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Electroacoustic Impedance Measurements: A Learning Packet

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ELECTROACOUSTIC IMPEDANCE MEASUREMENTS:

A LEARNING PACKET

by

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Michael J. Cevette

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ABSTRACT

Electroacoustic Impedance Measurements:

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The purpose of this paper is to provide an instructional format in the presentation of the clinical application of electroacoustic impedance measurements. Journal articles and impedance procedural booklets were used as a source of data for the information contained in the learning packet. Fundamentals of acoustic theory were treated to show the conceptual relationship of acoustic impedance and acoustic admittance. The terminology, normative data, and clinical interpretation of static acoustic impedance measures were examined. Diagnostically significant variables of the tympanogram were related to the audiometric-medical status of the patient. Clinical application of the acoustic reflex was investigated through descriptions of various pathologies and the particular indications expected in acoustic reflex testing for those pathologies. The learning packet is divided into four sections: impedance versus admittance, static acoustic impedance measurements, tympanometry, and acoustic reflex.

(177 pages)

INTRODUCTION

Statement of the Problem

With the genesis of each diagnostic tool, the role of the audiologist changes in both scope and dimension. This statement is particularly evident with the emergence of electroacoustic impedance measurements. As Zwislocki (1965, p. 18) states, the measurement of acoustic impedance at the lateral surface of the tympanic membrane represents "a whole new field of investigation with an inherent new methodology."

The origin of impedance measurements on a clinical basis is generally associated with Metz (1946). In North America, Zwislocki (1963) devised a bridge suitable for measuring absolute changes of acoustic impedance at discrete frequencies. In Scandinavia, emphasis was placed on the measurement of changes in impedance produced by pressure alterations in the auditory canal and by middle ear muscle contractions. These investigations preceed the current commercially available electroacoustic impedance bridges. Subsequent contributors have refined instrumentation, technique, and interpretation to produce an essential clinical tool for the otological setting. The current literature abounds with information which helps define and refine the diagnostic role of impedance audiometry.

There is a need for assimilation of the extensive and dispersive information which generates from the current literature on the clinical use of impedance audiometry. There does not exist a manual which exclusively instructs the audiologist, physician, or student in the interrelationships among anatomy, acoustic theory, impedance measuring procedures, and interpretation of impedance data. It has remained a difficult task to obtain a solid understanding of the fundamentals and clinical use of electroacoustic impedance measurements.

The present paper has been designed as a learning packet. This method of presentation utilizes programmed instruction which is by definition a planned sequence of experiences, leading to proficiency in terms of stimulus-response relationships (Espich and Williams, 1967). Stated simply, a program is an educational device that will cause the reader to progress through a series of experiences that the programmer believes will lead to the reader's proficiency.

With the basic understanding that there is a great deal of background information necessary to the understanding of impedance audiometry, it also remains beyond the scope of one paper to effectively instruct in all of the fundamentals. Specific instruction in anatomy, physiology, acoustic theory, and impedance-measuring procedures has been omitted from the learning packet except in cases where that information is directly necessary to the development of an instructional goal. The reader must first understand these areas before he will be able to effectively utilize the information contained within the learning packet. The focus of this learning packet rests primarily with the clinical use of impedance measurements. It will attempt to answer two questions: (1) What does impedance data tell one about the status of the middle ear, inner ear, and retrocochlear network? and (2) How does this information relate to other audiological data in arriving at a differential diagnosis?

In designing a learning packet, the fundamental objective is to present the material in a concise and sequential manner such that objective data can be readily discerned, and examination of that data can be readily evaluated. In providing a concise and sequential basis for the present learning packet, four major goals will be presented: Goal One: The reader will be knowledgable of various concepts used in the description of the impedance/admittance relationship; Goal Two: The reader will be knowledgeable of terminology, normative data, and clinical interpretation using static acoustic impedance measurements; Goal Three: The reader will be able to identify diagnostically significant variables of the tympanogram and relate them to the audiometric-medical status of the patient; and Goal Four: The reader will be knowledgeable of the diagnostic significance of the acoustic reflex.

Several objectives will encompass the specific desired information which the reader will be expected to acquire in the satisfaction of each goal. The format of each objective is concept-oriented, both in presentation and evaluation of the information. The reader's demonstration of knowledge will be directly evaluated through a written and/or performance post-test. The post-test will be designed such that incorrect answers lead to further explanatory material, while correct answers restate the concept focused upon by the objective. In this way the reader who does not achieve 100 percent accuracy on his first attempt at the post-test evaluation will be re-oriented and re-evaluated on the content under consideration.

As a restatement, the post-test evaluations will be written and/or performance based in nature. In considering this, a specific criterion for each objective will not be presented since various branching exercises will re-orient the reader to the post-test evaluation content material. The objective is considered met in all cases when the reader selectes an "A" (Ace) in answering the post-test questions.

The Multiple Purpose Self Trainer (Appendix) developed by Charles W. Nelson, Ph. D. will be used in the evaluation procedure. It is a card numbered 1 to 24, with each number having corresponding tabs (selections) of a., b., c., d., and e. Under each tab are random presentations of A for Ace, K for King, Q for Queen, J for Jack and T for Ten. Aces in all cases are correct answers and Kings, Queens, Jacks and Tens are incorrect answers. For post-test evaluations there will be presentations of all four alternate answers (K, Q, J, T), which are incorrect in nature. In every case the Ace will be present and in every case the alternate will give an explanation of why the choice of the alternate was incorrect and/or instructions for review. In this way the reader will be evaluated and re-evaluated on the concept presented, with re-orientation to the material presented with each incorrect answer. For this particular packet an additional six post-test evaluations were needed, making the total number of post-test evaluations 30.

In selecting a choice of either an a., b., c., d., or e., the reader will uncover either an A, K, Q, J, or T. What the reader uncovers for that objective post-test evaluation automatically instructs the reader to the same letter in the learning packet, which in turn sites an explanation of that answer. Thus, the answers to the post-test evaluation are only present on the Multiple Purpose Self Trainer. In case of an incorrect answer, the reader must review the content and make another selection (see Figure 1).

The objectives will be overlapped when possible within each major goal in an effort to add transition to the packet as well as to show relationships between concepts. At the completion of the four major goals, the reader will be completed with the learning packet.

The four major goals cover information under four procedural aspects of impedance measurements. They are specifically: (1) Impedance/Admittance differences, (2) Static Acoustic Impedance/Admittance measurements, (3) Typanometry, and (4) Acoustic Reflex. This paper is comprised of the four major goals, and the objectives which lead toward these goals deal with specific clinical entities.

The framework of the learning packet has been constructed in such a manner as to present to the reader a general understanding of the concepts of impedance audiometry which lead to specific use of those concepts in the interpretation of data obtained from electroacoustic impedance measurements.

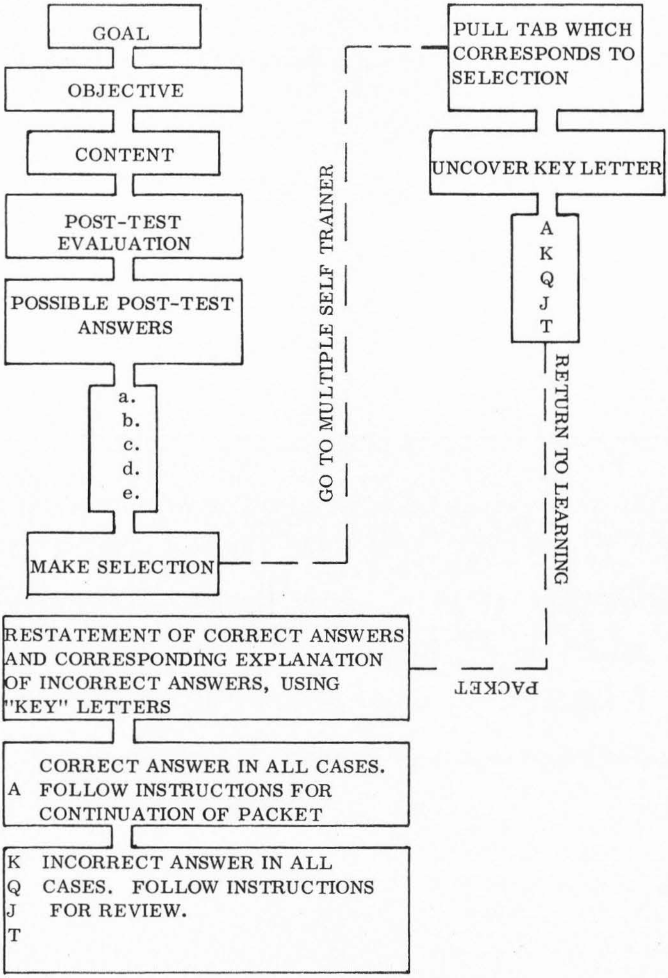


Figure 1. Schematic of the flow of the learning packet.

References

Espich, James E., and Williams, Bill. 1967. Developing programmed materials: A handbook for program writers. Lear Siegler, Inc./ Fearon Publishers, Belmont, California.

Metz, O. 1946. The acoustic impedance measured on normal and pathological ears. Unpublished thesis. Acta Otolaryngologica (Stockholm) (Supplement) 63.

Zwislocki, J. 1963. An acoustic method for clinical examination of the ear. Journal of Speech and Hearing Research 6:303-314.

Zwislocki, J. 1965. Summary by the moderator: The acoustic impedance of the ear. Journal of International Audiology 4:18-19.

Additional Readings

Alberti, P. W. R. M., and Kristensen, R. 1970. The clinical application of impedance audiometry. Laryngoscope 80:735-746.

Banathy, Bela H. 1968. Instructional systems. Lear Siegler, Inc./Fearon Publishers, Belmont, California.

Jerger, J. 1970. Clinical experience with impedance audiometry. Archives of Otolaryngology 92:311-324.

Lilly, D. J. 1972. Acoustic impedance at the tympanic membrane. In Jack Katz (Ed.). Handbook of Clinical Audiology, Chapter 23. Williams and Wilkins Co., Baltimore, Maryland.

Zwislocki, J. J., and Feldman, A. S. 1970. Acoustic impedance of pathological ears. ASHA Monograph No. 15. American Speech and Hearing Association, Washington, D. C.

IMPEDANCE VS. ADMITTANCE

Introduction

The efficiency of middle ear energy transfer is diminished by the presence of various pathologies, and the otherwise orderly transmission of acoustic energy is impeded. "Impedance" represents the difficulty energy encounters in flowing through a system. For one particular needs, impedance is a measure of resistivity to motion encountered at the tympanic membrane and this impedance determines the vibratory efficiency of the middle ear system. Impedance is measured in units called "ohms." As impedance increases, the ohmic value increases.

Admittance is the reciprocal of impedance and thereby represents the ease rather than the difficulty with which energy flow can be accomplished. Stated simply, admittance is a measure of energy flow through a system such as the middle ear and is measured in "millimhos." As may be apparent mho is ohm spelled backward and the relationship between the units ohm and mho is a relationship of reciprocality.

There are many electroacoustic instruments currently available for the clinical measurement of middle ear impedance. The measuring systems employ instrumentation for the investigation of either the "impedance" or "admittance characteristics of the middle ear. The most convenient comparisons are found in the impedance bridge (Madsen) and the otoadmittance meter

(Grason-Stadler). The two instruments measure quantities of impedance and admittance respectively. The discussion of the impedance/admittance relationship, then, will be presented with these particular instruments in mind when a reference to instrumentation is necessary.

Goal One

The reader will be knowledgeable of various concepts used in the description of the impedance/admittance relationship.

Enabling objective (EO) 1

The reader will differentiate concepts relating pressure and flow of acoustic energy to the two components of impedance which are "resistance" and "reactance."

In observing the middle ear, one is looking at a mechanical system whose properties are dictated by certain physical relationships. An investigation of acoustic energy and its transmission through the middle ear will satisfy our particular needs for differences inherent in impedance and admittance.

The primary function of the middle ear is to improve the transmission of acoustic energy from air to the fluid-filled inner ear. Airborne sound transmitted directly to the perilymph of the cochlea would results in a significant loss of energy due to the great difference in the mobility of air and that of the cochlear fluid. The middle ear, therefore, acts as a transformer which matches the low "characteristic impedance" of air in the ear canal to the high impedance of fluid in the cochlea, the characteristic impedance being an expression of the mobility of a medium (Møller, 1964). This mobility, or expression of impedance, in a mechanical system such as the middle ear is governed by friction, mass, and stiffness in the same manner as the flow of electricity in an electrical circuit is governed by resistance, inductance, and capacitance. The mechanical impedance is an inverse of mobility. That is, as impedance increases, mobility decreases and vice-versa.

Each of the characteristic quantities of impedance, namely friction, mass and stiffness, affect the pressure and flow of acoustic energy simultaneously but with different effects depending on the magnitudes and conditions under which they present themselves. Pressure refers to sound pressure, and is a measure of force. It is measured in dynes/cm^2. Flow is the amount of energy that can be transmitted through a system. For purposes of the present discussion, understanding can perhaps be facilitated by describing these interactions in pure frictional, pure energy loss-free storage, and combined friction and storage cases. In this way an arrival at an understanding of the particular interactions can be made quickly and clearly.

The pure frictional case. The previous discussion makes it now appropriate to note that the term "resistance" represents the "frictional" aspect of impedance. Friction accounts for the damping effect of the middle ear. Friction converts some of the acoustic energy into heat, with a net loss of energy from the system (Newman and Fanger, 1974). If the system is purely resistive (frictional), the pressure/flow relationships during a single cycle can be represented by the following diagram (Figure 2).

As can be seen from Figure 2, when pressure is at its maximum value, flow is also at its maximum value, and when pressure is at a minimum, flow is also at a minimum. From acoustic theory we know that the total amount of flow is an inverse function of the total amount of resistance; the less resistance, the greater the flow, and the more resistance the less the flow. Since power is the product of pressure and flow (power = pressure x flow), it follows that if flow increases, pressure must decrease proportionately for a constant energy system.

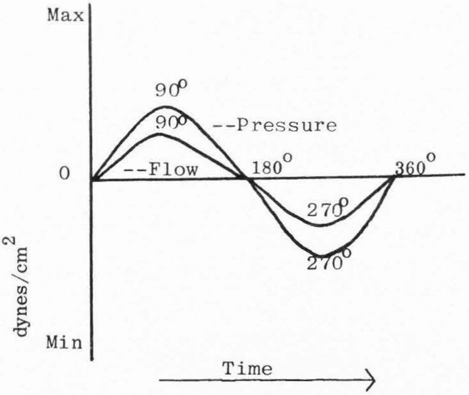


Figure 2. Purely resistive case: pressure vs. flow (Newman and Fanger, 1974, p. 13).

When impedance is high, flow is low and a given amount of energy can be imparted to the system only under the impetus of high pressure. When impedance is low, the same amount of energy can be imparted to the system with proportionately low pressure (Newman and Fanger, 1974).

The purely resistive or in-phase condition represents sound flow following sound pressure at all instances of time. The phase angle between the peaks of the two is 0 degrees. The two curves differ only in amplitude. The in-phase relationship results in maximum energy transmission and occurs only in pure frictional systems where all of the energy in an incident sound wave is absorbed by the system and none is stored. The ear manifests frictional losses on rough surfaces and in joints, as well as energy absorption in the cochlea. The ear is a dynamic system although, and also manifests energy-storage characteristics which will be investigated now.

Pure loss-free storage. The two energy storage components of impedance are "stiffness" and "inertia." Each results in an effect referred to as "reactance." Reactance (X_A) is the imaginary component of impedance and is frequency dependent. In the case of the middle ear, acoustic energy may be stored in alternately compressed or rarefied air in the canal and ear cavities and in the elastic membranes. Reactance (X_A) gives information about the flexibility of the ossicular chain. As is the case with resistance, reactance is measured in units called ohms ( ).

In the case of pure "stiffness," sound flow precedes the pressure wave by 90 degrees and creates the stiffness-dominated impedance characteristic called "negative reactance" ($-X_A$). The inertial or mass characteristic of impedance is referred to as "positive reactance" ($+X_A$). Pressure leads flow by 90 degrees. Flow is 180 degrees in phase opposition in mass and stiffness while both are 90 degrees out of phase with resistance but in opposite directions. Inertial effects rarely manifest themselves in middle ear measurements because the mass of the middle ear components is quite small for the low test frequencies employed, and also because the greater stiffness (negative reactance, $-X_A$) effects tend to nullify or overshadow the smaller inertial effects which might otherwise be measureable. Further explanation of this phenomenon will be entered later. It is important though to remember that these two are 180 degrees out-of-phase with one another. Thus the net effect in any system is the algebraic sum of the two and the appropriate symbol is "X" (Grason-Stadler, 1972).

"Compliance" is the reciprocal of negative reactance (stiffness). As the tympanic membrane becomes stiffer, compliance of the tympanic membrane decreases and more energy is stored in the stretched tympanic membrane. In the case of both stiffness and inertia, energy is stored briefly and returned to the system. Figure 3 shows pressure vs. flow for the stiffness case.

At point A the pressure is positive and maximum. The tympanic membrane is stretched to its fullest extent. At this point, energy flow is nonexistent. At point B pressure is 0 but changing in a negative direction at its maximum rate, with maximum flow, but also in the negative direction. The situation at points C and D is identical to that of A and B, except the polarities

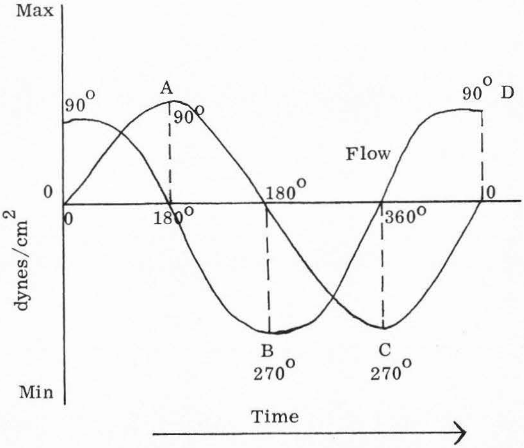


Figure 3. Stiffness case showing pressure vs. flow (Newman and Fanger, 1974, p. 15).

are reversed. Peaks of flow lead peaks of pressure and in a pure stiffness as illustrated, flow will lead pressure by one-quarter cycle or 90 degrees (Newman and Fanger, 1974).

