. ( Margolis & Heller, 1987; Nozza, et al., 1992; Shanks & Sheldon, 1991).
3. Males tend to exhibit higher values than females suggesting that norms may need to be available for each group. ( Jerger, Jerger, & Maudlin, 1972; Wiley et al., 1996; Zwislocki & Feldman, 1970).

### Laboratory Exercises

**LABORATORY EXERCISE # 3.2**

### Goals

1. To determine how the SAA values are calculated manually and therefore have a greater understanding of the admittance of the middle ear at various pressure points.

2. To become more familiar with functions available on the acoustic admittance instrument.

### Exercises

NOTE: in order to complete the following exercises the acoustic immittance device needs to be equipped with the following capabilities:

1. Baseline “on” and “off”
  2. Varying pump speed
  3. Change the direction of the pressure change
  4. Frequencies 226 and 678 Hz
1. Run an acoustic admittance (Y) tympanogram with the baseline function “off” on \_\_\_\_\_ volunteers.
    - a. Set up the acoustic admittance device as follows:
      - 226 Hz probe tone frequency
      - Baseline function is turned “off”
      - Positive to negative tracing
      - Pump speed of 50 daPa/sec
    - b. Run the tympanogram on both ears
    - c. Calculate the SAI or peak admittance as follows:
      - Determine the height of the peak. Look at the peak of the tympanogram and estimate the distance from the peak to the X-axis in a mmho. This will be your C2 value, the total admittance value that corresponds to the measurement of the middle ear and the ear canal.
      - Next, estimate the distance from the tracing at 200 daPa to the X-axis in a mmho. This will be your C1 value, the admittance value of the ear canal.
      - Finally, calculate the SAI as  $C2 - C1$ . This is the peak admittance of the middle ear.
      - Repeat the above calculations measuring from  $-200$  daPa.
  2. Run an acoustic admittance (Y) tympanogram with the baseline function turned “on” on \_\_\_\_\_ volunteers.
    - a. Set up the acoustic admittance device as follows:
      - 226 Hz probe tone frequency
      - Baseline function is turned “on”

- Positive to negative tracing
  - Pump speed of 50 daPa/sec
- b. Run the tympanogram on both ears
  - c. Record the peak admittance values in mmhos located on your screen or printout
3. Run an acoustic admittance (Y) tympanogram with the baseline function “off” on \_\_\_\_\_ volunteers.
    - a. Set up the acoustic admittance device as follows:
      - 226 Hz probe tone frequency
      - Baseline function is turned “off”
      - Positive to negative tracing
      - Pump speed of 200 daPa/sec
    - b. Run the tympanogram on both ears
    - c. Calculate the SAI or peak admittance as follows:
      - Determine the height of the peak. Look at the peak of the tympanogram and estimate the distance from the peak to the X-axis in a mmho. This will be your C2 value, the total admittance value that corresponds to the measurement of the middle ear and the ear canal.
      - Next, estimate the distance from the tracing at 200 daPa to the X-axis in a mmho. This will be your C1 value, the admittance value of the ear canal.
      - Finally, calculate the SAI as  $C2 - C1$ . This is the peak admittance of the middle ear.
      - Repeat the above calculations measuring from  $-200$  daPa.
  4. Run an acoustic admittance (Y) tympanogram with the baseline function turned “on” on \_\_\_\_\_ volunteers.
    - a. Set up the acoustic admittance device as follows:
      - 226 Hz probe tone frequency
      - Baseline function is turned “on”
      - Positive to negative tracing
      - Pump speed of 200 daPa/sec
    - b. Run the tympanogram on both ears
    - c. Record the peak admittance values in mmhos located on your screen or printout
  5. Repeat exercises 1-4 using a 678 Hz probe tone.

Questions

1. Review the results you obtained for exercises 1 and 2. Discuss differences observed between baseline function, direction of tracing, ears, or calculations from 200 daPa or –200 daPa.
2. Review the results you obtained for exercises 3 and 4. Discuss differences observed between baseline function, direction of tracing, ears, or calculations from 200 daPa or –200 daPa.
3. Review the results obtained regarding pump speeds for exercises 1-4. Discuss differences observed.
4. Review results obtained for exercise 5. How did they compare to your results obtained with the 226 Hz probe tone?

**LABORATORY EXERCISE # 3.3**Goals

1. To be able to interpret SAI values as normal or abnormal.
2. To speculate as to the possible middle ear condition present.

Exercises

1. In LABORATORY EXERCISE # 3.2 compare your results obtained to two of the sets of norms shown in Table 3.3. Determine the following regarding your SAI results:
  - a. Are they normal or abnormal?
  - b. If they are abnormal, are they above or below the normal range?
  - c. If they are abnormal, what is the speculated middle ear condition?
2. Review the following cases:
  - a. Case # 1, a 7 year old child:  
SAI → 0.30 a mmhos. Normal/abnormal (circle one). Possible middle ear condition\_\_\_\_\_.
  - b. Case # 2, a 3 year and 2 months old female:  
SAI → 0.30 a mmhos. Normal/abnormal (circle one). Possible middle ear condition\_\_\_\_\_.

- c. Case # 3, a 24 month old male:  
SAI → 1.25 a mmhos. Normal/abnormal (circle one). Possible middle ear condition\_\_\_\_\_.
  
- d. Case # 4, a 42 year old female:  
SAI → 1.25 a mmhos. Normal/abnormal (circle one). Possible middle ear condition\_\_\_\_\_.
  
- e. Case # 5, a 35 year old male:  
SAI → 1.80 a mmhos. Normal/abnormal (circle one). Possible middle ear condition\_\_\_\_\_.
  
- f. Case # 6, a 32 year old female:  
SAI → 0.25 a mmhos. Normal/abnormal (circle one). Possible middle ear condition\_\_\_\_\_.

Questions

1. Review your interpretations in the two exercises above. Discuss what you observed.
2. Based on information provided by the available references, discuss disadvantages and advantages of relying in the SAI values alone in the determination of the presence of a middle ear condition.

ACOUSTIC REFLEX THRESHOLD (ART)

Key Words

VIIIth cranial nerve	Acoustic reflex	Acoustic reflex threshold
Admittance	Afferent	Brainstem
Contraction	Contralateral acoustic reflex	
Crossed acoustic reflex	Efferent	Elevated
Extra-axial	Facial Nerve	Immittance

Intra-axial	Ipsilateral acoustic reflex	Probe ear
Probe tone	Retrocochlear	Stapedius muscle
Stapedius tendon	Stimulus ear	Superior olivary complex
Tensor tympani muscle	Uncrossed acoustic reflex	Ventral cochlear nucleus

### History and Background Information

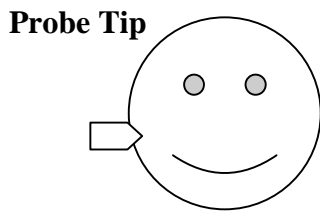
In 1878, while studying the anatomy and physiology of dogs, Hensen observed the contraction of the stapedius and tensor tympani muscles in response to acoustic stimuli. Lüscher made the first direct observations of the acoustic reflex in humans in 1929 (Potter, 1936). Lindsay, Kobrak, and Perlman reported in 1936 that the acoustic stapedius reflex provided little in the way of practical clinical value. In, 1946 Metz 's work was recognized as he contributed to the development of a mechano-acoustic bridge for middle ear measurement. He was the first to obtain acoustic-reflex measurements by monitoring changes in the acoustic immittance of the ear upon acoustic stimulation, and he noted patterns between acoustic-reflex thresholds and ear disease which provided the first clinical application of the acoustic reflex test.