It is important to note again that net acoustic reactance is always the algebraic sum of the mass reactance and the reactance at the lateral surface of the tympanic membrane.

Combined friction and storage case. Consideration will next be given to the combination of friction and storage. In the case of the ear, a portion of the energy flowing into the ear canal is dissipated in friction and the remainder is stored. Thus, the flow is neither exactly in phase with the pressure wave nor 90 degrees out-of-phase with the pressure wave as in the pure frictional and pure storage cases examined previously. Rather as shown in Figure 4, the two are separated by a phase angle between plus and minus 90 degrees (Newman and Fanger, 1974).

Since the flow is neither exactly in-phase with the pressure wave, nor 90 degrees out-of-phase with the pressure wave, impedance components must combine to account for all the frictional effects, the in-phase components and all the loss-free storage effects, the 90 degree component. Resistance and reactance combine into impedance exactly as the two legs of a right triangle combine in the hypotenuse as described by the Pythagorean relationship $c = \sqrt{a^2 + b^2}$. In the case of impedance $/Z/ = \sqrt{R^2 + X^2}$, where Z represents net reactance in ohms (Newman and Fanger, 1974).

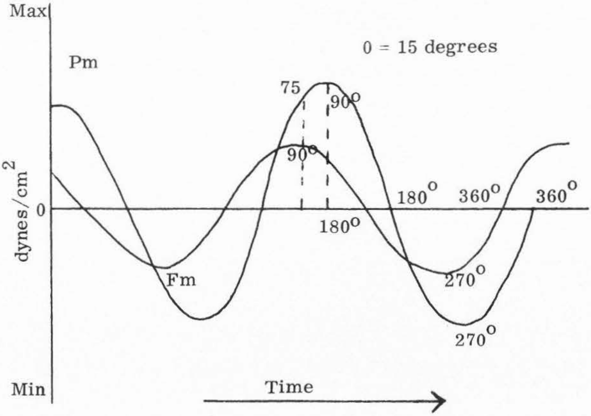


Figure 4. Flow and pressure differ in phase by values between 0 degrees or 90 degrees (Newman and Fanger, 1974, p. 16).

Resistance is independent of frequency while reactance varies as a function of frequency (Møller, 1964). Figure 5 shows the relationship between the different elements of impedance /Z/ and frequency /f/. As can be seen this combination emerges as a vector for impedance. A vector is a quantity which is completely specified by a magnitude and a direction. Mass, stiffness and friction are three factors which interact to give the vector for impedance. All three are vectors themselves since they all have magnitudes and directions. Their complex interaction produces a composite vector for impedance. Negative reactance and positive reactance are additive because the two vectors are 180 degrees out-of-phase with one another. Stated another way, these two forces act in opposite directions and their magnitudes can be added to obtain a net reactance value. Net reactance is 90 degrees out-of-phase with resistance and their sum is a complex vector for impedance with a phase angle between 0 degrees and 90 degrees.

The complex interaction between positive reactance (mass), negative reactance (stiffness) and resistance (friction) can be expressed mathematically as follows:

$$Z \text{ (total impedance} = \sqrt{R^2 + (2\,\pi fm = \frac{S}{2\,\pi f})^2}$$

where: $2\pi fm$ represents the positive reactance ($+X_A$) in ohms

$\frac{S}{2\,\pi f}$ represents the negative reactance ($-X_A$) in ohms

R represents the resistance in ohms

Positive reactance increases in direct proportion to an increase in frequency

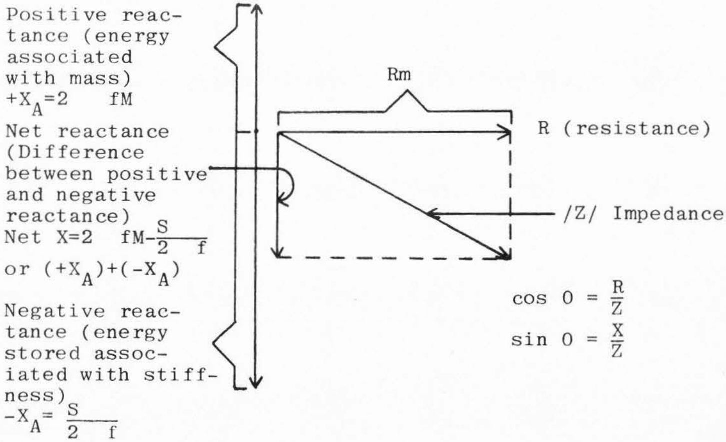


Figure 5. Relationship between the different elements of impedance /Z/ and frequency (f) (Møller, 1964, p. 124).

and negative reactance decreases as frequency increases, while resistance remains constant for all frequencies since it is independent of frequency.

In summary, acoustic impedance measurements at the plane of the tympanic membrane nearly always involve resistance and reactance components simultaneously. The characteristics operate in such a way as to impede the flow of acoustic energy. Resistance dissipates energy while reactances store energy and return it to its source. Because of the physical nature of the middle ear mechanism, measurements of stiffness and friction are the most diagnostically significant.

The discussion of the relationships of resistance and reactance to the pressure and flow of acoustic energy is now complete. Proceed to the post-test evaluation questions.

Post-test evaluation (Pte) 1. Impedance represents the difficulty with which acoustic energy can be made to flow through the middle ear system. What part of the impedance does resistance play? (Choose the best answer.)

a. Resistance stores acoustic energy and returns it to its source thereby reducing flow.

b. Resistance gives information about the flexibility of the ossicular chain.

c. Resistance is an inverse function of the total amount of flow and sound flow follows sound pressure at all instances in time and the pure frictional case.

d. Flow is an inverse function of the total amount of resistance and all the energy in an incident wave is contained in the system itself for the pure frictional case. Sound flow preceeds sound pressure in a reflected wave by 90 degrees.

e. Resistance is frequency dependent, thereby a function of frequency making flow a function of frequency.

A = Congratulations. It is obvious that you have acquired the relationship between sound flow, pressure and resistance. Proceed to Post-test evaluation 2.

K = Incorrect. Mass and stiffness exchanged with resistance in this answer makes the statement correct. Reread the pure friction case and reselect.

Q = The opposite of this statement is true. Reread the resistance case and make another selection.

J = You have confused resistance with reactance. Reactances store energy while resistance dissipates energy. Reread resistance section and reselect.

T = This is wrong for two reasons, reread the sections on Pure friction and Pure storage cases and reselect.

Post-test evaluation (Pte) 2. Reactance is the imaginary component of impedance. It is composed of both mass and stiffness. What characteristic of reactance best describes the mass/stiffness relationship?

a. Stiffness (negative reactance) effects are mullified by mass or inertia effects in middle ear measurements because of the great flexibility of the ossicular chain.

b. Both mass and stiffness are frequency independent and function independent of the frequency of the energy source.

c. The more complaint the membrane, the more energy is stored (result of reactance).

d. Negative reactance (stiffness) and positive reactance (inertia) are 90 degrees out-of-phase with one another; thus their net effect is 0, except at resonance.

e. All of the energy of an incident wave is contained in the air particles and in the system itself. Sound flow proceeds sound pressure in a reflected wave by 90 degrees and represents a stiffness dominated system.

A = Correct. The relationship is exactly as described. You may proceed to Pte 3.

K = Incorrect. Resistance, as you may recall, is frequency independent. Reread the pure storage case and make another selection.

Q = The opposite is true as you will find in rereading the pure tone storage case. Make another selection.

J = Their net effect is the algebraic sum of the two, thus they are 180 degrees out-of-phase. Make another selection after re-evaluation of Figure 3.

T = Incorrect. The opposite is true and can be readily realized when one takes into account the limited mass of middle ear components. (Hint: Look at Figure 3.) Make another selection.

Post-test evaluation (Pte) 3. In actuality, when combining impedance components, flow is neither exactly in-phase with the pressure nor 90 degrees out-of-phase with it. What statement best describes the situation?

a. A precise impedance value is independent of phase angle.

b. Resistance and reactance can be best described as magnitudes which are purely additive in describing impedance.

c. Resistance and reactance combine as vectors of some magnitude running at right angles (90 degrees) to one another.

d. A single absolute impedance value applies to one and only one resistance/reactance condition.

e. Impedance = Resistance^2 + Reactance^2.

A = Congratulations. You have correctly identified the correct statement. You are now ready to proceed to Enabling Objective 2 where we will look at Impedance/Admittance differences.

K = Incorrect. We can get an impedance value without phase angle information but it is not a precise one. Review Figure 5 and the component-combination section. Then make another selection.

$Q = Z = \sqrt{R^2 + X^2}$. Make another selection.

J = It applies to an infinite number of resistance/reactance relationships. Reread the section of the combination of friction and storage. Then make another selection.

T = One cannot simply add reactance and resistance since they describe both magnitude and direction of a force. They represent vectors. Review Figure 5 and make another selection.

Enabling objective (EO) 2

The reader will differentiate between admittance and impedance by knowing the relationship of their components.

When looking at flow, impedance is only implicit because the flow is somehow affected by the impedance. Under certain circumstances it is convenient to express the properties of the middle ear as admittance (Y). As stated earlier, admittance is a measure of energy flow and is the reciprocal of impedance (Z). Visually one can see the relationship emerge as follows for all conditions in which acoustic pressure is constant:

1) ADMITTANCE = FLOW;

2) $\text{FLOW} = \dfrac{1}{\text{IMPEDANCE}}$; and

3) $\dfrac{1}{\text{IMPEDANCE}} = \text{ADMITTANCE}$.

When the impedance is complex ($Za^2 = Ra^2 + Xa^2$) the admittance is also complex ($Ya^2 = Ga^2 + Ba^2$). The impedance constitutes resistance (Ra) and Reactance (Xa) find their counterparts in the admittance components of conductance (Ga) and susceptance (Ba) respectively. Conductance is a measure of energy flow through resistance while susceptance is a measure of energy flow through reactance. Susceptance can be equated to compliance which is commonly defined as the reciprocal of stiffness. Stated another way, susceptance is the reciprocal of negative reactance (Newman and Fanger, 1974). It should be noted, however, that although admittance and impedance are direct reciprocals of one another, conductance and resistance and also susceptance and reactance are direct reciprocals only in pure cases.

Figure 6 shows the relationships among conductance, positive and negative susceptance and complex admittance. It is important to note that the direction of the susceptance component is reversed from the reaction component of Figure 5 in (EO 1). As one can see in comparing Figures 5 and 6, complex admittance combines exactly as complex impedance does only the various forces have different directions in relation to one another.

Table 1 shows the equivalence of the terms used in mechanical, electrical and acoustic impedance terminology.

TABLE 1.--Factors relating to the flow of energy (Newman and Fanger, 1974, p. 19)

Mechanical	Electrical	Acoustic (impedance)	Acoustic (admittance)
Stiffness (springiness)	Capacitance	Negative reactance ($-S_A$)	Positive susceptance (Ba) compliance
Mass (inertia)	Inductance	Positive reactance (Xa)	Negative susceptance (-Ba)
Resistance (friction)	Resistance	Resistance (Ra)	Conductance (Ga)

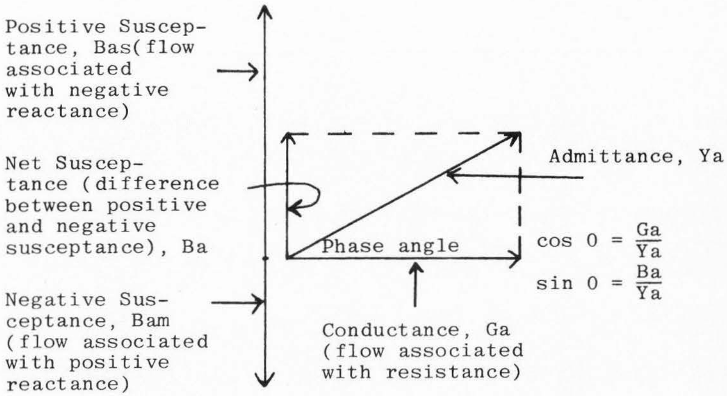


Figure 6. Relationships among conductance, positive and negative susceptance and complex admittance (Newman and Fanger, 1974, p. 19).

The foregoing concludes the discussion of the relationships between admittance and impedance components. The content under the next enabling objective discusses the clinical application of the terminology and how the factors of admittance and impedance relate as dictated by instrumentation.

Before preceeding to the next enabling objective, the student should complete Post-test evaluation No. 4.

Post-test evaluation (Pte) 4. Admittance and impedance are direct reciprocals. Which of the following statements is true regarding the relationships of admittance and impedance counterparts? (Choose the best answer.)

a. Conductance can be equated to compliance, the reciprocal of negative reactance.

b. Susceptance is a measure of energy flow through reactance.

c. Positive reactance represents the stiffness of a mechanical impedance model.

d. Admittance and flow are direct reciprocals.

e. The reciprocal of positive susceptance can be equated to compliance.

A = Correct. The statement is true. Proceed to Enabling Ovjective (EO) 3.

K = Incorrect. This statement would be true if you substituted susceptance for conductance. Review Figure 6 and make another selection.

Q = Incorrect. Negative reactance would make this statement true. Please review Figure 6 and make another selection.

J = Incorrect. These two terms are exactly the same. Review all of the content under Enabling Objective 2 and make another selection.

T = Stiffness is the reciprocal of compliance. Review Figure 6 and reselect another answer.

Enabling objective (EO) 3

The reader will be able to select functions of impedance and admittance instrumentation by selecting concepts representative of those functions.

As stated earlier, there are many instruments currently available for the clinical measurement of middle ear impedance. The measuring systems employ instrumentation for the investigation of either the impedance or admittance characteristics of the middle ear. The Madsen Electroacoustic Bridge yields an impedance value measured in ohms. The Grason-Stadler Otoadmittance meter yields an admittance value measured in millimhos. Investigation will now be directed toward similarities and differences in the clinical capabilities of impedance and admittance by comparison of instrumentation and procedure.

It should be noted in measuring a static impedance or admittance value that the measuring devices eliminate the effects of the ear canal through a drum-stiffened and drum-loose subtraction process. A positive or negative pressure introduced into a hermetically sealed ear canal creates, in effect, a hard-walled cavity. A hard-walled cavity influences ear drum mobility drastically and creates a "drum tight" acoustic environment. Tympanic membrane compliance approaches 0 and acoustic impedance is maximum. If the hard-walled cavity is eliminated and air pressure is equal on both sides of the tympanic membrane, a "drum loose" acoustic environment is created and the hard-walled situation no longer exists. For this situation eardrum compliance is maximum and acoustic impedance is reduced to a minimum. In the admittance case, when the eardrum is stiffened by means of air pressure introduced into the ear canal, the admittance at the drum approaches 0 and the value of admittance obtained is essentially that of the ear canal. When the air pressure on each side of the drum is equalized, the admittance measured at the entrance of the ear canal is the sum of the admittance of the ear canal and the admittance of the drum.

As a restatement, admittance is the ratio of sound flow to sound pressure and for low probe tone frequencies, the sound pressure within the canal is considered constant at all points. Sound flow and hence, admittance for the drum alone may be obtained by simple subtraction of the drum stiffened measurement. In the clinical setting, 200 mm H_2O of positive pressure is used as a standard for the drum tight condition. Two hundred mm H_2O is simply the pressure which a column of water 200 millimeters long will exert.

For the impedance case, when the eardrum is stiffened by means of air pressure introduced into the ear canal, the impedance at the drum reaches a maximum value. When the air pressure on each side of the drum are equalized the impedance measured at the entrance of the ear canal reaches a minimum value and the acoustic impedance in the plane of the eardrum equals product of the measurements of the ohmic value for drum stiff and drum maximally compliant divided by the difference.

$$Z_x = \frac{Z_1 \times Z_2}{Z_1 - Z_2}$$

i.e., where Z_x = acoustic impedance (unknown) in ohms ( ).

Z_1 = acoustic impedance measurement with the drum stiff in ohms ( ).

Z_2 = acoustic impedance measurement with the drum loose in ohms ( ).

When obtaining a static measure, the Madsen bridge gives only lumped numerical impedance values. That is, when one obtains an ohmic value, the ohmic value represents both the resistive and reactive factors of the impedance without the availability of phase angle information. The phase angle information, as stated earlier, is necessary for precise impedance calculations since the greater the difference between phase angles of the two impedance components, resistance and reactance, the greater the error will be when they are added together or subtracted.

At this point, one may have become confused about the usage of the term "compliance" or "compliant." When working with admittance terminology "compliance" was defined specifically as a reciprocal of negative reactance (stiffness) and was equated with susceptance. When using impedance terminology as is done when using the Madsen bridge, "compliance" was used in a more general sense and was equated with mobility of the eardrum. The term shares two different meanings depending on the particular instrument under consideration.

Zwislocki and Feldman (1970) state that some have voiced criticisms against evaluating the impedance of the ear in compliance terms, and have suggested that reactance, which is the imaginary part of the impedance expression, would be more appropriate. According to Zwislocki and Feldman, from a purist's point of view, the criticism is justified since the reactance together with the resistance are the actual impedance components. From a practical point of view, the compliance is a more convenient measure for diagnostic testing of the ear.

When the Grason-Stadler admittance terminology is thoroughly considered, it becomes apparent that "compliance" refers to the reciprocal of stiffness and involves the storage characteristics of the middle ear system in a technical sense. Compliance, therefore, is equated with susceptance and is the reciprocal of negative reactance.