The acoustic reflex is elicited as a contraction of the stapedius muscle in both ears when a sufficiently intense sound is presented to either ear. This contraction creates a change in the immittance of the middle ear by stiffening the middle ear system through the stapedius tendon. The change in immittance is seen as a decrease in the admittance of the middle ear system. This decrease in the ear's admittance is measured in the ear containing the probe tip, also known as the probe ear. The stimulus ear is the ear that receives the stimulus used to activate the reflex. The stimulus may be delivered to either ear from the receiver in the probe tip or the earphone/insert receiver on the opposite ear. When the stimulus is delivered to the probe ear, the ipsilateral or uncrossed acoustic reflex is being measured. Thus, in the ipsilateral test mode, the ear containing the probe is the same ear that receives the stimulus and it also monitors the changes in immittance. See Figure 3.30 and 3.31. When the probe tip is in one ear and the stimulus is presented to the other ear this is known as the contralateral or crossed acoustic reflex. During measurement of the contralateral acoustic reflex, the stimulated ear is used to identify the reflex (according to ANSI specifications, 1987). See Figure 3.32 and 3.33. The "right contralateral acoustic reflex" indicates that the stimulus was delivered to the right ear and the

probe in the left ear is monitoring the reflex response. The “left contralateral acoustic reflex” means that the stimulus was delivered to the left ear and the probe in the right ear is monitoring the reflex response. The ipsilateral acoustic stapedius reflex is generally elicited at a slightly lower loudness level relative the contralateral acoustic reflex.

**Probe and Stimulus Ear for the Acoustic Reflex**

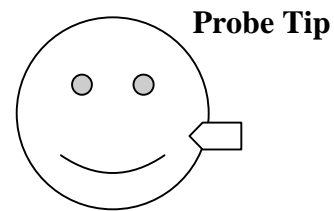
**Right Ipsilateral Acoustic Reflex**



Right Ear      Left Ear

**Fig. 3.30:** The right ear ipsilateral acoustic reflex . The right ear contains he probe and receives the stimulus.

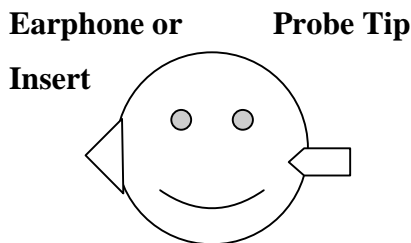
**Left Ipsilateral Acoustic Reflex**



Right Ear      Left Ear

**Fig. 3.31:** The left ear ipsilateral acoustic reflex. The left ear contains the probe and receives the stimulus.

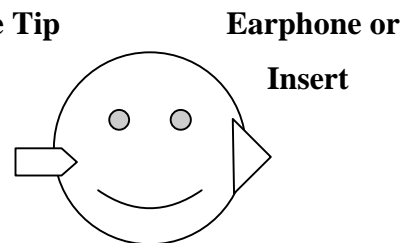
**Right Contralateral Acoustic Reflex**



Right Ear      Left Ear

**Fig. 3.32:** The right ear contralateral

**Left Contralateral Acoustic Reflex**



Right Ear      Left Ear

**Fig. 3.33:** The left ear contralateral

acoustic reflex . The right ear receives the stimulus and the left ear contains the probe.

acoustic reflex. The left ear receives the stimulus and the right ear contains the probe.

**Note: the stimulated ear is the test ear.**

### Anatomical and physiological overview

The stapedius muscle, the smallest skeletal muscle in the body, is about 6 mm in length, with a cross section width of about 5 mm<sup>2</sup>. It is contained within a bony canal that runs almost parallel to the facial nerve canal on the posterior wall of the tympanic cavity. Only the stapedius tendon that originates from the stapedius muscle enters the tympanic cavity. The direction of the bony canal is almost vertical, but the direction of the stapedius tendon is nearly horizontal. The stapedius muscle is attached to the posterior neck of the stapes via the stapedius tendon. The motor or stapedial branch of the VIIth (facial) cranial nerve, (Wiley & Fowler, 1997) innervates the stapedius muscle.

When the stapedius muscle contracts, the tendon exerts tension on the stapes; the stapes footplate is moved laterally from the oval window and the head of the stapes is drawn posteriorly, at right angles to the direction of the ossicular chain. The ossicular chain is then stiffened and there is a reduction of low frequency energy transmission through the middle ear. As a result of this reduced energy transmission, there is a noticeable increase in the SPL reading in the external ear canal. Upon elicitation of the acoustic reflex, its contraction tends to act as a high pass filter of the transmission of sound through the middle ear. Rabinowitz (1977) reported attenuation of low frequency signals with the maximum effect for approximately 600 Hz. He also noted little, if any, effect of the acoustic reflex on the loudness level for frequencies above 1000 Hz that reached the inner ear. The stapedius muscle in both ears contract as a result of sound being delivered to either ear.

Borg (1973) described the acoustic reflex arc based on his research in rabbits. As an example, the pathway is as follows when the normal right ear has been stimulated:

1. The sound is presented to the right ear, passes through the middle ear and then through the cochlea.



2. The stimulus then proceeds through the afferent (sensory) and efferent (motor) parts of the acoustic reflex arc as follows:
  - a) Afferent:
    - 1) The stimulus passes along the auditory (VIII) nerve from the right ear;
    - 2) then goes to the right (ipsilateral) ventral cochlear nucleus;
    - 3) from there the neurons go to the superior olivary complexes on both sides of the brain stem; and then
    - 4) signals from the right and left superior olivary complexes are sent to the facial (seventh) nerve nuclei on their respective sides to complete the afferent part of the acoustic reflex pathway.
  - a) Efferent:
    - 1) The signal then proceeds through the efferent part of the acoustic reflex pathway by involving the right and left facial nerves;
    - 2) This in turn directs the stapedius muscles to contract in both ears.

Keep in mind that the tensor tympani muscles also respond to extremely intense sounds but evidence supports that the acoustic reflex in humans is a stapedius reflex (Gelfand, 1990). The stapedius reflex is also activated to nonacoustic stimulation such as tactile stimulation of the external ear or a puff of air to the eye (Wiley & Block, 1984).

<b>GO TO LABORATORY EXERCISE</b>
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<b>AR # 3.4</b>
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### The Acoustic Reflex Threshold (ART)

The ART is the lowest intensity level of a stimulus presented to the test ear that results in the smallest measured change in acoustic immittance at the level of the tympanic membrane. The reflex is elicited upon presentation of a sufficiently loud stimulus and generally becomes larger as the stimulus level is increased. In the clinical setting, ipsilateral ART's are usually obtained for 1000 Hz and contralateral ART's are usually obtained for frequencies 500, 1000, and 2000 Hz using pure tone stimuli in both ears. The inclusion of 4000 Hz is not recommended because research reveals that even young people with normal hearing demonstrate elevated thresholds at this frequency due to rapid adaptation (Gelfand, 1984; Silman & Silverman, 1991).

### Purpose of the acoustic reflex threshold

ART testing, an objective measurement, is useful in the differential assessment of auditory disorder, in the assessment of middle ear function and the differentiation of cochlear from retrocochlear disorder. A comparison of uncrossed and crossed acoustic thresholds has been helpful in the differentiation of VIIIth nerve from brainstem disorders. (Stach, 1998). The determination of the ART's has been used by some audiologists to predict hearing sensitivity in difficult to test patients or those suspected of pseudohypacusis.

## INSTRUMENTATION

### Test Set up

1. Turn on the immittance device and calibrate as specified by the manufacturer.
2. Complete tympanometry for the right ear first, leave probe assembly on the patient. Prior to inserting the headphone or insert to the left ear, instruct your patient as suggested below under "Instructions to the patient".
3. The ART test is usually administered using a 220 or 226 Hz probe tone.
4. When testing neonates, a 660 Hz probe tone is used as their acoustic reflexes are often elevated or absent with a 226 Hz probe tone. The reflexes of neonates is more similar to that of adults when a 660 Hz probe tone is used (Bennett & Weatherby, 1982; Gelfand, 1984; Sprague et al, 1985).
5. Research has documented that the stimulus presentation level should not exceed 105 dB HL (110 dB SPL) for several reasons (Wilson & Margolis, 1999). Presentation levels at these high levels may be upsetting to the patient. Patients may experience a temporary and/or permanent hearing loss following acoustic reflex testing. (Stach, 1998).

### Instructions to the patient

Make sure you face your patient as you already have one ear plugged with the probe tip. Instructions should include what the patient may hear and what you are about to do. Also inform the patient that the test may be discontinued at any time should the patient experience intense pain or discomfort. An example of instructions you may provide to your patient:

*Now you will hear some loud beeps, you do not need to tell me when you hear the beeps. Please continue to sit very still and avoid talking, as any movement or sound can affect the test results. If you should feel any intolerable pain or too much discomfort, please tell me and I will stop the test. Do you have any questions? Now I will place this headphone over your other ear.*

### Step-by-Step Procedures

The following are suggested procedures for completing ipsilateral and contralateral ART's:

1. Complete tympanometry on the right ear first.
2. Verify that the immittance probe is in one ear, and the supra-aural or insert earphone for contralateral stimulation is properly seated in the other ear.
3. Adjust the ear canal pressure to the point at which the tympanometric peak is at its maximum value. This is done automatically by some immittance instruments.
4. Select the ipsilateral acoustic reflex mode on the immittance instrument.
5. Present a 1000 Hz tonal signal at 85 dB HL (this is the average normal acoustic reflex threshold level). Avoid presentation levels in excess of 105 dB HL.
6. Determine by visual inspection whether the admittance tracing changed immediately after presentation of the signal. Also inspect the admittance change as indicated numerically (e.g., 0.04 ml) on the instrument screen. The lowest amount of acceptable admittance change varies from instrument to instrument, it is important to read the manual for the instrument used to determine this value.
7. If there was acoustic reflex activity at the initial signal intensity level, decrease the intensity by 10 or 5 dB and repeat. Using the bracketing approach, obtain two responses at the lowest intensity level where the least amount of appropriate deflection occurs as specified by the manufacturer of the instrument.
8. If there was no acoustic reflex activity at the initial signal intensity level, increase the intensity in 10 dB steps until a response is obtained and continue as in Step 7.
9. Select the contralateral acoustic reflex mode and pulsed tone stimulus type.
10. Present a 1000 Hz tonal signal at or 10 dB above the ipsilateral ART, but be cautious not to exceed a 105 dB HL presentation level.
11. Repeat steps 6, 7, and 8.

12. Continue to obtain contralateral ART's for 2000 Hz and 500 Hz.
13. Reverse ears and repeat these procedures.
14. Record all ART's on an audiogram form.
15. Interpret the acoustic reflex pattern.
16. Consider measurement of acoustic reflex decay before removing the probe tip from the patient's ear.
17. Record the acoustic reflex threshold results on the audiogram.

Note. From Audiologists' desk reference: diagnostic audiology principles, procedures, and practices (p. 206), by J. H. Hall & H. G. Mueller, 1998 San Diego, CA: Singular Publishing Group, Inc. Copyright 1997 by Singular Publishing Group, Inc. Adapted with permission.

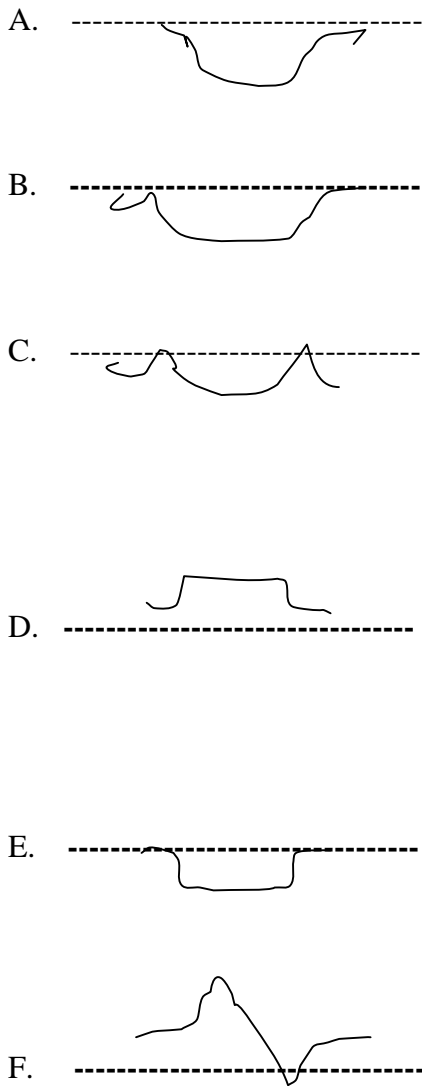
**GO TO LABORATORY EXERCISE**

**# 3.5**

Is the deflection the acoustic reflex response or an artifact?

Green and Margolis (1984) reported the occurrence of several artifacts to be aware of when determining whether an observed deflection is that of the stapedial reflex. Admittance change may occur in the positive or negative direction depending on the instrument that is used. The artifacts discussed here will be based on the immittance change in the negative direction. See Figure 3.4 for the various acoustic reflex responses that the tester may observe during threshold determination. The true acoustic reflex results in a negative deflection, an increase in admittance that is associated in time with the presentation of a stimulus. The response should also be present at higher stimulus levels and is generally observed as a larger deflection with each increase in intensity. The eardrum artifact generally occurs during ipsilateral recording with the 226 Hz probe tone (Kunov, 1977; Lutman & Leis, 1980; MØller, 1978). It is due to the non-linear interaction between the reflex-activator signal and the probe signal. In the recording,

the artifact is seen as an upward deflection that is a decrease in admittance. The additive artifact can occur during ipsilateral or contralateral recording, but is more likely to be seen in the ipsilateral recording. It is due to the compilation of the energy in the reflex-activator signal to the energy of the probe signal. In the recording, the artifact is seen as downward deflection that is an increase in admittance. This artifact can be misinterpreted as a true reflex (Margolis & Gilman, 1977; Popelka & Dubno, 1978).



**Fig. 3.4:** Deflections that may be observed upon acoustic reflex threshold determination. **A.** Normal deflection. **B.** Variation of the normal deflection. **C.** Abnormal deflection as seen in cases of early otosclerosis. **D.** Tympanic membrane artifact. **E.** Additive artifact. **F.** Tympanic membrane artifact and the true acoustic reflex deflection.

Note. Drawn by P. Carr, 2001.

## RECORDING AND SCORING OF TEST RESULTS

### Transference of acoustic reflex results from the strip chart or impedance device screen to the audiogram

1. Locate the *Acoustic Stapedial Reflex Thresholds* section of the audiogram.
2. When preparing to transfer the ipsilateral acoustic reflex for the right ear (probe right and stimulus right), take into consideration the probe ear (right ear), test mode (ipsilateral), test frequency (1000 Hz), and the lowest dB HL at which the acceptable amount of admittance change occurred. Record the threshold value obtained onto the audiogram.
3. Next, transfer the contralateral acoustic reflexes for the left ear (probe right, stimulus left) for frequencies 500, 1000, and 2000 Hz onto the audiogram.
4. Repeat steps 2 and 3 for the ipsilateral ART for the left ear (probe right and stimulus right) and the contralateral ART for the right ear (probe left and stimulus right) onto the audiogram.
5. If there is a sensorineural hearing loss as indicated by the pure tone audiogram and there is a designated place in the audiogram, calculate sensation levels (SL) for the contralateral acoustic reflexes. This calculation is used to confirm cochlear hearing loss as discussed under TEST INTERPRETATION.
6. To determine the SL values, the pure tone thresholds of the right ear are subtracted from its respective contralateral ART's for the right ear. Record these calculations on the audiogram if applicable.