As the Madsen manual states, "As the absorption of acoustic energy increases, the compliance increases, or expressed another way, the acoustic impedance decreases." (Madsen Electromedics Corporation, n.d., p. 4) Therefore in practical application, the Madsen Company uses the term compliance as an inverse of impedance represented by an actual increase in actual volume of the ear canal. Compliance in this case is equated to the mobility of the middle ear mechanism. It is not used to represent the storage characteristics alone, but to represent the complete resistance/reactance function.

In either case, one can speak of the mobility of the drum in compliance terms, equivalent volume expressed in cubic centimeters (cm^3), by determining the volume of air which has a compliance equivalent to the middle ear system under test. The inconsistency of terms emerges only when one speaks in a technical sense through interpretation of the physical characteristics of an absolute impedance value. Most clinical measurement devices ignore the contribution of the three factors independently, and present an approximation of the resultant vector as a total impedance measure. As Berlin and Cullen (1975) state, most of the impedance changes in the pathological human ear are reflected in changes of stiffness, or compliance, the reciprocal of stiffness.

Returning now to the static admittance value, the otoadmittance instrument (Grason-Stadler) provides readings for both the susceptance and conductance components. That is, when measuring the statis admittance, two sets of readings emerge along with the availability of phase angle information.

drum tight: conductance Ga (1); susceptance Ba (1)

drum loose: conductance Ga (2); susceptance Ba (2)

Susceptance and conductance at the plane of the drum is easily calculated because

Ga (drum = Ga (2) - Ga (1)

and

Ba (drum) = Ba (2) - Ba (1)

since

$$Ya = \sqrt{Ga^2 + Ba^2}$$

$$Ya\ (drum) = \sqrt{Ga(drum)^2 + Ba(drum)^2}$$

and since

$$\text{impedance } /Z/ = \frac{1}{\text{admittance } /Y/},$$

$$/X/\ (\text{drum})\ \text{ohms} = \frac{1}{/Y/\ (\text{drum})\ \text{mmhos}}$$

In summary, the otoadmittance instrument (Grason-Stadler) offers a precise admittance value because it offers both susceptance and conductance information. The impedance instrument (Madsen) offers only a lumped numerical impedance value without separate values for the resistance and reactance components. It is important to note, however, that for clinical purposes, the difference between the admittance and impedance interpretation for the same set of ears will not have large consequence (Newman and Fanger, 1974).

As will be shown in the section on "Static Acoustic Impedance Measurements," normative values for both instruments show great variability.

Proceed to post-test evaluation No. 5.

Post-test evaluation (Pte) 5. Admittance and impedance values are obtained with the otoadmittance meter (Grason-Stadler) and with the electro-acoustic impedance bridge (Madsen) respectively. What statement best describes how instrumentation and procedure reflex measurement capacilities?

a. Phase angle information can be derived from measurements of susceptance and conductance when using the otoadmittance meter.

b. The mathematical procedure for deriving an admittance or impedance value is exactly the same for the instrumentation currently available.

c. The Madsen bridge measures compliance which is the direct reciprocal of negative reactance. Therefore with the Madsen bridge one is actually obtaining a reactance value alone.

d. The drum tight admittance value approaches maximum admittance.

e. Reactance and resistance values for the Madsen instrument are calculated separately.

A = Very Good. That is the way this information can be obtained. Proceed to Pte 6.

K = Incorrect. Instrumentation is different and procedures for measurements are different. Reread the content of EO 3 again and make another selection.

Q = Incorrect. It approaches 0. Reread EO 3 content and make another selection.

J = The impedance values are lumped numerically. Reread the section on phase angle information and make another selection.

T = Incorrect. Although the terms are the same, the meaning is different. Read the compliance section again and make another selection.

Post-test evaluation (Pte) 6. If the mass (positive) reactance of a given unit is "2" and the frequency of stimulation is 220 Hz, one might say that positive reactance of this system is: (Hint: $\pi = 3.14$).

a. 2,763 mass reactance units ( )

b. 1,382 mass reactance units ( )

c. $\frac{2}{1382}$ mass reactance units ( )

d. 4 mass reactance units ( )

e. $\frac{2}{2 \times 220} = \frac{2}{6.28 \times 220}$

A = Correct. Your computation was accurate and included the correct formula. Proceed to (Pte) 7.

K = Inocrrect. You are using the formula for resistance. Examine the positive reactance formula and reselect.

Q = Incorrect. You are using the formula for negative reactance. Examine the positive reactance formula and make another selection.

J = Incorrect. You are using the formula for negative reactance. Examine the positive reactance formula and make another selection.

T = Incorrect. Look at the formula for mass reactance and make another selection.

<u>Post-test evaluation (Pte) 7.</u> What statement best clarifies the confusion of the term "compliance" in reference to impedance and admittance measurements?

a. Compliance is simply a reciprocal of susceptance and a measure of mobility of the middle ear.

b. One cannot speak in terms of compliance when investigating meansures of admittance.

c. With the Madsen instrument a precise resultant vector is obtained and is defined in terms of equivalent volume.

d. Most of the changes in the pathological human ear are reflected in changes in stiffness or compliance, but the total impedance is composed of compliance effects as well as resistance and inertial effects.

e. Resistance is a more appropriate term than compliance when speaking of the stiffness characteristics of the middle ear mechanism.

A = Correct. You have selected the best answer. Proceed to the "Static-Acoustic Impedance Measurements" section.

K = Incorrect. If you speak of the mobility of the middle ear when using compliance, then you can speak of admittance indirectly. Make another selection.

Q = Incorrect. Compliance is equated to this measure. Make another selection.

J = Incorrect. An approximation is obtained. Reread the compliance section and make another selection.

T = Incorrect. Reactance is more appropriate. Reread the compliance section and make another selection.

References

Berlin, I., and Cullen, J. K. 1975. The physical basis of impedance measurements. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter I. American Electromedica Corporation, Dobbs Ferry, New York.

Grason-Stadler. 1972. Otoadmittance handbook: A guide to users of the Grason-Stadler Model 1720 Otoadmittance Meter. Grason-Stadler, Concord, Massachusetts.

Madsen Electromedics Corporation. Madsen Model Z070 electroacoustic impedance bridge: Applications and instructions for use. Madsen Electromedica, Denmark.

Møller, A. R. 1964. The acoustic impedance in experimental studies on the middle ear. Journal of International Audiology 2:123-135.

Newman, B. T., and Fanger, D. M. 1974. Otoadmittance handbook 2. Grason-Stadler, Concord, Massachusetts.

Zwislocki, J. J., and Feldman, A. S. 1970. Acoustic impedance of pathological ears. ASHA Monograph No. 15. American Speech and Hearing Association, Washington, D. C.

Additional Readings

Burke, K. S., Herer, G. R., and McPherson, D. L. 1970. Middle ear impedance measurement: Acoustic and electroacoustic comparisons. Acta Otolaryngologica 70:29-34.

Lamb, L. E., and Norris, T. W. 1969. Acoustic impedance measurement. In R. T. Fulton and L. L. Loyd (Eds.). Audiometry for the retarded, Chapter 6. Williams and Wilkins, Baltimore, Maryland.

Lilly, D. J. 1972. Acoustic impedance at the tympanic membrane. In Jack Katz (Ed.). Handbook of clinical audiology, Chapter 23. Williams and Wilkens Co., Baltimore, Maryland.

Møller, A. R. 1965. An experimental study of the acoustic impedance of the middle ear and its transmission properties. Acta Otolaryngologica 60:129-149.

Rock, E. H. 1972. Electroacoustic impedance measurements in clinical otology. Impedance newsletter. American Electromedics Corporation 1:Revised.

Weaver, E. G., and Lawerence, M. 1954. Physiological acoustics. Princeton University Press, Princeton, New Jersey.

Zwisloci, J. 1963. An acoustic method for clinical examination of the ear. Journal of Speech and Hearing Research 6:303-314.

Zwislocki, J. 1962. Analysis of the middle ear function: Part I--Input impedance. Journal of the Acounstical Society of America 24:1514.

Zwislocki, J. 1961. Acoustic measurement of middle ear function. Annals of Otology, Rhinology and Laryngology 70:599-606.

STATIC-ACOUSTIC IMPEDANCE MEASUREMENTS

Introduction

It is assumed that the reader understands the theory and procedure for determining static-acoustic impedance/admittance measures. What follows represents a review of normative data in relation to pathologies of the middle ear. The reader must understand that a normative value is not always mutually exclusive to the category which it represents. There is some overlapping among pathologies and ears of normal status. It is the intent of this packet to carefully acknowledge these incongruities and report as comprehensively as possible the status acoustic impedance/admittance interpretation.

Static-acoustic impedance and static-acoustic compliance are terms representing the same function clinically. Impedance and compliance, as the terms are used by users of electroacoustic impedance instrumentation (Madsen) are directly inversely related. More specifically, as impedance increases, compliance decreases and as impedance decreases, compliance increases. The static-acoustic compliance measurement is accomplished by finding the volume of air in cubic centimeters which has a compliance equivalent to the compliance of the middle ear is then expressed as this equivalent volume (in cm^3) while static impedance is expressed as an ohmic value. When using the otoadmittance meter (Grason-Stadler), static admittance is expressed in units of millimhos.

Measurements of static acoustic impedance/admittance at the tympanic membrane are of primary value in differential diagnosis of conductive lesions. Lilly (1973) states that, in general, acoustic impedance at the tympanic membrane is (1) lower than normal with ossicular discontinuity, (2) higher than normal with clinical otosclerosis, and (3) very much higher than normal with acute inflammatory and chronic diseases of the middle ear.

Goal Two

The reader will be knowledgeable of terminology, normative data, and clinical interpretation in the use of static-acoustic impedance measurements.

Enabling objective (EO) 4

The reader will differentiate between definitions of "static" and "dynamic" in relation to acoustic impedance/admittance measurements.

Acoustic impedance measurements may be classified as either "static" or "dynamic." The term "static" is intended to reflect measurements made while the middle ear is in a passive or resting state. The term "dynamic" implies measurement of how middle ear function varies with changes in relevant variables. The similarity can be drawn to photography. In observing a static measure, one is looking at an impedance "snapshot" of the middle ear while a dynamic measure would reflect a series of simultaneous impedance "snapshots" or a motion picture of middle ear function. Both are measures of middle ear function but, as one can see, one has a different frame of reference with respect to time.

As stated previously, the term "static" represents a measure of impedance while the middle ear is in a resting or changeless state. This measure is accomplished by comparing the impedance of an artificially stiffened tympanic membrane and middle ear system (+ 200 mm H_2O pressure applied) and maximally compliant (usually but not necessarily at ambient pressure or 0 mm H_2O) tympanic membrane and middle ear system. As a restatement from (EO) 3, the procedure for accomplishing static measures is the same for both impedance and admittance instrumentation.

The static impedance of the middle ear has two principle components, one due to resistance and the other due to reactance. In addition, static impedance measures have historically been obtained under two different conditions of air pressure in the external canal (Jerger, 1972). Both impedance components may be measured either at ambient atmospheric pressure in the external canal or at some other ear canal pressure which produces maximum compliance. As Jerger (1975b) notes that in actual clinical diagnostic use, the most useful measure of static impedance is the compliance measured at the air pressure which yields minimum impedance (maximum compliance).

The term "dynamic" implies measurement of how function varies with changes in relevant variables. The traditional "dynamic" measurements are "tympanometry" and elicitation of the "stapedial reflex." The tympanogram is a function relating changes in some aspect of impedance or admittance to artificially induced positive and negative air pressure changes in the external canal. The stapedial reflex represents the functional relation between some component of middle ear impedance or admittance and the intensity of sound delivered usually to the opposite ear. The dynamic measures of acoustic impedance, namely tympanometry and the acoustic reflex, will be treated later in the learning packet.

Table 2 shows the measurements obtained with the Madsen and the Grason-Stadler measuring systems. Notice again that the capabilities of the particular instruments are different only in regard to the design of the instrumentation.

Table 3 is a more detailed summary of impedance terminology with a sketch of the clinical importance of each concept (Jerger, 1975a).

TABLE 2.--The measurements obtained with the Grason-Stadler Otoadmittance meter and the Madsen Electroacoustic Impedance bridge (Jacobsen, Kimmel and Fausti, 1975, p. 12)

Measurement	Otoadmittance Meter	Madsen bridge
Static admittance	yes	no
Static impedance	no	yes
Tympanometry	susceptance (B) conductance (G)	impedance (compliance)
Acoustic reflex	yes	yes

TABLE 3.--Summary of impedance terminology (Jerger, 1975a, p. 590)

Term	Symbol	Concept	Clinical Importance
Impedance	Z	Total opposition to energy flow	Extremely limited--useful only when very high or very low
Admittance	Y	Total energy flow (reciprocal of Z)	See Z
Reactance	X	Opposition to energy flow due to storage	See Y
Susceptance	B	Energy flow associated with reactance (reciprocal of X)	See X
Resistance	R	Opposition to evergy flow due to dissipation	HNSY*
Conductance	G	Energy flow associated with resistance (reciprocal of R)	HNSY*
Compliance	C	Reciprocal of stiffness-principal component of X at low frequencies	See Z
Tympanogram	T	Graph relating air pressure to either Z, Y, X, B, or C	Great--second in importance only to AR
Acoustic reflex	AR	Contraction of stapedius muscle as detected by change in either Z, Y, X, B, or C	Very great--a powerful diagnostic tool

*Has not surfaced yet.

Table 4 is a table of suggested nomenclature for impedance audiometry provided by Jerger (1972). It helps to redefine the terms static and dynamic, and shows how the nomenclature is related to the measurement.

TABLE 4.--Suggested nomenclature for impedance audiometry (Jerger, 1972, p. 3)

Measure	Type	Unit of Measure	Nomenclature
Compliance at atmospheric air pressure	Static	Cubic centimeter (cu cm)	Ambient compliance (C_A)
Compliance at air pressure yielding maximum	Static	Cubic centimeter (cu cm)	Maximum compliance (C_M)
Compliance vs. air pressure	Dynamic	cu cm/mm H_2O	Tympanogram
Compliance vs. sound level in opposite ear	Dynamic	HTL in dB	Strapedius reflex threshold

Post-test evaluation (Pte) 8. Acoustic impedance measurements may be classified as either static or dynamic. What statement best represents the differences inherent in the two measurements?

a. The complex admittance/impedance values are procedurally a static measure while tympanometry and acoustic reflex are functions which vary with changes in relevant variables.

b. Maximum impedance has no diagnostic significance for either static or dynamic measures.

c. Tympanometry and acoustic reflex measurements are determined by comparing a maximally compliant and artificially stiffened tympanic membrane.

d. Dynamic measures are measures of the middle ear in a resting or natural state.

e. The most useful static impedance measurements are those where the compliance is measured at the pressure yielding maximum impedance instead of ambient atmospheric pressure.

A = Correct. You have identified the correct answer. Proceed to Enabling Objective 5.

K = Incorrect. This is the procedure for static measurements. Reread the content under (EO) 4 and reselect.

Q = Incorrect. It is necessary for calculations of complex impedance/admittance values. Reread (EO) 4 and make another selection.

J = Incorrect. This answer is illogical since one would be comparing an eardrum artificially stiffened with the same ear artificially stiffened (maximum impedance). Reread (EO) 4 and make another selection.

T = Incorrect. Static instead of dynamic would make this statement correct. Reread all of (EO) 4 and make another selection.

Enabling objective (EO) 5

The reader will be able to select sources of normative data and to identify static compliance and static impedance/admittance values in the absence of middle ear pathology.

Normative data for static compliance/impedance measures with the electroacoustic bridge were sparse until 1970. Most of the data has been generated from studies using the Zwislocki mechanical-acoustic bridge (Bicknell and Morgan, 1968; Feldman, 1963, 1964, 1967; Zwislocki and Feldman, 1970). In general, impedance values obtained with the Zwislocki acoustic bridge appear to be higher than those obtained with the electroacoustic systems (Lilly, 1973).

Burke, Herer, and McPherson (1970) have made acoustic and electroacoustic comparisons of middle ear impedance measurements. After testing a sample of normal adult middle ears, it was concluded that the Zwislocki and Madsen bridges yield similar impedance results where comparisons are possible. This finding is in agreement with, and extends the conclusion of Terkildsen and Nielsen (1960) to the effect that both the mechanical (acoustic) and electroacoustic methods are concerned with variations of the same acoustic properties of the ear.

After a comparative study involving patients with ear disease and persons in the normal range, Alberti and Kristensen (1970) reported that results using the Madsen ZO70 compare well with the results of other published studies using the Zwislocki bridge. From a diagnostic point of view, results appear to be as useful as those obtained using the Zwislocki bridge.

Feldman, Djupesland, and Grunes (1971) compared compliance results obtained with the electroacoustic and mechanical bridges. In 11 normal adult ears, he found results to be in good agreement for the two measuring devices.

Jerger (1972) states, however, that compliance measures obtained by an electroacoustic bridge such as the Madsen ZO70, and an electromechanical bridge such as the Zwislocki E8872A are not directly comparable because the Zwislocki norms are based on compliance read only at atmospheric air pressure. If static negative pressure exists in the middle ear of the patient in particular question, the maximum compliance will be slightly underestimated since maximum compliance can be measured only by compensating for static negative pressure in the middle ear, as is done with the Madsen instrument. Unless negative pressure is taken into account, both the central tendency and the variability of compliance measures will be underestimated. Jerger (1972) continues to state that this effect will be small in normal ears, but that this effect could be substantial in middle ear disorders, especially in otitis media.

Brooks (1968) noted that the greatest compliance change occurred within 50 mm of static middle ear pressure. Thus, the compliance values for normal ears would be somewhat higher when the compliance is measured at maximum than it would be at atmospheric pressure. Bluestone, Berry, and Paradise (1973) suggest a -50 mm/H_2O be indicative of middle ear abnormality in some cases. The present concensus of clinicians appears to suggest that as much as -100 mm/H_2O, in the absence of any other indications of middle ear pathology, represents the normal range (Harford, 1975).