**GO TO LABORATORY EXERCISE****# 3.6**Test Interpretation

The acoustic stapedial reflex may be present, absent, elevated, or reduced depending upon the hearing sensitivity and the presence or absence of pathological conditions of the outer, middle, and inner ear. Below are acoustic reflex outcomes and some associated possible pathological conditions to consider when interpreting acoustic reflex patterns:

Acoustic reflex is absent

1. Facial lesion
2. Abnormalities in the middle ear muscles
3. The ossicular chain is immobile or interrupted
4. Brain stem lesion
5. Severe cochlear hearing loss
6. Retrocochlear lesions

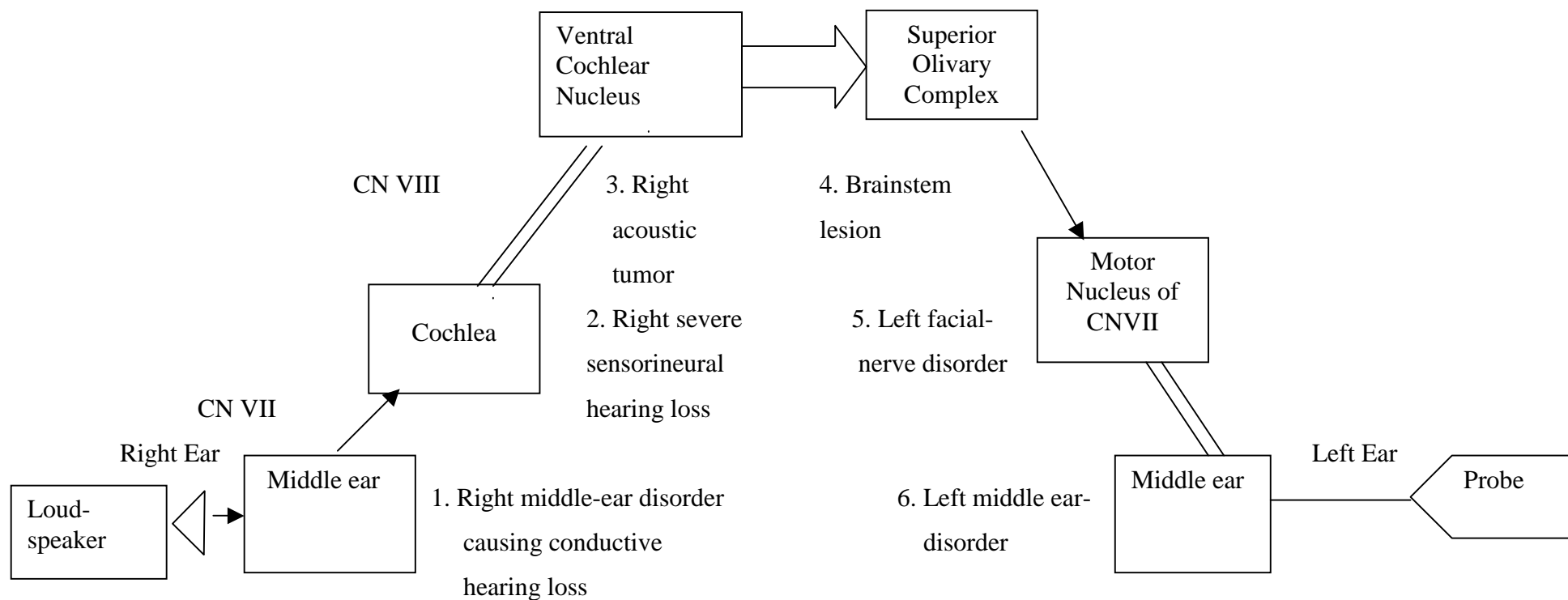
Acoustic reflex is elevated or absent

1. Conductive hearing loss
2. VIIIth nerve lesion

Acoustic reflex is elicited at a reduced SL (< 70 dB SL)

1. Mild to moderate cochlear hearing loss

Stach (1998) provides a diagram, see Figure 3.5, that represents the auditory and nervous system structures and depicts possible causes for the absence of a right crossed acoustic reflex. When interpreting the contralateral acoustic reflexes, refer to the norms as suggested by Silman & Gelfand (1981). See Table 3.4. The patient's ART's are



**Fig. 3.5:** A diagram depicting the auditory and nervous-system structures involved in a contralateral acoustic reflex including six possible causes for the absence of a right contralateral acoustic reflex.

Note. From Clinical Audiology: An Introduction (p. 271), by B. A. Stach, 1998, San Diego, CA: Singular Publishing Group, Inc. Copyright 1998 by Singular Publishing Group, Inc. Adapted with permission.



compared to the respective 90<sup>th</sup> percentiles that correspond to his hearing thresholds for the frequencies tested. If the patient’s ART value falls on or below the depicted 90<sup>th</sup> percentile, then it is considered to be essentially within the normal and /or cochlear distribution. On the other hand, if the patient’s ART falls above the depicted 90<sup>th</sup> percentile value, the threshold is considered to be abnormally elevated. If a conductive disorder is not present in a patient and the reflexes are abnormally elevated or absent, then the patient is considered to be at risk for eighth nerve pathology in the ear that received the stimulus (Gelfand, 1994). Lesions in the higher areas of the auditory cortex usually produce no abnormalities in either contralateral or ipsilateral reflexes because these centers are above the acoustic reflex arc.

Acoustic Stapedial Reflex -Are they present, absent, elevated, or reduced?

Table 3.5 provides a quick reference depicting possible ipsilateral and contralateral acoustic reflex outcomes and associated pathological conditions. If the acoustic reflex is present, the tester then determines if the reflex is within normal limits ( $\leq$  to the cut off values depicted in Table 3.4), elevated (ART’s are greater than those suggested in Table 3.4), or reduced (in the presence of a sensorineural hearing loss the calculated SL values are less than 70 dB, this confirms cochlear hearing loss). If the reflexes are absent, they could be absent due to any of the possible pathological conditions mentioned at the beginning of this section. Following is a discussion regarding the interpretation of patterns of ipsilateral and contralateral acoustic reflex combinations that provide valuable information in the determination of the patient’s diagnosis. It is helpful to refer to a diagram of the acoustic reflex arc when reviewing each of these patterns.

**Table 3.4:** Acoustic reflex threshold 90<sup>th</sup> percentile cutoff values as a function of hearing level at 500, 1000, and 2000 Hz.

**90<sup>th</sup> Percentile Acoustic Reflex Threshold Norms (dB HL)**

dB HL	Silman & Gelfand (1981)			Gelfand, Schwander, & Silman (1990)		
	500 Hz	1000 Hz	2000 Hz	500 Hz	1000Hz	2000 Hz
0	95	100	95	95	95	95
5	95	100	95	95	95	95
10	95	100	100	95	95	95

15	95	100	100	95	95	95
20	95	100	100	95	95	95
25	95	100	100	95	95	95
30	100	100	105	95	95	100
35	100	100	105	95	95	100
40	100	105	105	95	95	100
45	100	105	105	95	95	105
50	105	105	110	100	100	105
55	105	105	110	105	105	110
60	105	110	115	105	110	115
65	105	110	115	110	110	115
70	115	115	125	115	115	120
75	115	115	125	120	120	125
80	125	125	125	120	125	NR*
85	125	125	125	NR	NR	NR
≥90	125	125	125	NR	NR	NR

\*NR indicates no response at 125 dB HL.

Note. From Essentials of Audiology (p. 244), by S. A. Gelfand, 1997, New York, NY: Thieme Medical Publishers, Inc. Copyright 1997 by Thieme Medical Publishers, Inc. Adapted with permission.

<b>Condition</b> R = right ear L = left ear	<b>Right Ipsilateral</b> Probe: right ear	<b>Left Ipsilateral</b> Probe: left ear	<b>Right Contralateral</b> Probe: left ear Insert or phone: right ear	<b>Left Contralateral</b> Probe: right ear Insert or phone: left ear
<b>R: Normal hearing</b> <b>L: Normal hearing</b>	Present	Present	Present	Present
<b>R: normal hearing</b> <b>L: Conductive hearing Loss</b>	Present	Absent	Absent	Absent or present
<b>R: Conductive hearing loss</b> <b>L: Conductive hearing Loss</b>	Absent	Absent	Absent	Absent
<b>R: Normal hearing</b> <b>L: Cochlear hearing Loss (mild to mod.)</b>	Present	Present	Present	Present
<b>R: Cochlear hearing Loss (mild to mod.)</b> <b>L: Cochlear hearing Loss (mild to mod.)</b>	Present	Present	Present	Present
<b>R: Cochlear hearing loss (severe)</b> <b>L: Cochlear hearing</b>	Absent	Absent	Absent	Absent

<b>Loss (severe)</b>				
<b>R: VIIIth hearing loss</b> <b>L: Normal hearing</b>	Absent Or Elevated	Present	Absent Or Elevated	Present
<b>R: Normal hearing (VIIth nerve)</b> <b>L: Normal hearing</b>	Absent	Present	Present	Absent
<b>R: Normal hearing</b> <b>L: Normal hearing (Brainstem)</b>	Present	Present	Present	Absent
<b>R: Normal hearing</b> <b>L: Normal hearing (Brainstem)</b>	Present	Present	Absent	Absent
<b>R: Normal hearing</b> <b>L: Normal hearing (Cortex)</b>	Present	Present	Present	Present

**Table 3.5: A quick reference of theoretical acoustic reflex patterns and possible associated pathologies.**

Note. Developed by P. Carr, 2001.

When all portions of the auditory system are considered to be normal, the acoustic reflex is then able to function properly. The acoustic reflex thresholds are expected to fall in the range of 70 to 100 dB HL (Jerger, Jerger, & Maudlin, 1972) with an average threshold level of approximately 85 dB HL (Jerger, 1970). *The patient presents with normal hearing in both ears, the following acoustic reflexes are expected to be elicited:*

Ipsilateral right – present	Contralateral left – present at normal SL
Ipsilateral left – present	Contralateral right – present at normal SL

### Conductive Hearing Loss

Conductive hearing losses may cause the acoustic reflexes to be either “elevated” or “absent”. Consider the following rules in the presence of a conductive hearing loss. Probe Ear Rule: The presence of conductive pathology in the probe ear causes the acoustic reflex to be absent. The stapedius muscle may be contracting, but the presence of the pathology prevents us from measuring any change in acoustic admittance that may be picked up by the probe. An air-bone gap of at least 5 dB HL may cause the acoustic reflex to be absent (Jerger et al, 1974). Stimulus Ear Rule: A conductive loss in the stimulus ear causes the acoustic reflex to be elevated by the amount of the conductive impairment. Thus, the amount of the stimulus that actually reaches the cochlea will be reduced by the amount of the A-B gap. If the A-B gap is large enough, the ART will be elevated so much that the reflex will be absent. An A-B gap of at least 30 dB may cause the ART to be absent. *The patient presents with a unilateral conductive hearing loss in the right ear, the following acoustic reflex threshold pattern may occur:*

Ipsilateral right – absent (pathology is in the probe ear)
Contralateral left – absent (pathology is in the probe ear)
Ipsilateral left – present
Contralateral right – elevated by the amount of the air-bone gap or absent if large enough air-bone gap (pathology is in the stimulated ear)

*The patient presents with a bilateral conductive hearing loss, the following acoustic reflex threshold pattern may occur:*

Ipsilateral right – absent	Air-bone gap reduces the effective level of stimulus
Contralateral left – absent	that reaches the cochlea (stimulus ear rule) and the
Ipsilateral left – absent	conductive pathology prevents an immittance
Contralateral right - absent	change from being monitored even if the reflex
	is activated (probe ear rule).

### Sensorineural Hearing Loss (cochlear disorders)

The ART may be present at reduced sensation levels (SL) or absent depending on the degree of the hearing loss. The presence of the ART depends on the patient's hearing sensitivity. Patients with hearing loss up to approximately 50 dB HL produce ART the same as those with normal hearing; the ART will be present. Metz (1946) and Jerger et al (1974) reported that as the amount of hearing loss increases above 50 dB HL, the ARTs become progressively higher in dB HL values and thus reduced dB SL values. Recall that the SL's are determined by subtracting the pure tone threshold from the contralateral ART for the same frequency and ear. Reduced SL values are considered to be those that are less than 70 dB SL. They noted that patients with cochlear disorders exhibited ARTs that were elicited by pure tones at lower sensation levels than were required in that of the normal ear. The minimal SL that may be obtained is 25 dB; that corresponds to about a maximum of an 85 dB hearing loss for which the reflex can be observed. The occurrence of the reduced SL values could be attributed to the "loudness recruitment" phenomenon (Jerger et al, 1974). ARTs tend to be absent for clients with hearing loss around 80-85 dB HL and higher. *The patient presents with a bilateral mild to moderate sensorineural hearing loss. The following ART pattern may occur:*

Ipsilateral right – present
Contralateral left – present at low SL
Ipsilateral left – present
Contralateral right – present at low SL

*The patient presents with a severe sensorineural hearing loss in the right ear, and normal hearing in the left ear. The following ART pattern may occur:*

Ipsilateral right – absent	Contralateral left - present
Ipsilateral left – present	Contralateral right – absent

Retrocochlear Disorders

ARTs may be absent or elevated in the stimulus ear in either the ipsilateral or the contralateral mode. The ART may be elevated by 20 to 25 dB even though hearing sensitivity is no more than 5 or 10 dB HL. As the hearing loss exceeds 70 to 75 dB, the ART become absent (Stach, 1998). *Patient presents with a VIIIth nerve lesion on the right side and normal hearing in the left. The lesion is extra axial, it is along the auditory nerve, medial to the cochlea. This is considered to be a problem along the afferent portion of the arc. The following ART pattern may occur:*

Ipsilateral right – absent or elevated (stimulus ear)
Contralateral left – present
Ipsilateral left – present
Contralateral right – absent or elevated (stimulus ear)

*Patient presents with a lesion within the brainstem, known as intra axial. The following ART pattern may occur:*

Ipsilateral right – present	Note:
Contralateral left – absent or elevated	Facial nerve
Ipsilateral left – present	pathways are unaffected.
Contralateral right – absent or elevated	

*Patient presents with normal hearing with a right facial lesion and normal hearing in the left. The following ART pattern may occur:*

Ipsilateral right – absent  
 Contralateral left – absent  
 Ipsilateral left – present  
 Contralateral right –present

Note: When the probe is on the side of the VIIth nerve lesion during ipsilateral testing, the ART will be absent. The VIIth nerve is the motor leg or the efferent portion of the acoustic reflex arc that innervates the stapedius muscle.