The question arises as to whether or not one is justified in comparing electromechanically measured data with electroacoustically derived data. Normative data can be comparable for both instruments if one remembers that often ears of normal status have slight negative pressure in the middle ear and as a consequence, the mechanical bridge tends to underestimate compliance. Brooks (1968), as a restatement, observed that the greatest compliance change occurs within 50 mm of static middle ear pressure. Thus, values for normal ears will be somewhat higher when the compliance is measured at maximum than when measured at atmospheric pressure. In conclusion, the central tendencies for the different measuring devices appear to be in agreement.

Jerger, Jerger, and Mauldin (1972) reported static compliance values of 825 subjects, aged 6 years and older. The mean compliance for these ears was 0.67 cc. ranging from 0.03 to 1.65 cc. Of these 825 subjects, 315 had normal hearing, 385 had sensorineural losses equal to or less than 70 dB, and 125 had sensorineural losses greater than 70 dB. No difference could be found in the distributions for the three groups. Since disordered middle ears were eliminated from the study, it can be stated that the extent to which a sensorineural pathology might affect middle ear function is not reflected by a change in static compliance.

In another study, Jerger et al. (1974b) found there are simply no significant differences among distributions for children with normal sensorineural, or conductive audiograms. There was again extensive overlap among this group of 398 children of less than 6 years of age. In general, they found that the absolute compliance/impedance data were the least useful of the three impedance measures in providing supplemental diagnostic information.

In a study on middle ear disorders, Jerger et al. (1974a), again found that maximum static compliance values had only limited diagnostic value due to overlap between conductive and normal groups from a sample of 454 consecutive patients with conductive hearing loss.

In yet another study, Jerger, Jerger, and Mauldin (1972) results showed that the static compliance/impedance of the normal middle ear varies uniquely with both the age and sex of the patient. They plotted compliance and its variance by age decade and sex for the 315 normal and 375 sensorineural losses equal to or less than 70 dB (see Figure 7). Compliance in males was consistently higher than that in females in all age decades. Compliance seemed to decrease with age. Dempsey (1975) states that in clinical practice, the evaluation of any individual compliance result must be related to the age and sex of the patient.

Bicknell and Morgan (1968) found that, in general, compliance values for women were lower than those for males. Zwislocki and Feldman (1970) found that static compliance in male ears is consistently higher than that for females for the low frequencies. As the probe tone frequency approached resonance of the middle ear, compliance values for females exceeded those for males. Resistance in female ears was greater than that in male ears for all the frequencies. Dempsey (1975) states that this may represent a lower resonant frequency in female ears due to anatomical differences in middle ear size.

Normative admittance values are supplied by Feldman in the Otoadmittance Handbook 2 (Newman and Fanger, 1974). The relationships of admittance and impedance are provided in Figure 8 for a normal population of 100 and an otosclerotic population of fifteen. The overlap between the two populations is also provided. A normal population shows admittance values at Y_A 220 Hz ranging from .15 mmhos to .5 mmhos (the median for Y_A 220 was not given) and for Y_A 660 Hz, a range from .5 mmhos to 4.0 mmhos, with a

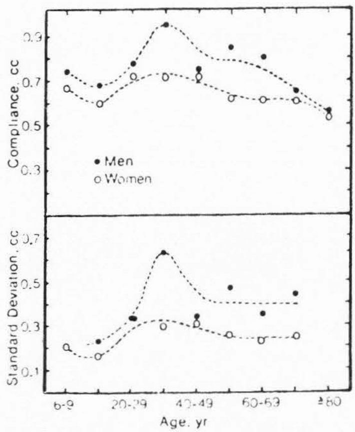


Figure 7. Effects of age and sex on static compliance; data from a single ear of 700 patients (315 normal, 385 sensorineural ≤ 70 dB) (Jerger, Jerger, and Mauldin, 1972, p. 517).

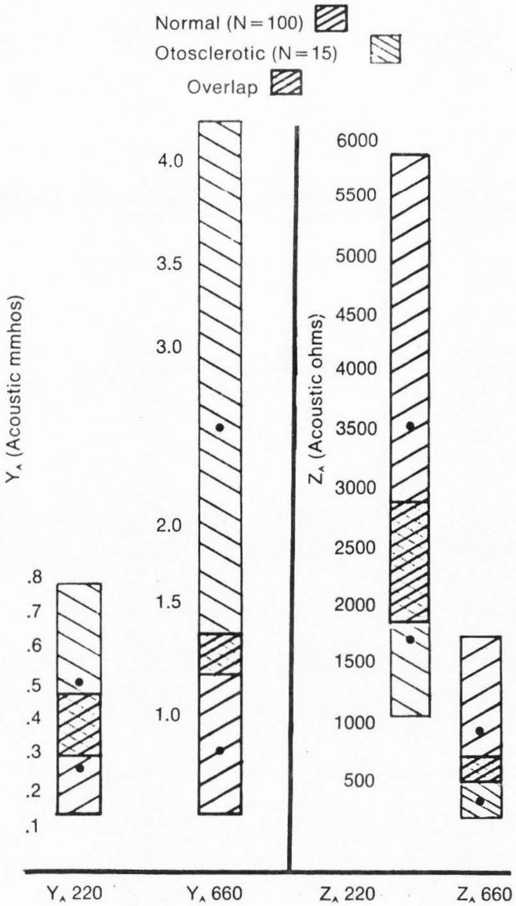


Figure 8. Distribution of Y_A and Z_A at 220 and 660 Hz for normal and otosclerotic ears (Feldman, 1972, in Newman and Fanger, 1974, p. 39).

median of 1.3 mmhos at Y_A 660 Hz. The acoustic impedance equivalent is given to the right.

Table 5 shows total admittance expressed in millimhos and total impedance expressed in ohms for three experimental groups of eighteen subjects in each group. As shown, no significant differences are indicated among the groups of normal hearing adults, normal hearing children, and deaf children (Porter, 1972).

Table 6 shows means and standard deviations, in millimhos of conductance (G) and susceptance (B) for this same test sample of normal hearing adults, normal hearing children and deaf children. No significant difference between the means was indicated for measurements of susceptance using the 660 Hz probe tone. Conductance at 220 Hz for the normal hearing adult group differed from the values obtained from both normal hearing children and deaf children. Of the means for susceptance at 220 Hz, however, the only significant difference was between normal hearing adults and deaf children. Finally, among the measures of conductance using the 660 Hz probe tone, the only significant difference was found to be between the value for normal hearing adults and that for deaf children. Thus, the only differences for admittance measures appears to be for normal hearing adults and deaf children.

Jerger (1970) states that, as a rough rule of thumb, most normal middle ears will yield impedance scores in the range from 1000 to 3000 ohms but that occasionally scores as low as 800 or as high as 4,200 ohms can be expected. The primary information contributed by Figure 9 relates to the fact

TABLE 5.--Admittance expressed in millimohs and impedance expressed in ohms for three experimental groups (after Porter, 1972, p. 56)

	220 Hz		660 Hz	
	Admittance	Impedance	Admittance	Impedance
Normal Hearing Adults	.79	1,265	2.93	341
Normal Hearing Children	.65	1,538	2.91	437
Deaf Children	.59	1,695	1.71	585

TABLE 6. Means and standard deviations, in millimhos, of conductance (G) and susceptance (B) for normal hearing adults, normal hearing children and deaf children (after Porter, 1972, p. 56)

Probe Frequency		Adult	Hearing Children	Deaf Children
200 Hz	G	.35 (.08)	.24 (.06)	.23 (.13)
	B	.71 (.22)	.60 (.19)	.54 (.21)
660 Hz	G	2.75 (1.01)	2.06 (1.01)	1.45 (.73)
	B	1.01 (.48)	1.01 (.40)	.91 (.39)

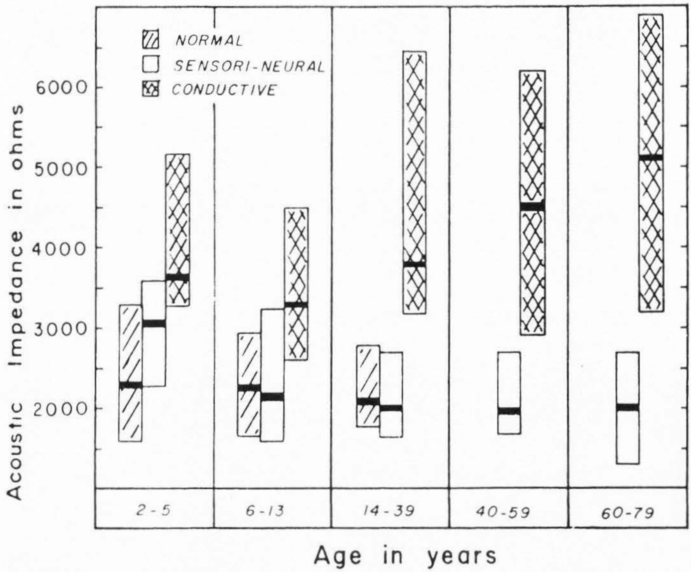


Figure 9. Distributions (median and semi-interquartile ranges) of acoustic impedance as function of age and type of audiometric configuration (Jerger, 1970, p. 315).

that there is considerable overlap between the impedance distributions of normal and disordered middle ears for all age groups. Jerger (1970) states that, as a very rough rule of thumb, one might expect that the highest 20 percent of normals overlap the lowest 20 percent of conductives.

Jerger (1975b) feels that probably the most valuable diagnostic application of the static compliance measure is the measurement of the volume of air in the external canal ("Z1"), one of the two measures involved in the computation of the static compliance. This initial volume measurement should be in the range from 0.5 cc to 1.5 cc. A volume in excess of 2.0 cc usually means that the tympanic membrane is perforated. Jerger continues to note that, in this case, the volume measurement reflects both the external canal and middle ear space. This volume measurement is extremely sensitive and will often reveal performations not readily visualized otoscopically.

Keith (1973) tested forty infants in the first few days of life. The median compliance was 1.1 cc, which was considerably higher than that reported for older children. Brooks (1971) found in a series of 697 children between the ages of 4 and 11, variability was smaller than in the larger sample reported by Jerger, Jerger, and Mauldin (1972). The age trend in variability appears to explain this difference (Dempsey, 1975). Brooks found the average compliance in these children to be 0.70 cc with a range of .35 to 1.40 cc. The mean compliance closely corresponded to that reported for adults.

Jerger et al. (1974b), found the median compliance in sixty-eight children from 0 to 6 years of age to be 0.55 cc. In review, Jerger (1970) in a study of static compliance in children from 3 to 5 years of age, found mean compliance to be 0.47 cc with a semi-interquartile range of 0.38 to 0.67 cc. The results from these two studies seem to be in agreement.

Dempsey (1975) provides two possible explanations of the high values in the infants. The cartilaginous external canal may provide an acoustic leak, increasing both volume measurements. Another possibility is that mass and resistance properties alter the resonances of the middle ear space. As was seen in adults, the compliance tended to increase as frequency approached resonance.

Much data has been generated in the last few pages and it is the author's intent at this point to summarize what has been said so that the reader will have a transitional set to use in a discussion of static compliance in the presence of middle ear pathology.

First, it can be stated that results of the Zwislocki mechanical bridge are comparable to results found with electroacoustic instrumentation provided one takes into account the possibility of negative pressure in the middle ear, and the subsequent underestimation of the maximum compliance. Second, the mean compliance for children 0 to 6 years of age appears to be 0.55 cc, while newborns in the first few days of life have considerably higher compliance values (mean of 1.10 cc). Third, for subjects 6 years and older with absence of middle ear disorders the mean compliance was 0.67 cc, ranging from 0.03 to 1.65 cc. Fourth, compliance values in males was consistently higher than that for females in all age decades for the low test frequencies usually employed. Fifth, normative admittance values indicate a range from .15 mmhos to .5 mmhos for Y_A 220 Hz, and a range from .5 to 4.0 mmhos for Y_A 660 Hz (median = 1.3 mmhos). Sixth, impedance scores range from 1000-3000 ohms but occasionally scores as low as 800 or as high as 4,200 can be expected.

One may become uncomfortable with the large variability found in normative static measures. Perhaps it is important to note that static measures by themselves have little diagnostic value, but in conjunction with tympanometry and acoustic reflex measurements they show clinical relevance. The picture is incomplete at this point, but the reader now has a frame of reference with which to explore various pathologies. Please proceed to Post-test evaluation 9.

Post-test evaluation (Pte) 9. What statement best describes the relationship between values obtained with the Zwislocki bridge and those obtained with electroacoustic instruments?

a. Since the procedures are exactly the same, the results are exactly the same.

b. Values obtained with the Zwislocki bridge appear to be lower than those obtained with the electroacoustic systems.

c. There is no research which has investigated the relationship between the measuring systems.

d. The data received from the two particular instruments is so different that comparisons of results are not possible.

e. The results of the Zwislocki and electroacoustic systems are comparable as long as one takes into account the possibility of negative pressure and the subsequent underestimation of the maximum compliance.

A = Correct. Proceed to (Pte) 10.

K = Incorrect. As Terkilden and Nielsen (1960) state, the methods are concerned with the same acoustic properties of the ear. Reread the first page of (EO) 5 and make another selection.

Q = You may not have known that the procedures were exactly the same, but you should have known that the results are not exactly the same. Reread the Zwislocki/electroacoustic section and make another selection.

J = Incorrect. The opposite of this statement is true. Reread the first paragraph of this section and make another selection.

T = Incorrect. Comparisons have been made. Reread the Zwislocki/electroacoustic section and make another selection.

Post-test evaluation (Pte) 10. What statement best represents normative values for children less than 6 years of age?

a. There are well defined impedance differences for individuals with normal, sensorineural, and conductive audiograms.

b. Impedance seems to decrease with age.

c. Newborns show considerably lower compliance values.

d. The range of compliance is from .35 to 1.4 cc for normal ears; suggesting great variability in static compliance/impedance measures.

e. Compliance seems to increase with age.

A = Very Good. You have identified the correct answer. Proceed to (Pte) 11.

K = Incorrect. There is much overlapping among all values. Return to the paragraph containing Jerger et al. (1974b) and make another selection.

Q = Incorrect. The opposite of this statement is true. Make another selection.

J = Incorrect. The opposite of this statement is true. Reread the paragraph of Dempsey (1975) and make another selection.

T = Incorrect. The opposite of this statement is true. Make another selection.

Post-test evaluation (Pte) 11. Which statement best describes normative impedance values for individuals 6 years and older?

a. As individuals get older, their middle ear measurements appear to be more compliant.

b. The most valuable diagnostic application of the static compliance measure is the measurement of the volume of air in the external canal.

c. As the probe tone frequency approaches resonance of the middle ear, compliance values for males exceed those for females.

d. A normal population show admittance values for Y_A 220 Hz ranging from .15 ohms to .5 ohms.

e. Compliance in females is consistently higher than that in males for all age groups.

A = Correct. Especially for perforations which are undetectable otoscopically. Proceed to (EO) 6 where static impedance and middle ear pathology will be treated.

K = Incorrect. The opposite of this statement appears to be true. Make another selection.

Q = Incorrect. The opposite of this statement is true for reasons given by Dempsey (1975). Make another selection.

J = Incorrect. If you switch females and males, the statement would be correct. Make another selection.

T = Incorrect. This statement was a little unfair, for if you place mmhos in the statement instead of ohms, it is correct. It is important to be familiar with the numerical values of both admittance and impedance. Make another selection.

Enabling objective (EO) 6

The reader will identify static-impedance relationships among normal ears and ears with otosclerosis, ossicular discontinuity, and otitis media.

It has already been shown that there exists great variability in static compliance/impedance measures for normal ears. As one would expect, this variability is also present in various middle ear pathologies. It is difficult, if not impossible, to isolate middle ear pathologies without other measures of middle ear function. This particular section will be brief since the data is so inconsistent in terms of diagnostic capability. Only three middle ear dysfunctions or disease processes will be presented: otosclerosis, ossicular discontinuity, and otitis media.

By way of introduction, Figure 10 shows the relationship between impedance values for forty-three otosclerotic ears and twelve ears with ossicular discontinuity as compared with the normal range. Although in both pathologies there is overlap with the normal range, the two disease groups are clearly separated.

Alberti and Kristensen (1970) state that, in the individual case, only highly raised impedance is significant, but in a clinical role the static impedance value will separate ossicular fixation from ossicular discontinuity. In both otosclerosis and serous otitis media, the impedance is raised although there is some overlap, particularly in otosclerosis. In general Table 7 shows the relationship between impedance and middle ear pressure for otosclerosis, serous otitis, and ossicular discontinuity.

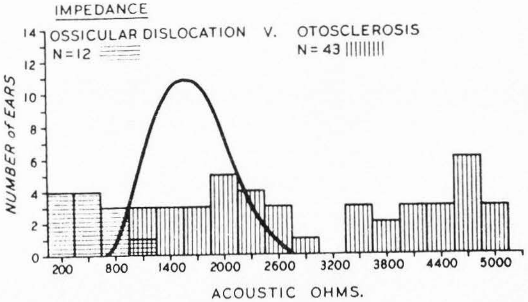


Figure 10. Impedance measurements in forty-three consecutive otosclerotic ears and twelve ears with ossicular discontinuity. The curve indicates the impedance range found in normal ears (Alberti and Kristensen, 1970, p. 740).

TABLE 7.--The relationship between impedance and pressure for otosclerosis, serous otitis, and ossicular discontinuity (Alberti and Kristensen, 1970, p. 730)

Impedance Measurements

Clinical Use:

Conductive Hearing Loss, and Intact Tympanic Membrane

	Impedance	Pressure
Otosclerosis:	High	Normal
Serous Otitis:	High	Negative
Ossicular Discontinuity:	Low	Normal

As a restatement, Jerger (1970) states that occasionally scores as low as 800 ohms or as high as 4,200 ohms can be expected. Generally, when impedance scores are below the range, ossicular discontinuity becomes highly suspect. Again generally speaking, when impedance scores are about 4,200 ohms, one should suspect otitis media or otosclerosis.

Otosclerosis. Otosclerosis is a pathological bone formation usually overgrowing the footplate of the stapes. It may or may not immobilize the stapes. The other ossicles are unaffected, the incudostapedial joint remains flexible, and the appearance of the tympanic membrane may be unremarkable (Dempsey, 1975).

In otosclerosis, impedance usually is high due to a reduction of energy transmitted to the cochlea. When the stapes becomes immobilized, the mechanical impedance presented by the cochlea is replaced by a much higher impedance and as a result, acoustic resistance at the tympanic membrane is controlled by the frictional resistance of the incudostapedial joint (Lilly, 1973). The subsequent result is an increased static impedance value.

Zwislocki and Feldman (1970), using the Zwislocki electromechanical bridge, show median compliance values and the 80 percent ranges for a population of thirty-three normal and twenty-four otosclerotic ears (see Figure 11). The only overlap exists at 1000 Hz (above the probe tone frequency of current electroacoustic instruments). Consequently, fewer than 10 percent of ears with stapedial ankylosis would be mistaken for normal ears and vise versa. The same relationship may be expected to prevail between ears with stapedial ankylosis and sensorineural hearing loss. Since the middle ear system of a person with sensorineural hearing loss is the same in all respects as that of a person with normal hearing.

Specific examples of impedance parameters of normal and otosclerotic ears have been provided by Feldman (1973). The equivalent volume of the otosclerotic ear is consistently smaller than in the normal ear for the test frequencies employed using the Zwislocki bridge (i.e., 125, 250, 500, 750 and 1000 Hz). The opposite relationship is true for resistance in otosclerotics. Specifically, resistance tends to be consistently higher at the lower frequencies.

Static compliance results have been reported in patients with confirmed otosclerosis using electroacoustic instrumentation. Jerger et al. (1974a), found that maximum static compliance is decreased in otosclerosis but that the variability in maximum static compliance is so great that the overlap

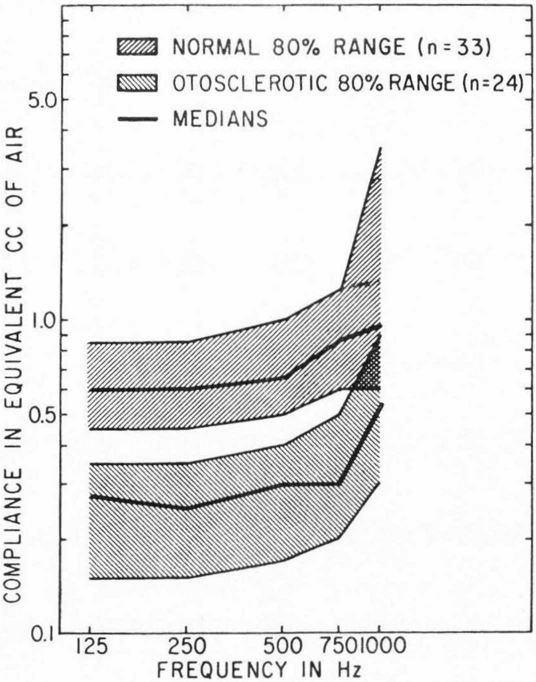


Figure 11. Zwislocki bridge median compliance values and 80 percent ranges of ears with normal hearing and with otosclerosis (Zwislocki and Feldman, 1970, p. 22).

between normals and otosclerosics precludes the effective diagnostic use of any absolute datum for an individual patient. They found the median compliance in sixty otosclerotic ears to be 0.35 cc and the range to be from 0.10 to 1.01 cc.

In summary, compliance is reduced and impedance is increased for an otosclerotic ear. There is overlap between otosclerotics and normals. One might expect a range in compliance from 0.10 to 1.01 cc for otosclerotics. As one can see tha 1.01 cc value of Jerger et al. (1974a) is in complete overlap with the Zwislocki and Feldman (1970) data for the normal range.

One cannot make a diagnosis on the basis of a static impedance value alone, but an increased impedance value is significant and should make one suspect of otosclerosis.

Ossicular discontinuity. Ossicular discontinuity has been investigated in detail (Priede, 1970) with reference to acoustic impedance using the Zwislocki bridge. A reasonable expectation is an increase in compliance and a decrease in resistance when ossicular discontinuity is encountered. Bicknell and Morgan (1968) observed that any pathological changes in the middle ear structures affected the compliance values more than the resistance values. A complete break in the ossicular chain will produce increased compliance and the normal reluctance of the system to accept low energy frequency will not be present (Dempsey, 1975).

Ossicular discontinuity classifications range in severity from small hairline fractures to completely necrosed or congentially absent structures.

Dempsey (1975) states the range of compliance results also reflects this variability.

Zwislocki and Feldman (1970) note that in a dozen ears with confirmed ossicular separation, all showed a high compliance and low resistance using the Zwislocki electromechanical bridge. They concluded that compliance values above the normal range indicate ossicular separation. Under these conditions the resistance is low, usually below the 80 percent normal range.

Jerger et al. (1974a), found that in eighteen cases of ossicular discontinuity the range of compliance (0.76 to 3.66 cc) median (1.93 cc) were high in relation to normal, but again there was overlap. It was concluded that, because of the variability, the static compliance did not provide consistent and reliable diagnostic information using the electroacoustic impedance bridge.

Priede (1970) states that measurements of the static impedance confirmed the diagnosis in two cases of ossicular discontinuity. However, he also states, that even cases of otosclerosis can yield impedance findings suggestive of some degree of ossicular discontinuity.

In summary, ossicular discontinuity usually yields increased compliance values (0.76 to 3.66 cc) and decreased impedance values (below 800 ohms) for the general case. The normative ranges are such, however that a differential diagnosis cannot be made on a static impedance or compliance value alone.

Otitis media and its sequalae. Static acoustic impedance measurements for ears with otitis media are no more definitive than measurements from patients with otosclerosis or ossicular discontinuity. As one would predict, a middle ear filled with fluid greatly increases the stiffness of the ossicular chain, typically resulting in a great increased impedance value. This appears to be true for ears with middle ear fluid; but the picture is complicated somewhat by the fact that there are various stages of otitis media. The physical status of the middle ear in otitis media may vary from slight Eustacian tube malfunction to chronic serous otitis media with numerous complications. It is important for the audiologist to understand these stages when examining impedance results in cases suffering from otitis media.

Dempsey (1975, p. 78) provides a description of the progression of otitis media wherein she writes:

> As otitis media progresses, the middle ear space fills with a light, watery fluid, which may change to a viscuous matter. Tympanic perforation may initially heal with a layer of flaccid tissue, which may or may not be overlaid with scar tissue. The pneumatic cells of the temperal bone usually do not appear to be normally aerated. In chronic cases, adhesions may form on the ossicles or tympanic membrane, effectively immobilizing the vibrating system. Cholesteotomas can develop, which may or may not impinge on any of the sound conducting structures of the middle ear.
>
> Later sclerotic bone may form along the ossicles. Placques may appear on the tympanic membrane, and the pneumatic cells of the temporal bone may undergo sclerotic changes.

Static compliance/impedance measures will reflect the stiffness changes depending on the severity of the pathology affecting the ossicular chain.

Brooks (1968) notes that, in early stages of otitis media, the middle ear cavity shows increased negative pressure. This increased negative pressure is due to Eustachian tube malfunction. In the determination of static impedance measures it is important to measure maximum compliance for it indicates middle ear pressure. According to Brooks, an increase in middle ear pressure of more than 50 mm H_2O is indicative of a pathological middle ear. However, as stated earlier in the discussion of normative values, negative pressure may not be diagnostically significant until it reaches a value of -100 mm H_2O or greater.

In 118 ears with otitis media, Jerger et al. (1974a), found the central tendency for maximum compliance to be 0.29 cc and the range to be 0.29 cc and the range to be from 0.06 to 0.81 cc. In thirty ears with cholesteotoma, the central tendency was 0.16 cc and the range was from 0.04 to 0.44 cc. Although the average compliance was lower than in normal ears for both of these pathologies, the overlap is still evident among the three distributions.

Zwislocki and Feldman (1970) in studies of electromechanical impedance bridge have concluded from cases of acute and serous otitis media that these ears are characterized by either a very low compliance, a very high resistance and no detectable muscle reflex, or with a moderately low compliance, high resistance, and a weakly detectable muscle reflex. The particular set of symptoms encountered depends on the place and severity of the disorder. The role of the acoustic reflex in determining the existence of otitis media will be discussed in the tympanometry section.

Otitis media then, at an early stage, shows an increased negative pressure in the middle ear space of more than 50 mm H_2O and usually minus 100 mm H_2O or greater. Any stage of the disease affecting the sound-conduction mechanism either increases or decreases the static acoustic impedance/ compliance of the middle ear. The fluid stage shows a greatly increased impedance with a decreased compliance resulting from an increased stiffness of the middle ear. Again, there is overlapping among normals otosclerosis, and ears with otitis media and this overlap severely limits the clinical usefullness of static measures.

Post-test evaluation (Pte) 12. What statement is representative of static impedance measures in otosclerosis?

a. When the stapes is immobilized, acoustic resistance at the tympanic membrane is controlled by the mechanical impedance of the cochlea.

b. There is little overlap between impedance values for otosclerosis and otitis media at 220 and 660 Hz.

c. Compliance is reduced and impedance is raised for the otosclerotic ear at all frequencies.

d. There is little variability in maximum static compliance values for otosclerotic and normal ears.

e. There is no overlap between impedance values for normals and otosclerotics at 660 Hz.

A = Correct. This is the general characteristic. Proceed to (Pte) 13.

K = Incorrect. There is great overlap. Note Figure 11 and make another selection.

Q = Incorrect. With static measures, you would expect basically the same results. Make another selection.

J = Incorrect. There is variability at all frequencies. Review Figure 11 and make another selection.

T = Incorrect. This impedance is replaced by the frictional resistance of the incudostapedial joint. Make another selection.

Post-test evaluation (Pte) 13. What statement best represents static impedance measures in ossicular discontinuity?

a. Any complete break in the ossicular chain will produce increased impedance.

b. Impedance measures for ossicular discontinuity are as variable as the range in severity of the pathology.

c. Compliance values below the normal range indicate ossicular discontinuity.

d. Due to the great differences in impedance for pathologies of ossicular discontinuity and otosclerosis, there can be no overlap between them.

e. Static compliance for ossicular discontinuity provides consistent diagnostic information.

A = Correct. You have identified the correct statement. Proceed to (Pte) 14.

K = Incorrect. "Above" would make this statement true. Review Zwislocki and Feldman (1970) and make another selection.

Q = Incorrect. Reread what Priede (1970) reported and make another selection.

J = Incorrect. It will be a decreased value. Make another selection.

T = Incorrent. It should have been evident that this was not true. Reread the selection on ossicular discontinuity and make another selection.

Post-test evaluation (Pte) 14. Static acoustic impedance measurements for ears with otitis media are best represented by what statement?

a. A middle ear filled with fluid greatly increases the compliance of the ossicular chain.

b. Otitis media at an early stage shows an increased positive pressure.

c. Otitis media is indicated when impedance is very much lower than normal.

d. An increased middle ear pressure of more than 0 mm H_2O is indicative of a pathological ear.

e. Although a middle ear filled with fluid shows a greatly increased impedance, other stages of the disease will reflect different impedances depending upon the effect on the ossicular chain.

A = Correct. The variability exists. Proceed to the Tympanometry section.

K = Incorrect. Higher than normal makes this true. Make another selection.

Q = Incorrect. It decreases. Make another selection.

J = Incorrect. It shows an increased negative pressure. Review Brooks (1968) finding and make another selection.

T = Incorrect. Generally speaking, the value is above this at approximately -100 mm H_2O. See the paragraph containing Brooks information (1968) and make another selection.

References

Alberti, P., and Kristensen, R. 1970. The clinical application of impedance audiometry. Laryngoscope 80:735-746.

Bicknell, M., and Morgan, N. A. 1968. A clinical evaluation of the Zwislocki acoustic bridge. Journal of Laryngology Otology 82:673-692.

Bluestone, C., Berry, Q., and Paradise, J. 1973. Audiometry and tympanometry in relation to middle ear effusions in children. Laryngoscope 83:594-604.

Brooks, D. 1968. An objective method of detecting fluid in the middle ear. Journal of International Audiology 7:280-286.

Burke, K. S., Herer, G. R., and McPherson, D. L. 1970. Middle ear impedance measurement: Acoustic and electroacoustic comparisons. Acta Otolaryngologica 70:29-34.

Dempsey, C. 1975. Static compliance. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 4. American Electromedics Corporation, Dobbs Ferry, New York.

Feldman, A. 1963. Impedance measurements at the eardrum as an aid to diagnosis. Journal of Speech and Hearing Research 6:315-327.

Feldman, A. 1964. Acoustic impedance measures as a clinical procedure. Journal of International Audiology 3:1-11.

Feldman, A. 1967. Acoustic impedance studies of the normal ear. Journal of Speech and Hearing Research 10:165-176.

Feldman, A., Djupesland, G., and Grunes, C. 1971. A comparison of impedance measurements. Archives of Otolaryngology 93:416-418.

Harford, E. R. 1975. Tympanometry. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 3. American Electromedics Corporation, Dobbs Ferry, New York.

Jacobson, J. T., Kimmel, B. L., and Fausti, S. A. 1975. Clinical application of the Grason-Stadler Otoadmittance Meter. A Journal of the American Speech and Hearing Association 17(1):11-16.

Jerger, J. 1970. Clinical experience with impedance audiometry. Archives of Otolaryngology 92:311-324.

Jerger, J. 1972. Suggested nomenclature for impedance audiometry. Archives of Otolaryngology 96:1-3.

Jerger, J. 1975a. Impedance terminology. Archives of Otolaryngology 101:589-590.

Jerger, J. 1975b. Diagnostic use of impedance measures. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 7. American Electromedics Corporation, Dobbs Ferry, New York.

Jerger, J., Jerger, S. J., and Mauldin, L. 1972. Studies in impedance audiometry: I. Normal and sensorineural ears. Archives of Otolaryngology 96:513-523.

Jerger, J., Anthony, L., Jerger, S., and Mauldin, L. 1974a. Studies in impedance audiometry: III. Middle ear disorders. Archives of Otolaryngology 99:165-171.

Jerger, S., Jerger, J., Mauldin, L., and Segal, P. 1974b. Studies in impedance audiometry: II. Children less than six years old. Archives of Otolaryngology 99:1-9.

Keith, R. 1973. Impedance audiometry with neonates. Archives of Otolaryngology 97:465-467.

Lilly, D. J. 1973. Measurement of acoustic impedance at the tympanic membrane. In James Jerger (Ed.). Modern developments in audiology, Edition 2. Academic Press, New York.

Newman, B. T., and Fanger, D. M. 1973. Otoadmittance handbook 2. Grason-Stadler, Concord, Massachusetts.

Priede, V. M. 1970. Acoustic impedance in two cases of ossicular discontinuity. Journal of International Audiology 9:127-136.

Porter, Thomas. 1972. Normal otoadmittance values for three populations. Journal of Auditory Research 12(1):53-58.

Terkildsen, K., and Scott-Nielsen, S. 1960. An electroacoustic impedance bridge for clinical use. Archives of Otolaryngology 72:339-346.

Zwislocki, J., and Feldman, A. 1970. Acoustic impedance of pathological ears. ASHA Monograph, No. 15. American Speech and Hearing Association, Washington, D. C.

Additional Readings

Brooks, D. N. 1971. A new approach to identification audiometry. Audiology 10:334-339.

Brooks, D. 1971. Electroacoustic impedance bridge studies on normal ears of children. Journal of Speech and Hearing Research 14:247-253.

Rock, E. H. 1972. Electroacoustic impedance measurements in clinical otology. Impedance newsletter. American Electromedics Corporation, 1:Revised.

Sheehy, J. L., and Hughes, R. L. 1974. The ABC's of impedance audiometry. Laryngoscope 84:1935-1949.

TYMPANOMETRY

Introduction

Tympanometry is a dynamic measure of middle ear impedance. It is a technique that assesses the mobility or compliance of the tympanic membrane during variation of air pressure in a hermetically sealed ear canal. Tympanometry, as an objective test, provides for the simultaneous assessment of the compliance of the tympanic membrane, the status of the ossicular chain, and the air pressure of the middle ear. The technique of tympanometry yields a tympanogram which is a graph relating compliance change at the tympanic membrane to air pressure variation in the ear canal. The tympanogram is a pressure-compliance function.

A normal tympanogram is shown in Figure 12. The horizontal axis is represented by air pressure in mm H_2O and typically is a continuum from negative air pressure at 400 mm H_2O to positive pressure of 200 mm H_2O. At the lower end of the continuum, - 400 mm H_2O, the negative pressure is sufficiently great to, in effect, create a hard-walled cavity where the vibratory capacity of the middle ear system is reduced to a minimum. As air pressure is increased toward 0 mm H_2O, the eardrum becomes more compliant and more capable of transmitting acoustic energy. For a normal tympanogram the initial change when increasing pressure progressively from -400 mm H_2O to +200 mm H_2O, increases in compliance are typically observed in the neighborhood

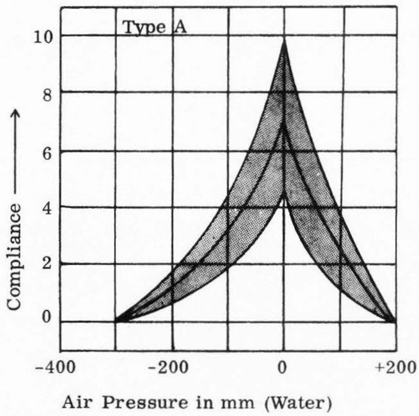


Figure 12. Typical normal pressure/compliance curve obtained by varying air pressure in the sealed ear canal from positive through normal atmospheric pressure to negative pressure (Harford, 1975, p. 50).

of -200 mm H_2O. Since this is the case, normal tympanograms do not usually extend beyond -200 mm H_2O in the negative direction.