Cortical Disorders

Lesions in the higher areas of the auditory cortex usually produce no abnormalities in either contralateral or ipsilateral reflexes because these centers are above the acoustic reflex arc. *Patient presents with cortical lesion with normal hearing in both ears may produce the following ART pattern:*

Ipsilateral right – present	Contralateral left – present
Ipsilateral left – present	Contralateral right – present.

**GO TO LABORATORY**  
**EXERCISE # 3.7**

Test Limitations

1. The clinician would be unable to perform ART testing on a patient with actively draining ear(s).
2. The patient may be sensitive to intense sounds and would therefore be unable to tolerate the ART test.
3. As with tympanometric testing, the clinician may be unable to maintain the hermetic seal necessary to complete the testing.
4. Research recommends that the clinician not present stimuli at intensity levels greater than 105 dB HL.



Laboratory Exercises

**LABORATORY EXERCISE # 3.4**

Goals

1. To be able to trace the pathway through the acoustic reflex arc of the ipsilateral acoustic reflex response.
2. To be able to trace the pathway through the acoustic reflex arc of the contralateral acoustic reflex response.
3. To be able to distinguish between the afferent and efferent portions of the acoustic reflex arc.

Exercises

1. In the Audiology lab, log onto the computer and locate computer software programs such as *Audiology Clinic* and *Clinical Journeys* and view the ipsilateral and contralateral acoustic reflex pathways.
2. Draw accurately the pathway through the acoustic reflex arc of the ipsilateral acoustic reflex response for both ears.
3. Draw accurately the pathway through the acoustic reflex arc of the contralateral acoustic reflex response for both ears.

Questions

1. Discuss briefly the nonacoustic stimulation of the acoustic stapedial reflex. Utilize sources sited in the REFERENCES section of this unit.
2. Discuss briefly the role of the tensor tympani muscle in the acoustic stapedial reflex. Utilize sources sited in the REFERENCES section.

<b>LABORATORY EXERCISE # 3.5</b>
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Goals

1. Develop the ability to administer the ipsilateral and contralateral acoustic reflex thresholds for various frequencies.
2. Develop the awareness of differences in thresholds obtained with broadband noise and pulsed tone stimuli.
3. Develop the ability to determine acceptable acoustic reflex deflections when obtaining thresholds.

Exercises

1. Perform acoustic reflex thresholds on \_\_ classmates.
  - a. Obtain the ipsilateral acoustic reflex threshold for 1000 Hz for both ears using pulsed tone stimuli.
  - b. Obtain the ipsilateral acoustic reflex threshold for both ears using broadband noise.
  - c. Obtain the contralateral acoustic reflex threshold for 500, 1000, 2000, and 4000 Hz for both ears using pulsed tone stimuli.
  - d. Obtain the contralateral acoustic reflex threshold for both ears using broadband noise.
  
2. Perform acoustic reflex thresholds on \_\_ subjects, other than classmates and other audiology students.
  - a. Obtain the ipsilateral acoustic reflex threshold for 1000 Hz for both ears
  - b. Obtain the contralateral acoustic reflex threshold for 500, 1000, and 2000 Hz for both ears.
  - c. Determine pure tone thresholds for 500, 1000, and 2000 Hz for both ears.

Questions

1. Did you notice any differences in thresholds obtained with the two types of stimuli – pulsed tone and broadband noise? Briefly state what differences you noticed and to what do you account for these differences? Utilize sources such as those cited in the REFERENCES section.
2. Did you notice any acoustic reflex threshold patterns occurring within subjects or between subjects? If so, what were they?

<b>LABORATORY EXERCISE # 3.6</b>
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Goals

1. Develop the ability to accurately transfer acoustic reflex thresholds to the audiogram.
2. Develop the ability to determine SL values for contralateral acoustic reflex thresholds.
3. To develop awareness of reflex patterns.
4. To formulate some basic diagnoses based on acoustic reflex thresholds.

Exercises

1. Transfer the acoustic reflex threshold results from the immittance strip charts or the immittance device screen to the audiogram on the five sample cases provided.
2. Calculate the SL values for the contralateral acoustic reflex thresholds on the five sample cases provided.

Questions

1. In general, state how the HL and SL values related to each other?
2. Did you notice any patterns in the appearance of the deflections within or between the sample cases? State briefly your observations.

<b>LABORATORY EXERCISE # 3.7</b>
----------------------------------

Goals

1. To be aware that pathological conditions can affect the presence or absence of the acoustic reflex response.
2. To be aware that degrees of hearing loss can affect the presence or absence of the acoustic reflex response.
3. To arrive at diagnoses based upon the ipsilateral and contralateral patterns of acoustic reflex responses and audiometric results obtained on a patient.
4. To predict possible outcomes for ipsilateral and contralateral acoustic reflexes given pathological conditions.

Exercises

1. Complete the ACOUSTIC PATTERNS EXERCISE as shown following this page.

Questions

1. Review literature and discuss what happens to the physical characteristics of the sound signal (quality, intensity) as it travels through the auditory pathways of a patient with a conductive hearing loss. How does this relate to the presence or absence of the acoustic reflex response?
2. What happens in patients with sensorineural hearing losses?
3. Review the resources to determine the sensitivity and specificity of the acoustic reflex threshold test. How useful is this test in the differential diagnosis of various pathological conditions?

STUDENT \_\_\_\_\_

LABORATORY EXERCISE: PATTERNS OF ACOUSTIC REFLEXES AND RELATED PATHOLOGIES

The following are situations you may encounter during clinic. Based upon the information provided you may need to determine the condition (disorder) with given reflexes or you may need to determine the reflexes given the condition:

Note: more than one condition/disorder may present for several of the situations.

1. Patient exhibits normal hearing in the left ear and a mild to moderate cochlear hearing loss in the right ear. Complete the following reflexes you would expect to obtain:

- Ipsilateral right ⇔ \_\_\_\_\_
- Contralateral right ⇔ \_\_\_\_\_
- Ipsilateral left ⇔ \_\_\_\_\_
- Contralateral left ⇔ \_\_\_\_\_

Why would you expect to obtain these? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_.

2. Patient exhibits a mild to moderate cochlear hearing loss for both ears. Complete the reflexes you would expect to obtain:

- Ipsilateral right ⇔ \_\_\_\_\_
- Contralateral right ⇔ \_\_\_\_\_
- Ipsilateral left ⇔ \_\_\_\_\_
- Contralateral left ⇔ \_\_\_\_\_

Why would you expect to obtain these? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_.

3. The following reflexes were obtained:

- Ipsilateral right ⇔ absent or elevated

- Contralateral right ⇔ absent or elevated
- Ipsilateral left ⇔ present
- Contralateral left ⇔ present

The condition/disorder is \_\_\_\_\_.

Why, what is happening? \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_.

4. The following reflexes were obtained:

- Ipsilateral right ⇔ present
- Contralateral right ⇔ absent
- Ipsilateral left ⇔ present
- Contralateral left ⇔ absent

The suspected condition/disorder is \_\_\_\_\_.

Why, what is happening? \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_.

5. Patient exhibits normal hearing in both ears. The acoustic reflexes are as follows:

- Ipsilateral right ⇔ present
- Contralateral right ⇔ absent
- Ipsilateral left ⇔ present
- Contralateral left ⇔ absent

The condition/disorder is \_\_\_\_\_.

Why, what is happening? \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_.

6. The patient exhibits a bilateral conductive hearing loss, what reflexes would you expect to obtain?

- Ipsilateral right ⇔ \_\_\_\_\_
- Contralateral right ⇔ \_\_\_\_\_
- Ipsilateral left ⇔ \_\_\_\_\_
- Contralateral left ⇔ \_\_\_\_\_

Why would you expect to obtain these? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_.