The vertical axis is the compliance scale in arbitrary units when using the electroacoustic impedance instrument (Madsen) or in millimhos when using the otoadmittance meter (Grason-Stadler). As the hard-walled cavity situation is progressively reduced from the -200 mm H_2O position, compliance increases until the tympanometric curve reaches a peak. Since a normal tympanogram is the focus of the discussion, the peak should occur at a pressure of approximately 0 mm H_2O. That is, the existing middle ear pressure should approximate atmospheric pressure (external auditory canal pressure equaling middle ear cavity pressure). As the pressure continues to increase from 0 mm H_2O to a positive 200 mm H_2O the external auditory canal becomes progressively more like a hard-walled cavity, with the simultaneous reduction in the acoustic transmitting capabilities of the middle ear. At +200 mm H_2O the hard-walled cavity situation is again present.

There are five tympanogram types and each indicates either a normal or a pathological middle ear system. The impedance of the conductive mechanism can be inferred from the tympanogram. As Harford (1975) states, the greater the change in compliance, the lower the impedance and vice-versa. As will be seen, there are variations of the five types of tympanogram with characteristic changes in the compliance-pressure function.

Goal Three

The reader will be able to identify significant variables of the tympanogram and relate them to the audiomatric-medical status of the patient.

Enabling objective (EO) 7

The reader will be able to define the term "gradient" and use the measure in the interpretation of the tympanometric curve.

The "gradient" is a term which has been used to describe the tympanogram in numerical terms (Brooks, 1968). At the present time, the "gradient" is used infrequently in tympanogram interpretation but it may provide diagnostic utility in the future. For this reason, it is entered in the discussion.

As idealized representation of changes in the compliance function which occurs as a consequence of changing the external auditory canal pressure as shown in Figure 13 for a normal ear (a), and one with middle ear fluid (b) (Brooks, 1969). The effective middle ear compliance is given by the height of the curve. A measure of slope of the compliance curve near the peak of the tympanogram is made to define to some extent the shape of the curve. The percent of total change in compliance for a difference of $\pm$ 50 mm H_2O pressure from the peak value is measured and the value is called the "gradient."

To determine an actual numerical percent gradient value, take the peak compliance value or maximum compliance; as an example let ten arbitrary units indicate peak compliance. From this peak compliance value draw two vertical lines, one through +50 mm H_2O and one -50 mm H_2O so that the lines intersect the tympanometric curve. The distance from the point of intersection to peak compliance is the "gradient value." For the moment, assume that the intersection points between +50 mm H_2O above the pressure at which peak compliance

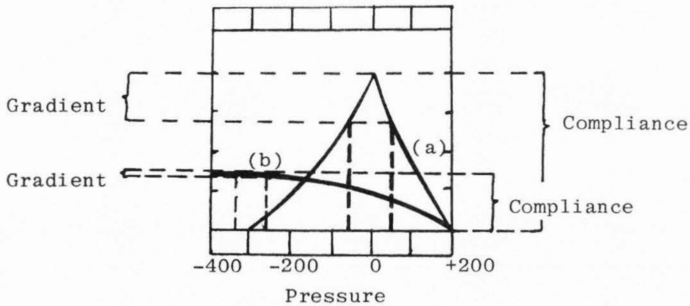


Figure 13. Variation of compliance for a., normal middle ear (right), and b., middle ear filled with fluid (left) (Brooks, 1969, p. 563).

occurs and -50 mm H_2O below the pressure at which peak compliance occurs coincides with an arbitrary compliance scale value to "two." In this case eight arbitrary units indicates the gradient value on both the positive and negative side of peak compliance. To determine percent (%) gradient, divide the maximum or peak compliance value into the gradient value (Figure 14).

The calculation provides the percent gradient value and using the values from the example, eight arbitrary units (gradient value) divided by ten arbitrary units (maximum or peak compliance value) equals an 80 percent gradient value. The value could be representative of a hypermobile tympanic membrane.

Brooks (1969) states that in the normal ear the gradient value is about 40 percent of the total compliance change. In other words, when changes in compliance are plotted as a function of changing the pressure in the external auditory meatus, a peak in the compliance function will occur near a pressure of 0 mm H_2O in a normal ear. In a normal ear, approximately 40 percent of the total change in compliance which occurs between 200 mm H_2O and 0 mm H_2O will occur within 50 mm H_2O of the peak. However, in an ear where the middle ear is filled with fluid the gradient is usually less than 10 percent, and in an ear that is hypermobile, it may reach over 80 percent of the compliance value. By means of these three measurements (peak compliance value, gradient value and the difference for these two values) the shape of the tympanogram can be reasonably well defined in numerical terms.

As Brooks (1969) states, however, there is a continuum and some overlap between what is clearly normal and what is clearly abnormal. The

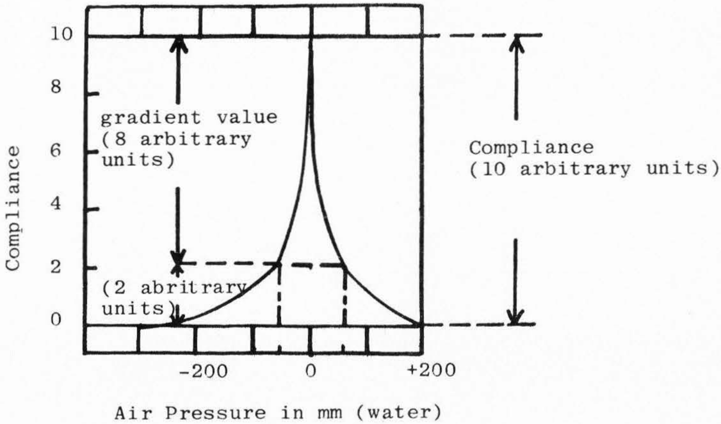


Figure 14. Example of peak compliance (ten arbit rary units) in relation to the gradient value (eight arbitrary units).

determination of what the tympanogram indicates is not based on a gradient numerical value alone. The decision determined must be in conjunction with the general shape of the tympanogram and also the static impedance and acoustic reflex measurements.

Post-test evaluation (Pte) 15. The term "gradient" is used to define the shape of the tympanometric curve in numerical terms. What statement best specifies this definition?

a. The gradient is simply the height of the curve minus the compliance at 50 mm H_2O pressure.

b. The change in compliance for a difference of 100 mm pressure from maximum compliance is measured.

c. Gradient measures are precise and do not overlap among pathologies.

d. The percent change in compliance for a difference of 50 mm H_2O pressure from maximum compliance is measured.

e. For the normal ear, the gradient value is 80 percent of the compliance.

A = Correct. This best represents gradient measures. Proceed to Enabling Objective 8.

K = Incorrect. Look at Figure 12 and make another selection.

Q = Incorrect. There is no strict definition between what is normal and what is abnormal. Make another selection.

J = Incorrect. The cut-off is not at 50 mm, but a difference of 50 mm at peak compliance. Make another selection.

T = Incorrect. It is usually about 40. Make another selection after reviewing Figure 13.

Enabling objective (EO) 8

The reader will be able to identify characteristics of the Type A tympanogram and to identify interpretations of this tympanogram in reference to the audiometric-medical status of the patient.

A point of significance is that the tympanic membrane is at maximum compliance when the air pressure in the middle ear is equal to the air pressure in the external auditory canal. Maximum transmission of the tympanogram gives direct measure of existing middle ear pressure. The audiologist must simply identify the air pressure in the external auditory canal at which the eardrum shows maximum compliance. The pressure at which this phenomenon occurs will be the middle ear pressure.

The Type A tympanogram types are usually obtained from persons with a normal conductive mechanism or stapes fixation (Harford, 1975). Type A tympanogram shows that eardrum compliance is greatest when air pressure in the middle ear and, in the ear canal is approximately equal to atmospheric pressure (0 mm H_2O). The peak of the curve (see Figure 15) represents the air-pressure-point of greatest compliance of the eardrum. This peak should approximate 0 mm H_2O pressure, but the normal range can vary to within -100 mm of H_2O pressure in the absense of any other indications of middle ear pathology. The peak is designated as "maximum compliance."

A Type A tympanogram is usually associated with either normal hearing or a pure sensorineural loss with normal middle ear pressure. McCandless and Thomas (1974) have suggested that a person's hearing threshold

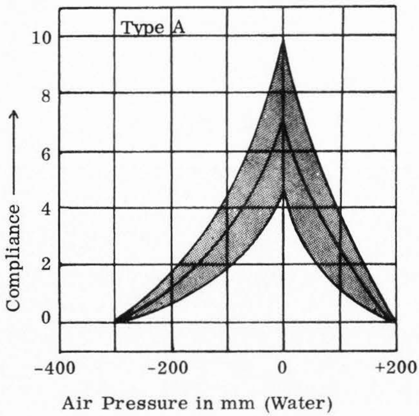


Figure 15. The Type A tympanogram, indicating normal middle ear compliance, obtained by varying air pressure in the sealed ear canal from positive through normal atmospheric pressure to negative air pressure. The dark line represents mean compliance while the shaded area represents the 80 percent range for normal compliance (Harford, 1975, p. 53).

for pure tone audiometry can be within the normal range (0 to 25 dB) and yet the person may have a mild conductive disorder manifested by an abnormal tympanogram. It is apparent, therefore, that it is possible for pure tone thresholds to be within the normal range and yet for the patient to have a mild conductive loss as evidenced by the tympanogram.

As one might expect, the maximum compliance is typically reduced for an ear with stapes fixation (see Figure 16). The air pressure at the peak of the tympanogram approximates 0 mm H_2O because of normal middle ear pressure. Jerger (1972) has suggested calling this particular curve Type A_s and it is much shallower than the normal Type A curve, suggesting increased impedance. If a patient has normal pure tone air and bone thresholds and a shallow Type A tympanogram, it is of no diagnostic significance. However, if pure tone air and bone thresholds show a conductive hearing loss and the tympanogram is Type A_s (normal pressure but shallow), one might suspect the presence of stapedial fixation.

If the Type A curve is unusually deep, it is designated as a "Type A_d" (see Figure 17). This particular curve suggests the presence of ossicular discontinuity when air and bone conduction pure tone thresholds indicate a conductive hearing loss. The curve shows very high compliance and the balance meter and recorder peak off the scale around atmospheric or 0 pressure. The resultant is a very deep notch, or high peak, or an incomplete tracing as is shown in Figure 17. It should be mentioned that the Type A_d curve is consistent for cases of ossicular discontinuity when using a 220 Hz probe tone, but when

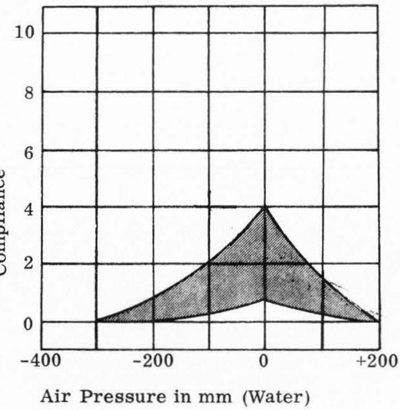


Figure 16. Type A_s tympanogram representing stapes fixation. Diagonal lines indicate the 80 percent range for the A_s tympanogram.

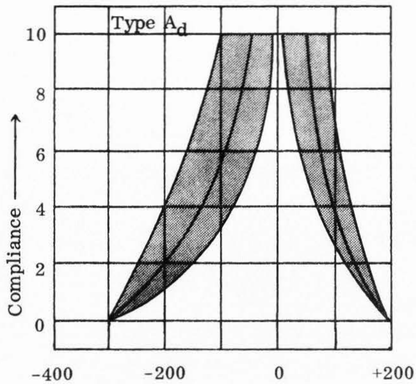


Figure 17. Type A_d tympanometric curve suggesting ossicular discontinuity; obtained with a 220 Hz probe tone (Harford, 1975, p. 60).

employing probe tones of higher frequencies (660 and 800 Hz) different patterns emerge as will be seen in a later enabling objective.

It is important to remember that the tympanogram reflects how pressure variation affects impedance at the tympanic membrane.

When an acoustic stimulus, such as the probe tone in impedance audiometry, enters the external canal and impinges on the tympanic membrane, what sound is reflected depends directly on this first middle ear structure. If the tympanic membrane is normal and transfers the energy, then very little sound will be reflected. If increased tympanic membrane stiffness exists, then there will be the subsequent increased reflection of energy. The acoustic stimulus is transferred unless it is dampened by increased stiffness of the middle ear system.

Since the progression of an acoustic stimulus is linear; that is, the stimulus travels from the external canal to the tympanic membrane through the middle ear in a linear fashion, to the oval window, it seems logical that the first encounter with middle ear stiffness would be responsible for the reflected acoustic message; and any change in stiffness proximal to the initial change would be represented but to a less significant extent.

In the case of the A_s tympanometric curve it is possible to have an essentially normal middle ear mechanism in the presence of tympanosclerosis. This pathology will decrease compliance and yield a tympanogram which resembles the tympanogram found in stapedial fixation. It is also possible to have stapedial fixation in the presence of a hypermobile eardrum. What one sees graphically then is a Type A_d curve suggesting ossicular discontinuity. It is true that these particular cases happen rarely, but it shows that the interpretation of tympanometry is dependent on the status of the tympanic membrane or the pathology nearest the tympanic membrane.

Post-test evaluation (Pte) 16. What statement best represents the diagnostic significance of the Type A tympanogram ?

a. Impedance is reduced for an ear with stapes fixation and the tympanogram is designated Type A_s.

b. If the Type A curve is unusually deep it is designated as Type A_d and is representative of negative pressure in the middle ear.

c. Tympanographic results are the same concerning ossicular discontinuity with probe tones of 220 and 800 Hz.

d. A person cannot show a conductive loss tympanometrically if he has normal pure tone thresholds.

e. A normal tympanogram shows that eardrum compliance is greatest when air pressure in the middle ear and in the ear canal is equal to atmospheric pressure.

A = Correct. This statement is basic to tympanogram interpretation and it is obvious you understand the concept involved. Proceed to (Pte) 17.

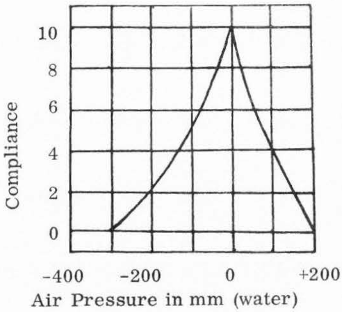
K = Incorrect. This does not appear to be the case as will be seen in a later (EO). Make another selection.

Q = Incorrect. Look closely at Figure 15 and make another selection.

J = Incorrect. Review what McCandless and Thomas (1974) report and then make another selection.

T = Incorrect. It is still representative of the Type A curve suggesting middle ear pressure equal to atmospheric pressure. Review the first paragraph of this (EO) and make another selection.

<u>Post-test evaluation (Pte) 17</u>. Select the pathology most representative of the following tympanogram.



a. Otitis media.

b. Stapes fixation with hypermobile eardrum.

c. Stapes fixation.

d. Negative pressure in the middle ear.

e. Tympanosclerosis.

A = Correct. This is the most representative pathology. Proceed to Enabling Objective 9.

K = Incorrect. This is unlikely since compliance is decreased in this pathology. Review the last paragraph in this (EO) and make another selection.

Q = Incorrect. This is unlikely since compliance is reduced in this pathology. Review the last paragraph in this (EO) and make another selection.

J = Incorrect. Air pressure is at 0 mm suggesting normal middle ear pressure. Review the first paragraph in this (EO) and make another selection.

T = Incorrect. As will be seen later this condition reduces compliance drastically. Review the last paragraph in this (EO) and make another selection.

Enabling objective (EO) 9

The reader will be able to identify characteristics of the Type B tympanogram in relation to stages of otitis media.

Pure tone audiometry is not as reliable an indicator of middle ear fluid as tympanometry for two main reasons (Brooks, 1968). First, the threshold change may be very small if the middle ear fluid is thin and serous; possible 10 dB or less. This phenomenon has been demonstrated experimentally by Goodhill (1958). On the other hand the hearing loss may be much more severe if the fluid is thick and viscous; possibly reaching 50 dB. Thus, no particular level can be adopted as a critical value. Secondly, with children which are very young, the pure tone thresholds obtained must themselves be treated with reserve.

In most tympanometric studies, Brooks (1968), Jerger, Jerger, and Mauldin (1972), and Jerger et al. (1974), the Type B curve has been extremely accurate as a diagnostic tool for detecting the presence of secretory otitis media. A large tympanosclerotic placque, however, can cause a rigid tympanic membrane and a Type B curve may result (Rock, 1972). The possibility of fluid behind this type of tympanic membrane should not be overlooked.

Type B tympanograms will be obtained in cases with chronic adhesive otitis or middle ear fluid that causes reduced compliance of the eardrum. The tympanogram shows virtually no change in compliance of the eardrum with change in air pressure, suggesting a high impedance or low admittance. The result is a relatively flat or shallow tympanogram indicating an immobile eardrum (see Figure 18).

Type B curves do not reveal a point of greatest compliance since air pressure in the ear canal increased by an air pump can never match the pressure of fluid in the middle ear space.

Harford (1975) states that one should be wary of an absolutely flat tympanogram. It usually means the presence of a perforated eardrum or a fault in the testing apparatus. Impacted or a large amount of cerumen in an ear canal will also preclude tympanometry.

A flat tympanogram results because the acoustic or probe tone signal is never reflected from the middle ear system back to the receiving microphone. The pick-up microphone receives no feedback from the impedance-servo network. In other words, there is no change in the impedance/compliance for a constant acoustic environment even with varying air pressure. This condition rarely, if ever, manifests itself totally in middle ear pathology.

A variation of the Type B tympanogram has been generated by Martin, Butler, and Burns (1973). It is representative of a transitional tympanogram between the standard Type C and Type B patterns (see Figure 19). This transitional tympanogram has been designated as Type B_E (early Type B).