7. Patient exhibits normal hearing in the left ear and a conductive hearing loss in the right ear.

Complete the reflexes you would expect to obtain:

- Ipsilateral right ⇔ \_\_\_\_\_
- Contralateral right ⇔ \_\_\_\_\_
- Ipsilateral left ⇔ \_\_\_\_\_
- Contralateral left ⇔ \_\_\_\_\_

Why would you expect to obtain these? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_.

8. The following reflexes were obtained:

- Ipsilateral right ⇔ absent
- Contralateral right ⇔ absent
- Ipsilateral left ⇔ absent
- Contralateral left ⇔ absent

The condition/disorder is \_\_\_\_\_.

Why, what is happening? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_.

9. Patient exhibits normal hearing in both ears. The acoustic reflexes are as follows:

- Ipsilateral right ⇔ absent
- Contralateral right ⇔ present
- Ipsilateral left ⇔ present
- Contralateral left ⇔ absent

The condition/disorder is \_\_\_\_\_.  
Why, what is happening? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_.

10. Patient exhibits normal hearing in both ears, but has been diagnosed with a lesion on the left cortex. Complete the reflexes you would expect to obtain:

- Ipsilateral right ⇔
- Contralateral right ⇔
- Ipsilateral left ⇔
- Contralateral left ⇔

Why would you expect to obtain these? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_.



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**APPENDIX A**

**Shows acceptable ambient noise levels.**

<b>Frequency (Hz)</b>	<b>Under earphones only (in dB SPL)</b>	<b>Sound field or bone Conduction (in dB SPL)</b>
125	34.0	28.0
250	22.5	18.5
500	19.5	14.5
1000	26.5	14.0
2000	28.0	8.5
4000	34.5	9.0
8000	43.5	20.5

Note. From ANSI criteria for permissible ambient noise during audiometric testing (ANSI, 1977) and “Pure-tone audiometry: air and bone conduction” by L. A. Wilber, found in Contemporary perspectives in hearing assessment (p. 11), by F. E. Musiek & W. F. Rintelmann (Eds.), 1999, Needham Heights, MA: Allyn and Bacon. Copyright 1999 by Allyn and Bacon. Adapted with permission.

**APPENDIX B**

**Alphabetical list of the ASHA spondaic words. (ASHA, 1988).**



<b>List A</b>	<b>List B</b>
Airplane	Armchair
Baseball	Backbone
Blackboard	Birthday
Cowboy	Cookbook
Drawbridge	Doorman
Duckpond	Earthquake
Eardrum	Eyebrow
Horseshoe	Greyhound
Hot dog	Hardware
Ice cream	Headlight
Mousetrap	Inkwell
Northwest	Mushroom
Oatmeal	Nutmeg
Pancake	Outside
Playground	Padlock
Railroad	Stairway
Sunset	Toothbrush
Whitewash	Woodwork

Note. From “Guidelines for determining threshold level for speech,” by American Speech-Language-Hearing Association, 1988, *ASHA*, p. 103. Copyright 1988 by the American Speech-Language-Hearing Association. Adapted with permission.

## APPENDIX C

**The 13 homogeneous spondees (Hurley, 1999).**

Mousetrap	Stairway	Padlock	Eardrum
Northwest	Playground	Woodwork	Toothbrush
Drawbridge	Railroad	Birthday	Iceberg
Sidewalk			

Note. From Manual of Tests Procedures: these materials were prepared for use in COMD 6203: “Advanced Diagnosis in Audiology,” Spring Term, 1999, 1999, by R. M. Hurley. These thirteen spondees were judged to be homogeneous for intelligibility by 5 of 7 investigators as follows: Beattie, et al. (1975), Journal of American Auditory Society, 1, pp. 97-101; Beattie, et al. (1975), Journal of Speech and Hearing Disorders, 40, pp. 84-91; Bowling & Elpern (1961), Journal of Auditory Research, 1, pp. 152-157; Conn et al. (1975), Journal of Speech and Hearing Disorders, 40, pp. 388-396; Curry & Cox (1966), Journal of Auditory Research, 6, pp. 419-424; Dubno et al. (1984), Journal of the Acoustical Society of America, 76, pp. 87-96; Young et al. (1982), Journal of Speech and Hearing Research, 25, pp. 586-593. Adapted with permission.

## APPENDIX D

### Children’s picture spondaic word list. (ASHA, 1988).

Cupcake	toothbrush	popcorn	flashlight
Airplane	bathtub	fire truck	bluebird
Baseball	ice cream	mailman	toothpaste
Cowboy	Shoelace	Snowman	Reindeer
Hotdog	Football	Sailboat	seesaw

Note. From “Guidelines for determining threshold level for speech,” by American Speech-Language-Hearing Association, 1988, ASHA, p. 103. Copyright 1988 by the American Speech-Language-Hearing Association. Adapted with permission.

## APPENDIX E

List 1A		List 2A		List 3A	
1. an	26. you	1. yore	26. and	1. bill	26. aim
2. yard	27. as	2. bin	27. young	2. add	27. when
3. carve	28. wet	3. way	28. cars	3. west	28. book
4. us	29. chew	4. chest	29. tree	4. cute	29. tie
5. day	30. see	5. then	30. dumb	5. start	30. do
6. toe	31. deaf	6. ease	31. that	6. ears	31. hand
7. felt	32. them	7. smart	32. die	7. tan	32. end
8. stove	33. give	8. gave	33. show	8. nest	33. shove
9. hunt	34. true	9. pew	34. hurt	9. say	34. have
10. ran	35. isle	10. ice	35. own	10. is	35. owes
11. knees	36. or	11. odd	36. key	11. out	36. jar
12. not	37. law	12. knee	37. oak	12. lie	37. no
13. mew	38. me	13. move	38. new	13. three	38. may
14. low	39. none	14. now	39. live	14. oil	39. knit
15. owl	40. jam	15. jaw	40. off	15. king	40. on
16. it	41. poor	16. one	41. ill	16. pie	41. if
17. she	42. him	17. hit	42. rooms	17. he	42. raw
18. high	43. skin	18. send	43. ham	18. smooth	43. glove
19. there	44. east	19. else	44. star	19. farm	44. ten
20. earn	45. thing	20. tare	45. eat	20. this	45. dull
21. twins	46. dad	21. does	46. thin	21. done	46. though
22. could	47. up	22. too	47. flat	22. use	47. chair
23. what	48. bells	23. cap	48. well	23. camp	48. we
24. bathe	49. wire	24. with	49. by	24. wool	49. ate
25. ace	50. ache	25. air	50. ail	25. are	50. year

**APPENDIX F**

**NU-6 word list.**

List 1A		List 2A		List 3A		List 4A	
1. laud	26. love	1. pick	26. mill	1. base	26. gun	1. pass	26. lean
2. boat	27. sure	2. room	27. hush	2. mess	27. jug	2. doll	27. tape
3. pool	28. knock	3. nice	28. shack	3. cause	28. sheep	3. back	28. tire
4. nag	29. choice	4. said	29. read	4. mop	29. five	4. red	29. dip
5. limb	30. hash	5. fail	30. rot	5. good	30. rush	5. wash	30. rose
6. shout	31. lot	6. south	31. hate	6. luck	31. rat	6. sour	31. came
7. sub	32. raid	7. white	32. live	7. walk	32. void	7. bone	32. fit
8. vine	33. hurl	8. keep	33. book	8. youth	33. wire	8. get	33. make
9. dime	34. moon	9. dead	34. voice	9. pain	34. half	9. wheat	34. vote
10. goose	35. page	10. loaf	35. gaze	10. date	35. note	10. thumb	35. judge
11. whip	36. yes	11. dab	35. pad	11. pearl	36. when	11. sail	36. food
12. tough	37. reach	12. numb	37. thought	12. search	37. name	12. yearn	37. ripe
13. puff	38. king	13. juice	38. bought	13. ditch	38. thin	13. wife	38. have
14. keen	39. home	14. chief	39. turn	14. talk	39. tell	14. such	39. rough
15. death	40. rag	15. merge	40. chair	15. ring	40. bar	15. neat	40. kick
16. sell	41. which	16. wag	41. lore	16. germ	41. mouse	16. peg	41. lose
17. life	42. hire	17. rain	42. bite	17. life	42. hire	17. mob	42. near