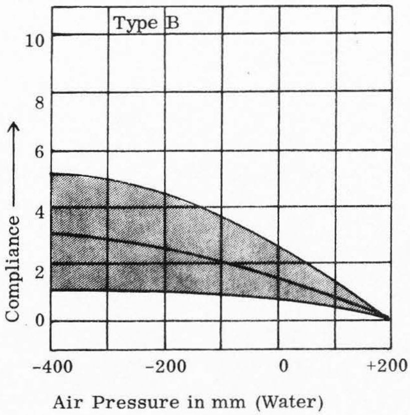


Figure 18. The Type B tympanogram suggestive of middle ear fluid (Harford, 1975, p. 53). The dark line represents mean compliance while the shaded area represents the 80 percent range for normal compliance.

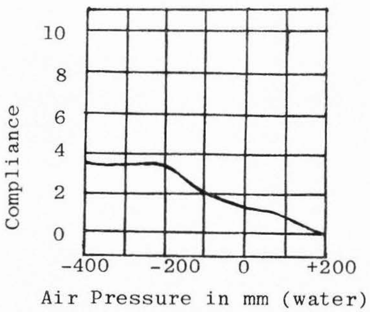


Figure 19. Illustration of the Type B_E tympanogram suggesting shift from negative middle ear pressure to fluid accumulation within the middle ear (Martin, Butler, and Burns, 1973, p. 1784).

The typical development of serous otitis media follows a characteristic pattern. As the pressure within the middle ear space drops because of inadequate ventilation, the tympanogram shifts from Type A to Type C. If allowed to continue untreated or without spontaneous resolution, the negative middle ear pressure results in the accumulation of middle ear fluid with a resultant Type B tympanogram (Martin, Butler, and Burns, 1973).

The Type B_E curve is similar to the Type B curve at pressure settings above about - 100 mm H_2O and shows little or no change in tympanic membrane compliance with changes in ear canal pressure below -100 mm H_2O. At about -100 mm H_2O, there is a dip in the curve but no recovery with progressively decreased negative pressure as is seen in the typical Type C curves to be discussed in the next enabling objective. In most cases, these curves have been found clinically (Martin, Butler, and Burns, 1973) among patients with partially retracted tympanic membranes and an accumulation of some fluid in the middle ear.

Post-test evaluation (Pte) 18. What statement is most representative of the Type B tympanogram in relation to the presence of middle ear fluid?

a. Pure tone audiometry is more reliable as an indicator of middle ear fluid than the Type B curve since a threshold value is obtained.

b. The Type B tympanogram will be obtained in cases with chronic adhesive otitis or middle ear fluid that causes reduced impedance of the eardrum.

c. The shape of the tympanogram is relatively flat indicating a mobile eardrum.

d. The Type B_E curve shows no change in compliance with changes in ear canal pressure.

e. There is no change in compliance with the change in air pressure because the air pump can never match the pressure of fluid in the middle ear.

A = Correct. You understand the relationship between the impedance/ compliance of the tympanogram and the presence of middle ear fluid.

K = Incorrect. There are changes below -100 mm. Examine Figure 18 and make another selection.

Q = Incorrect. Review the first paragraph of this (EO) and make another selection.

J = Incorrect. There will be increased impedance because of the fluid behind the tympanic membrane. Make another selection.

T = Incorrect. There is relatively no eardrum compliance. Make another selection.

Enabling objective (EO) 10

The reader will be able to identify characteristics of the Type C tympanogram, and tympanometric interpretations in the evaluation of Eustachian tube function.

If the middle ear is at negative pressure relative to normal atmospheric pressure, maximum compliance will occur when the induced air pressure in the external ear canal is equal to the negative air pressure in the middle ear cavity (Harford, 1975). The resulting tympanogram is designated as Type C and is shown in Figure 20. The Type C curve is extremely useful in confirming tubal incompetency in the absence of fluid behind the tympanic membrane.

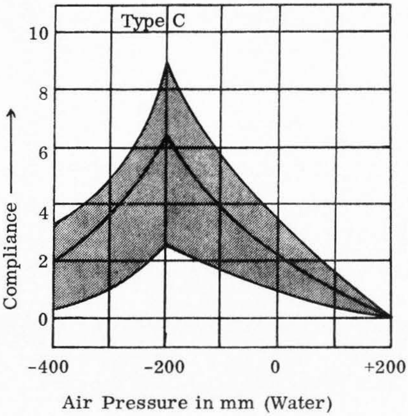


Figure 20. The Type C tympanogram indicative of negative pressure in the middle ear cavity relative to atmospheric air pressure. The dark line represents mean compliance while the shaded area represents the 80 percent range for normal compliance (Harford, 1975, p. 53).

However, rarely does Eustachian tube incompetency occur without secretory otitis media (Rock, 1973).

It is worthwhile to measure and indicate the middle ear pressure at which maximum compliance occurs. Harford (1975) offers three reasons for being explicit: (1) Further research will doubtlessly provide valuable data for correlation between amount of pressure and causative factors; (2) For a patient monitored over time, the amount of change of middle ear pressure could provide valuable clues to the course of the pathology; and (3) Negative middle ear pressure can attenuate a stapedial reflex measure and it is wise to compensate for such a condition by equalizing ear canal pressure with that in the middle ear when measuring the reflex.

Yet to be determined is a logical pressure that can be safely tolerated before classifying a tympanogram as abnormal. Clinicians use values from -50 mm H_2O to -100 mm H_2O. As Harford (1975) states, the question needs further investigation. It does appear though that the value of -100 mm H_2O is more consistently used criterion for clinical determination of negative pressure abnormality.

The Type C curve can exist with a slight hearing loss. The greater the negative pressure, the greater the hearing loss. Flisberg (1963) demonstrated this by direct control of middle ear pressure in man. With small negative pressures, low tones are first impaired while increasing negative pressures also affect high tones. An intratympanic pressure of -400 mm H_2O can cause an average loss of 25 cB, while 135 mm H_2O pressure causes an average

15 minutes, a thin transudate of clear yellow fluid is produced in the middle ear.

In a discussion of the Type C tympanogram, we are indirectly talking about Eustachian tube function. Eustachian tube dysfunction appears to be one of the most important factors in the pathogenesis of middle ear disease. That is not to say, however, that negative middle ear pressure necessarily signifies serous otitis or a nonfunctioning Eustachian tube or both. Harford (1975) feels that a more justifiable interpretation is "insufficient" Eustachian tube function Bluestone, Paradise, and Beery (1972) have noted that this insufficiency is related to the actual compliance of the Eustachian tube itself. In particular, compliance appears to be an important factor in the response of the Eustachian tube to increased positive or negative pressures.

The Eustachian tube has three functions with respect to the middle ear: (1) protection from naso-pharyngeal secretions; (2) drainage into the nasopharynx of secretion produced within the middle ear; and (3) ventilation of the middle ear to produce an equilibration of air pressure in the middle ear with atmospheric pressure (Bluestone, 1975).

Bluestone (1975) continues to state that tympanometry offers the most physiologic approach to the study of Eustachian tube function and is technically the simplest of all tests of ventilation function.

We have talked about the various stages of otitis media in section three and in the discussion of Type B tympanograms. In summary, as air in the middle ear space is exhausted due to blockage or faulty function of the

Eustachian tube negative pressure causes retraction of the eardrum. The peak of the tympanogram is shifted from atmospheric pressure in the negative direction until the negative pressure of the middle ear space is reached. The Type C tympanogram with a peak below -100 mm H_2O is the result.

The lack of sufficient air in the middle ear space causes effusion from tissues lining the tympanic cavity. According to Jerger (1975) as the fluid fills the middle ear space, the first effect is a rounding of the peak of the Type C tympanogram. As the fluid level increases, the mobility of the ossicular chain decreases and the middle ear impedance increases to a fairly substantial extent. This increase in impedance and decrease in compliance causes the rounded peak of the tympanogram to drop progressively lower. In a completely fluid-filled ear, the tympanogram may be almost flat as described in the Type B tympanogram.

As the otitic ear heals, the process is reversed and the tympanogram gradually returns from Type B to Type C to Type A. When the acoustic reflex returns, a near normal middle ear mechanism can be assumed (Jerger, 1975). Figure 21 shows a series of tympanograms illustrating the various stages of acute serous otitis media.

If a patulous Eustachian tube is suspected, the diagnosis can be confirmed by tympanometry. What one sees graphically (see Figure 22) is a curve which is synchronous with respiration. This phenomenon is due to increases and decreases in middle ear pressure which accompany expiration and inspiration during respiration. This fluctuation can be exaggerated by

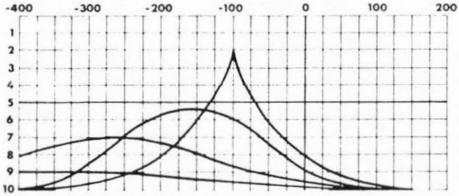


Figure 21. Series of tympanograms illustrating the various stages of serous otitis media (Dempsey, 1975, p. 79).

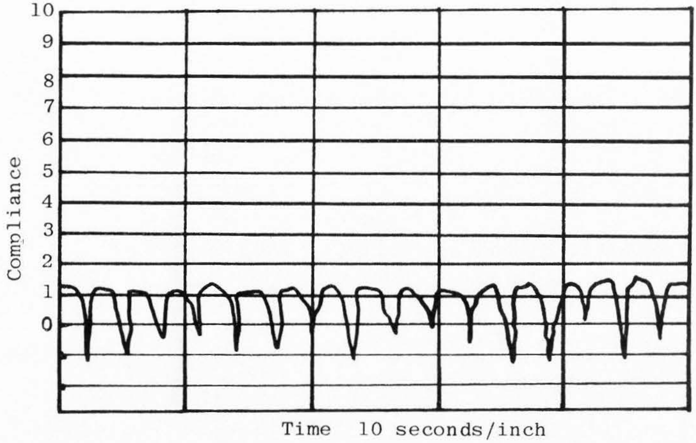


Figure 22. Tympanometric curve indicating a patulous Eustachian tube where compliance is in synchrony with respiration at 0 mm H_2O.

asking the patient to occlude one nostril with the mouth closed during forced inspiration and expiration (Bluestone, 1975).

Post-test evaluation (Pte) 19. The Type C tympanogram is extremely useful in confirming tubal incompetency. What statement is further descriptive of the Type C curve?

a. An abnormal tympanogram is one which has -50 mm H_2O pressure.

b. The middle ear pressure is indirectly provided through examination of the air pressure point of peak compliance on the Type C curve.

c. Negative pressures, although warning of serous otitis, do not cause hearing loss.

d. Fluid in the middle ear causes a sharpening of the compliance peak of the Type C curve.

e. Negative pressure in the middle ear signifies serous otitis and a nonfunctioning

A = Correct. The statement is as stated. Proceed to (EO) 11 where we will investigate Type D and Type E tympanograms.

K = Incorrect. As a matter of fact, there is no flattening. Review what Jerger (1975) has stated and make another selection.

Q = Incorrect, but not altogether wrong. It is wrong because negative pressure does not always signify these pathologies. Make another selection.

J = Incorrect. It has been demonstrated by Flisberg (1963). Review and make another selection.

T = Incorrect. There is no value which is diagnostic although 100 appears to be more consistent clinically.

Enabling objective (EO) 11

The reader will be able to identify relationship among different probe tone frequencies and pathologies in descriptions of the Type D and Type E tympanograms.

As previously stated the Madsen instrument can only be used to measure impedance at the single probe-tone frequency of 220 Hz. The otoadmittance meter measures admittance at 220 and 660 Hz. These facts are significant for it appears that the Type D or "W-shaped" tympanogram, as well as the Type E tympanogram, is critically dependent on probe-tone frequency.

Liden, Peterson, and Bjorkman (1970) showed that, in the same patient, the "W" shape was obvious at 800 Hz, present but attenuated at 625 Hz, and absent at 220 Hz. Liden Bjorkman, and Peterson's (1972) custom built unit contained an 800 Ha probe tone.

Liden, Harford, and Hallen (1974) found that the "Type D" tympanogram shown in Figure 23 is often found in persons with normal hearing or a pure sensorineural hearing loss but with a scarred, atrophic, or flaccid eardrum. It is not necessarily associated with a conductive ear pathology. In 182 subjects with normal hearing, Liden, Harford, and Hallen found fourteen or 18 percent to have a Type D tympanogram. A possible explanation for the "W" tympanographic configuration is offered by Harford (1975) and is only speculative at this time. Possibly these persons have a loosely coupled incudostapedial joint. Changes in the air pressure in the canal around barometric pressure may give rise to a partial decoupling of the ossicular chain. It is

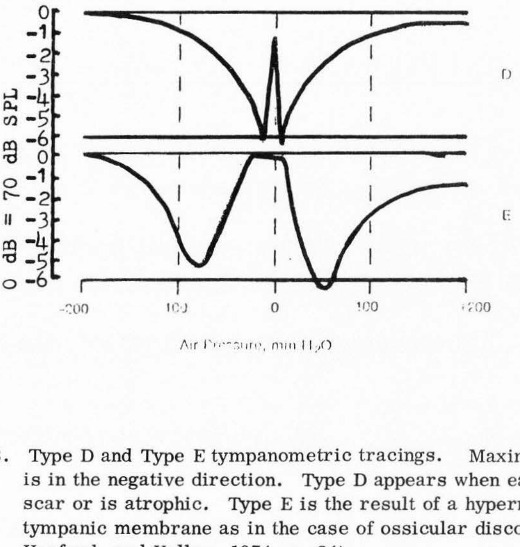


Figure 23. Type D and Type E tympanometric tracings. Maximum compliance is in the negative direction. Type D appears when eardrum has a scar or is atrophic. Type E is the result of a hypermobile tympanic membrane as in the case of ossicular discontinuity (Liden, Harford, and Hallen, 1974, p. 24).

also possible, as Harford states, that a small atrophic scar, even non-visible, on the eardrum may cause a "W" or Type D tympanogram.

At this point in time, a Type D tympanogram does not seem to have any significant diagnostic value. Harford (1975) states that the Type D tympanogram appears to be fairly common and not necessarily atypical in a normal population when employing a probe frequency of 800 Hz or one slightly lower or higher. To avoid obtaining a "W" tympanogram a lower probe frequency such as 220 Hz should be employed.

The Type E or undulating tympanogram (see Figure 23) appears to signify the presence of ossicular chain discontinuity. It appears when employing a higher probe tone frequency such as 625 or 800 Hz. When using a probe tone frequency of 220 Hz the typical A_d pattern emerges with a very high peak or an incomplete tracing.

Alberti and Jerger (1974) obtained tympanograms on a cross section of their clinical population using probe-tone frequencies of 220 Hz and 800 Hz. They obtained tympanograms for these 1,143 ears and found that in 85 percent of the cases, the probe-tone frequencies yielded the same pattern. In 15 percent of the total group there was a difference between the 220 and 800 Hz tympanograms. Alberti and Jerger conclude that the most significant determinant of the "W" pattern is some degree of tympanic membrane disease. They also state that the greater the degree of eardrum abnormality, the deeper and more complex the "W" pattern. They do not draw a clear distinction between the Type D and an undulating or Type E pattern.

Liden, Harford, and Hallen (1974) feel that the frequency of the probe tone has a major effect on the type of tympanographic recording obtained on cases of ossicular disruption. The 800 Hz probe tone is closer to the resonant frequency of the middle ear than is the 220 Hz probe tone, and apparently the lower 220 Hz tone is virtually unaffected by resonance of the cavity. In cases with discontinuity of the ossicular chain, changes in air pressure will exaggerate the changes in resistance and give rise to a tympanogram with undulations (Type E), especially pronounced on the negative side.

This discussion simply implies that the higher the probe frequency, the more sensitive tympanometry is as a tool for the detection of abnormalities of the middle ear. If one employs a higher probe frequency, then one would expect a greater percentage of false positive cases.

In summary, the Type D or "W" pattern offers no significant information concerning middle ear pathology, except for an indication of atrophic scars of the tympanic membrane. The Type E or undulating pattern is characteristic of ossicular discontinuity and may be helpful in the confirmation of this pathology when a 220 Hz probe offers a deep, but vague, Type A_d tympanogram.

Post-test evaluation (Pte) 20. What statement best describes the difference between the diagnostic significance of the Type D and Type E tympanograms?

a. The Type E pattern, for Liden, is the same as the "W" or Type D tympanogram.

b. The Type D pattern shows sharper compliance for the 800 Hz probe than for the 220 Hz probe.

c. The Type E pattern is characteristic of ossicular disruption while the Type D is representative of atrophic scars of the tympanic membrane.

d. Resonant frequency of the middle ear has little to do with different tympanographic patterns of Type D and Type E.

e. Different probe-tone frequencies have the same affect on the tympanographic shape of the Type E pattern.

A = Correct. This is the diagnostic significance. Proceed to acoustic reflex.

K = Incorrect. The patterns are not the same. Review Liden's work, then make another selection.

Q = Incorrect. They have different affects as you will see in review of the relationship of the Type E and Type A_d tympanograms. Make another selection.

J = Incorrect. As probe tones become closer to middle ear resonance, they appear to be more sensitive. Make another selection.

T = Incorrect. One cannot obtain a Type D pattern with the lower probe tone. See Liden (1970), then make another selection.

References

Alberti, P. W., and Jerger, J. F. 1974. Probe-tone frequency and the diagnositc value of tympanometry. Archives of otolaryngology 99:206-210.

Bluestone, C. D. 1975. Assessment of Eustacian tube function. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 6. American Electromedics Corporation, Dobbs Ferry, New York.

Bluestone, C. D., Paradise, J. L., and Beery, Q. 1972. Physiology of the Eustacian tube in the pathogenesis and management of middle ear effusions. Laryngoscope 84:247-255.

Brooks, D. N. 1968. An objective method detecting fluid in the middle ear. Journal of International Audiology 7:280-286.

Brooks, D. N. 1969. The use of the electro-acoustic impedance bridge in the assessment of middle ear function. Journal of International Audiology 8:563-569.