18. fall	43. size	18. witch	43. haze	18. team	43. cab	18. gas	43. perch
19. raise	44. mode	19. soap	44. match	19. lid	44. hit	19. check	44. shirt
20. third	45. bean	20. young	45. learn	20. pole	45. chat	20. join	45. bath
21. gap	46. tip	21. ton	46. shawl	21. road	46. phone	21. lease	46. time
22. fat	47. chalk	22. keg	47. deep	22. shall	47. soup	22. long	47. hall
23. met	48. jail	23. calm	48. gin	23. late	48. dodge	23. chain	48. mood
24. jar	49. burn	24. tool	49. goal	24. cheek	49. seize	24. kill	49. dog
25. door	50. kite	25. pike	50. far	25. beg	50. cool	25. hole	50. should

**APPENDIX G**

**“Lower and upper limits of the 95% critical differences for percentage scores. Values within the range shown are not significantly different from the value shown in the percentage Score columns ( $p > 0.05$ ). From Thornton & Raffin (1978).” (Gelfand, 1997, p. 274).**

% Score	n = 50	N = 25	N = 10	% score	N = 100 <sup>a</sup>
0	0-4	0-8	0-20	50	37-63
2	0-10			51	38-64
4	0-14	0-20		52	39-65
6	2-18			53	40-66
8	2-22	0-28		54	41-67
10	2-24		0-50	55	42-68
12	4-26	4-32		56	43-69

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14	4-30			57	44-70
16	6-32	4-40		58	45-71
18	6-34			59	46-72
20	8-36	4-44	0-60	60	47-73
22	8-40			61	48-74
24	10-42	8-48		62	49-74
26	12-44			63	50-75
28	14-46	8-52		64	51-76
30	14-48		10-70	65	52-77
32	16-50	12-56		66	53-78
34	18-52			67	54-79
36	20-54	16-60		68	55-80
38	22-56			69	56-81
40	22-58	16-64	10-80	70	57-81
42	24-60			71	58-82
44	26-62	20-68		72	59-83
46	28-64			73	60-84
48	30-66	24-72		74	61-85
50	32-68		10-90	75	63-86
52	34-70	28-76		76	64-86
54	36-72			77	65-87
56	38-74	32-80		78	66-88
58	40-76			79	67-89
60	42-78	36-84	20-90	80	68-89
62	44-78			81	69-90
64	46-80	40-84		82	71-91
66	48-82			83	72-92
68	50-84	44-88		84	73-92
70	52-86		30-90	85	74-93
72	54-86	48-92		86	75-94

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74	56-88			87	77-94
76	58-90	52-92		88	78-95
78	60-92			89	76-96
80	64-92	56-96		90	81-96
82	66-94			91	82-97
84	68-94	60-96		92	83-98
86	70-96			93	85-98
88	74-96	68-96		94	86-99
90	76-98		50-100	95	88-99
92	78-98	72-100		96	89-99
94	82-98			97	91-100
96	86-100	80-100		98	92-100
98	90-100			99	94-100
100	96-100	92-100	80-100	100	97-100

<sup>a</sup> If score is less than 50%, find % score = 100 – observed score and subtract each critical difference limit from 100.

Note. From Essentials of Audiology (p. 274), by S. A. Gelfand, 1997, New York, NY: Thieme Medical Publishers, Inc. Copyright 1997 by Thieme Medical Publishers, Inc. Adapted with permission.

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**EDUCATION**

**Northeastern University, Boston, MA**

M.Ed. - Audiology, June 1979

**University of Connecticut, Storrs, CT**

B.A. – Speech, June 1977

**EXPERIENCE**

**University of South Florida, Tampa, FL**

*Clinical Instructor of Audiology, August 1996 - Present*

Supervise and instruct graduate students in clinical Audiology practicum.

Identify and supervise graduate students in Clinical Assistance Programs.

Provide a variety of audiological services to all age groups. Other duties include assist faculty in the instruction of areas related to Audiology on an as-needed basis and service on various departmental committees.

**University of South Florida, Tampa, FL**

*Adjunct Clinical Audiologist, January 1996 - August 1996*

Provided audiological services to children referred by the Hillsborough County Public Schools, 6-10 hours per week. Supervised graduate students in Audiology during clinical practicum. Evaluated graduate students on clinical performance.

**Hillsborough County Public Schools, Tampa, FL**

*Teacher, Parent-Infant Hearing Impaired Homebound Program, April 1995 - July 1996*



Patricia Irene Carr

Provided services to children, birth to five, with hearing impairment and their families. Assessed speech, language, and auditory skills. Devised Family Support Plans or Individual Education Plans. Assisted in the development of monthly newsletters.

**Cook-Fort Worth Children's Medical Center, Fort Worth, TX**

*Clinical Audiologist*, April 1994 - March 1995

Provided pediatric diagnostic audiologic assessment, hearing aid evaluations and dispensing, central auditory processing testing, auditory brainstem response (ABR) testing, and NICU ABR screens. Participated in the craniofacial malformation clinic and neurorehabilitation team staffings.

**Hillsborough County Public Schools, Tampa, FL**

*Clinical Audiologist*, August 1986 - April 1994

Provided pediatric audiological services to county residents, aged birth to 21, focus on birth to 5 and exceptionalities. Services included hearing aid evaluations and dispensing, central auditory processing testing. Provided, distributed, and monitored FM systems. In-serviced speech-language pathologists and school personnel. Developed and conducted the annual hearing screening program of exceptional education students. Assisted in the revision of the county school hearing screening conservation program; trained and monitored hearing technicians. Assisted in the revision of the county nurse hearing screening program in the schools. Involved in the management of students with deafness and blindness

**PRESENTATIONS**

ACurrent Hearing Aid Issues.® Presentation to a speech reading group at the Gulfport Senior Citizen Center, Gulfport, Florida. February 1998

AWhat is an FM System?@ Presentation to members of a local Sertoma chapter, Sertoma at the University of South Florida. July 1997

APersonal Experience of a Person with Hearing Impairment@  
Presentation to local chapter of SHHH, Tampa, Florida. May 1997

ASolving Communication Problems Among the Deaf and Their Families@. Presentation to late deafened adults(ALDA/PEACH) and their families in St. Petersburg, Florida. May 1997

AInfection Control Program.@ Presentation to clinical faculty and staff at the University of South Florida. February 1997

AHearing Screening of the Severe to Profound Mentally Handicapped Population.@ Mini-seminar at the Spring Florida Speech, Language, and Hearing Association Convention, St. Petersburg, Florida. May 1991

AHearing Testing of the Pediatric Population.@ Presentation to Brandon Area Pediatricians, Brandon Humana Hospital, Florida. May 1991

AHillsborough County Parent Infant Hearing Impaired Homebound Program.@ Presentation at Spring Florida Speech, Language, and Hearing Association Convention, Jacksonville, Florida. May 1986

## **CERTIFICATION AND LICENSURE**

Certificate of Clinical Competence in Audiology. Since 1986  
State of Florida Department of Business and Professional Regulation.  
Board of Speech-Language Pathology/Audiology, License in Audiology.  
Since 1986

**MEMBERSHIPS**

American Speech-Language-Hearing Association