Dempsey, D. 1975. Static compliance. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 4. American Electromedics Corporation, Dobbs Ferry, New York.

Flisberg, K., Inglestect, S., and Ortegren, U. 1963. Controlled "ear aspiration" of air: A "physiological test of tubal function." Acta Otolaryngologica, Supplement No. 182.

Goodhill, V. 1958. Auditory response in relation to viscosity of tympanic fluids. Acta Otolaryngologica 49:38.

Harford, E. R. 1975. Tympanometry. In James Jerger (Ed.). Handbook of clinical impedance audiometry. American Electromedics Corporation, Dobbs Ferry, New York.

Jerger, J. 1975. Diagnostic use of impedance measures. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 7. American Electromedics Corporation, Dobbs Ferry, New York.

Jerger, J., Anthony, L., Jerger, S., and Mauldin, L. 1974. Studies in impedance audiometry: III. Middle ear disorders. Archives of Otolaryngology 99:164-171.

Jerger, J., Jerger, S. J., and Mauldin, L. 1972. Studies in impedance audiometry: I. Normal and sensorineural ears. Archives of Otolaryngology 96:513-523.

Liden, G., Bjorkman, G., and Peterson, J. L. 1972. Clinical equipment for measurement of the middle-ear muscle reflexes and tympanometry. Journal of Speech and Hearing Disorders 37:100-112.

Liden, G., Harford, E., and Hallen, O. 1974. Tympanometry for the diagnosis of ossicular disruption. Archives of Otolaryngology 99:23-29.

Liden, G., Peterson, J., and Bjorkman, G. 1970. Tympanometry. Archives of Otolaryngology 92:248-257.

McCandless, G. A., and Thomas, G. K. 1974. Impedance audiometry as a screening procedure for middle ear disease. Transactions of the American Academy of Opthalmology and Otolaryngology 78:2.

Martin, F. M., Butler, E. C., and Burn, P. 1973. A variation of the Type B tympanogram. Laryngoscopy 83(11):1783-1785

Rock, E. H. 1972. Electroacoustic impedance measurements in clinical otology. Impedance newsletter. American Electromedics Corporation. 1:Revised.

Additional Readings

Bluestone, C. D., Beery, Q. C., and Paradise, J. L. 1973. Audiometry and tympanometry in relation to middle ear effusions in children. Laryngoscope 83(4):594-604.

Harford, E. R. 1973. Tympanometry for Eustacian tube evaluation. Archives of Otolaryngology 97:17-20.

Holmquist, J. 1969. Eustachian tube function assessed with tympanometry: A new testing procedure in ears with intact tympanic membrane. Acta Otolaryngologia 68:501-508.

Terkildsen, K., and VanDishoech, H. 1970. Impedance measuring and tubal function. Reprinted with permission of the authors, courtesy of Madsen Electromedics Corporation.

ACOUSTIC REFLEX MEASUREMENTS

Introduction

There is a measurable change in the impedance/admittance characteristics of the normal ear as a result of the intra-aural reflex. This middle ear muscle reflex constitutes a physiological feedback system where a primary stimulus, whether auditory or non-auditory, initiates contraction of the stapedius and tensor tympani muscles. When speaking of the acoustically activated reflex, the stapedius muscle is the muscle which is implicated in the increase in impedance. The tensor tympani does contract to a sufficiently intense acoustic stimulus, but the contraction is delayed and the impedance change is largely due to the stapedial contraction.

The tensor tympani is inserted at the manubrium of the malleus and when this muscle contracts it pulls the malleus inward (Jepsen, 1963). This action results in an inward motion of the tympanic membrane. The stapedius is attached at the neck of the stapes and its contraction pulls this bone outward from the oval window and also in a direction which is at a right angle to the major vibrating plane of the ossicular chain (Dallos, 1973). When the muscles contract, they exert opposing forces which result in a stiffening of the ossicular chain. The stiffening in turn reduces the flow of energy to the cochlea and results in an increase in impedance in middle ear transmission.

The middle ear muscle reflex is activated by a variety of auditory and nonauditory stimuli. When the chain of events that culminates in the contraction of either or both muscles is initiated by an acoustic stimulus, the overall process is described as the "acoustic reflex" and the reflex is bilateral in nature.

In reference to nonacoustically activated middle ear muscle reflexes, Djupesland (1962) has shown that blowing air into one ear can cause bilateral stapedial contraction. By inspection through perforations in the tympanic membrane, Luscher (1929) observed that contractions of the stapedius muscles coincided with tactile stimulation in the auditory meatus. Klockhoff and Anderson (1959) and Klockhoff (1961) found that normal ears consistently exhibited a recordable stapedius response when cutaneous electrical stimulation was applied in the external canal. Reflex contractions of the tensor tympani muscle elicited by blowing toward the orbital region were observed by Klockhoff and Anderson (1960). Djupesland (1964, 1967) found that reflex contractions of the periorbital musculature brought about by sudden and powerful lifting of the eyelids were accompanied by simultaneous changes in impedance of the ear due to middle ear muscle contractions.

Although each of these investigators has successfully initiated middle ear muscle reflexes as a result of nonauditory stimulation, only a few techniques seem to be clinically practical as routine diagnostic procedures.

Due to the limitation of this paper, the acoustic reflex will be of primary concern, while the nonacoustically activated reflex will be discussed only in reference to additional diagnostic information.

As the reader will discover, the acoustic reflex is a stable phenomenon and offers significant information concerning the function of the auditory system and the physiologic role of the tympanic muscles.

Goal Four

The reader will be knowledgeable of the diagnostic significance of the acoustic reflex.

Enabling objective (EO) 12

The student will be able to identify the various way stations of the acoustic reflex arc and identify statements representative of the nature of the acoustic reflex.

The middle ear muscle reflex is a multipath physiological feedback mechanism as shown in Figure 24. The feedback process simply means that when sound initiates activity in the motor nuclei of the cranial nerves (VII and V) which innervate the stapedius and tensor muscles, the muscles contract and alter the middle ear transmission characteristics. The reduction of acoustic energy in turn changes the input to the motor nuclei.

When the stimulus is nonauditory but is rather tactile or somatic, there is no feedback involved. There is a straight forward path of action from the nonauditory centers of the brain stem to the motor nuclei of the middle ear muscles (Dallos, 1973). Thus, the nonauditory middle ear reflex influences middle ear transmission but is itself not directly influenced by the auditory input. Auditory input does not affect the nonacoustic middle ear reflex.

Reflex arc. An investigation of the reflex arc is essential to an understanding of impedance changes due to the acoustic reflex. A reflex arc is shown in Figures 25 and 26 and consists of an afferent (sensory) neuron, a synapse, and an efferent (motor) neuron. The acoustic middle ear muscle reflex exhibits such a pattern. The cochlear nerve constitutes the afferent part of the reflex arc. The first neurons in the auditory path are the bipolar cells of the spiral ganglion in the spiral canal of the modiolus and are, of

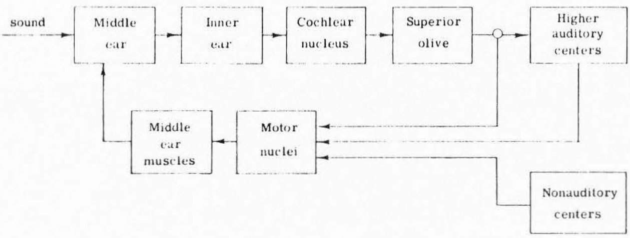


Figure 24. Simplified block diagram of the middle ear muscle reflex as a multipath feedback mechanism (Dallos, 1973, p. 473).

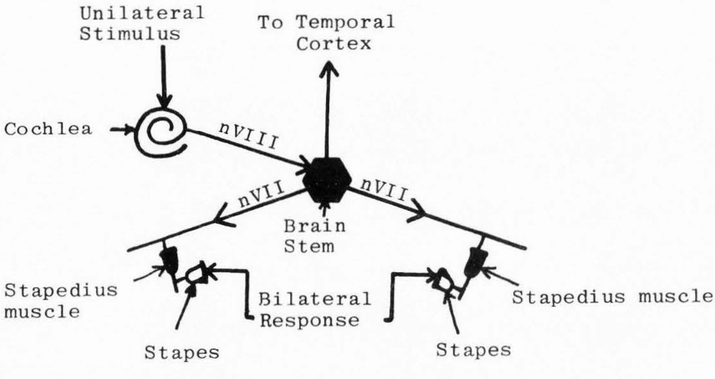


Figure 25. Unilateral acoustic stimulus with bilateral stapedial contraction.

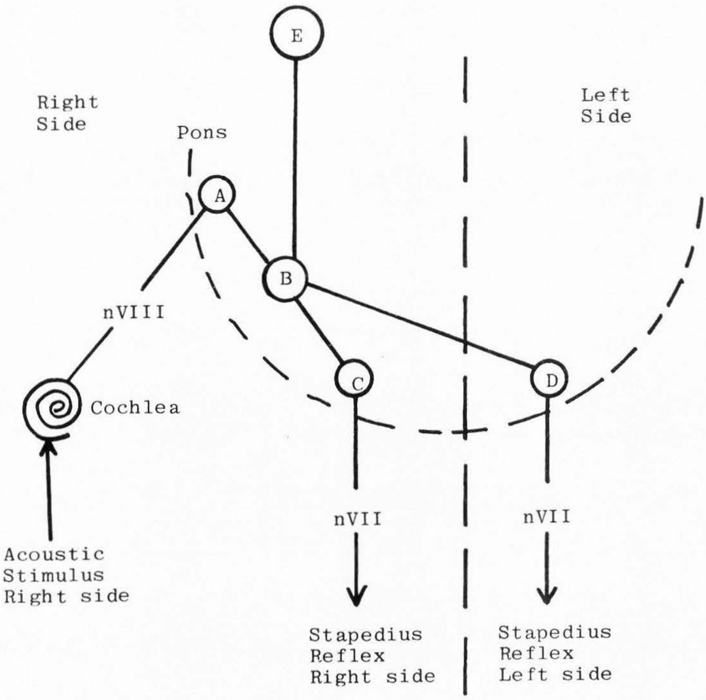


Figure 26. Unilateral acoustic stimulus with bilateral stapedial reflex. Where: a. dorsal and ventral cochlear nuclei; b. superior olivary nucleus; c. ipsilateral motor nucleus of facial nerve; d. contralateral motor nucleus of facial nerve; e. temporal lobe-higher auditory centers.

course, sensory and afferent. The central axons from the spiral ganglion of the VIII nerve neurons enter the brainstem together with the fibers from the vestibular nerve in the groove below the pons (Jepsen, 1963). Cochlear nerve fibers continue to the primary auditory centers, i.e., to the ventral and dorsal cochlear nuclei. All VIII nerve fibers synapse at the level of the dorsal and ventral cochlear nuclei and second order fibers from the ventral cochlear nucleus cross to the opposite side and help form a bundle of neurons called the trapezoid body. In the lateral part of the trapezoid body. In the lateral part of the trapezoid body and in the anterior part of the reticular formation lies the superior olivary complex. The superior olivary complex is considered to be the site of the reflex center (Rasmussen, 1946). The superior olivary complex is presumed to be connected with the nuclei of the trigeminal and facial nerves, which constitute the efferent portion of the middle ear reflex and which are motor to the tensor tympani and the stapedius muscles respectively.

As can be inferred from Figures 25 and 26, the acoustically elicited reflex is bilateral; that is, acoustic stimulation of either ear results in middle ear muscle contraction in both ears. This phenomenon has special significance in that greater precision in differential diagnosis is afforded by the elicitation of ispalateral and contralateral reflexes.

Post-test evaluation (Pte) 21. What statement is most representative of the nature of the acoustic reflex arc?

a. Sound is the only stimulus which activates the middle ear reflex.

b. The acoustic reflex is bilateral. That is, the superior olivary complex is connected to both ipsilateral and contralateral nuclei of the facial and trigeminal nerves.

c. The dorsal and ventral cochlear nuclei appear to be the reflex center and their connections to the motor nuclei provide the basis for the efferent portion of the acoustic reflex.

d. Since the acoustic reflex is a reflex phenomenon no message is sent higher than the brainstem for an incoming loud stimulus.

e. The nonauditory reflex is influenced by the auditory input.

A = Correct. The statement is correct as presented. Proceed to (EO) 13.

K = Incorrect. There is neural activity as high as the temporal lobe. Review Figures 25 and 26 and make another selection.

Q = Incorrect. There are a variety of nonauditory stimuli, which produce middle ear muscle reflexes. Review the second paragraph of this (EO).

J = Incorrect. There is no clear cut feedback involved in the nonauditory reflex. Review Figure 24 and make another selection.

T = Incorrect. It is the superior olivary complex which is the reflex center. Make another selection.

Enabling objective (EO) 13

The reader will be able to identify statements which describe the relationship between hearing threshold level and the acoustic reflex.

The threshold of the acoustic reflex is defined as the intensity in the stimulated ear which is just capable of inducing a reflex contraction of the stapedius muscle in the recorded ear as evidenced by a change in the impedance at the tympanic membrane.

The relationship between the hearing threshold level and the acoustic reflex threshold has special significance in differential diagnosis. The reader must understand the nature of the "normal" acoustic reflex before a determination can be made that a specific acoustic reflex threshold is pathological or abnormal. Since the recording of the reflex threshold does not require a behavioral response, the reflex procedure is an objective method of assessing the status of the conductive mechanism. In addition, reflex testing also provides information concerning the status of the cochlear and retrocochlear network in difficult to test patients.

It is known that pure tones of 65-105 dB above the threshold of hearing produce impedance changes in both ears of normal listeners (Metz, 1946; Jepsen, 1955; Klockhoff, 1961; Møller, 1961, 1962; Terkikdsen, 1960, 1962; Jerger, Jerger, and Mauldin, 1972).

In a series of ninety-one normal listeners of various ages, Jepsen (1963) showed that the sound intensity required to elicit stapedial reflexes declined systematically with increasing age. However, Jerger, Jerger, and Mauldin (1972) states, that although the acoustic reflex threshold is age related, the magnitude of the effect is not sufficient to cause serious difficulty.

In general, younger people show slightly higher acoustic reflex threshold intensities than older patients, but the rule that 95 percent of the normal reflexes will fall in the range between 70 and 100 dB HTL applies to the total population.

According to Jerger (1970) the mean reflex HL for normal listeners is 85 dB for all age groups. It is important to note that this figure applies only to recording of the reflex from the ear contralateral to the stimulated ear. The ipsilateral acoustic reflex (stimulate and record from the same ear) was found to be 2 to 14 dB better (Møller, 1961), i.e., less intensity is required to elicit the acoustic reflex where the acoustic reflex is measured on the ipsilateral side than when it is measured from the contralateral ear. This information is pertinent since the new instrumentation allows for ipsilateral reflex testing.

In a sample of forty-four subjects, Jepsen (1963) showed that the threshold of the stapedius muscle reflex is lowest for frequencies of 1000-2000 Hz and takes more intensity to elicit the acoustic reflex for lower and higher frequencies.

In a study conducted by Deutsch (1972), it was concluded that the stapedial reflex is approximately 20 dB better and significantly more stable when elicited by broadband noise rather than by pure tones.

When the acoustic reflex is used in conjunction with information related to critical bandwidth, interesting possibilities emerge. Several psychophysical methods have been used to measure the critical bandwidth. The critical bandwidth is basically derived from two assumptions (Licklider, 1951). First, the only important frequencies for making in a given noise are those frequencies which lie within a small band centering around the frequency of the pure tone being masked; Second, when a tone is just audible in a given noise, the total energy in this critical band of frequencies is equal to the energy of the tone.

The critical band has been variously defined and one definition states that the critical bandwidth is the bandwidth at which certain subjective responses such as loudness rather abruptly begin to change as the bandwidth of noise is increased or decreased, while the level per cycle remains constant (Feldtkeller, 1955; Zwicker and Feldtkeller, 1956; Zwicker, Flottorp, and Stevens, 1957; Zwicker, 1960).

Evidence (Zwicker, Flottrop, and Stevens, 1957) confirms that the principles involved in the critical bandwidth in loudness summation are consistent with the principles involved in critical bandwidth for other psychoacoustic measurement parameters such as threshold, masking, and phase relations.

The concept of the critical bandwidth becomes important when one uses the acoustic reflex in the prediction of degree and configuration of hearing loss in sensorineural pathology. Niemeyer and Sesterhenn (1974) demonstrated that sensorineural hearing loss reduces the difference between acoustic reflex thresholds for pure tones and the acoustic reflex for broadband noise. The basis for this phenomenon seems to be a change in the critical bandwidth for loudness summation in the ear with sensorineural hearing loss. An abnormal widening of these bands coupled with the loss in high frequency sensitivity characteristic of the sensorineural ear seems to produce a greater diminishing effect on the total loudness of a broadband noise than on the loudness of individual pure tones within the band (Jerger, 1975). The result is a reduction in the loudness advantage in a sensorineural ear. Specifically, as a consequence of the fact that the critical bands for loudness summation in sensorineural hearing loss are wider than in the normal case such that fewer bands are available to contribute to the loudness experience, and as a consequence of the decreased sensitivity for high frequencies which prevent full contribution to the loudness experience in the higher frequencies, loudness is decreased. Since the acoustic reflex is a "loudness" mediated phenomenon, an increase in physical intensity is necessary to achieve the required "loudness" for the acoustic reflex.

The information basic to this section covers four areas: (1) the acoustic reflex is a bilateral phenomenon but the ipsilateral ear seems to be more sensitive than the contralateral ear to the same acoustic stimulus; (2) the acoustic reflex threshold declines systematically with age, but the normal range for all ages is between 70-100 dB HTL; (3) the acoustic reflex threshold is elicited at a lower intensity at 1000-2000 Hz while more intensity is required to elicit the acoustic reflex at lower and higher frequencies; and (4) the critical bandwidth for loudness summation seems to change in the ear with sensorineural loss.

Post-test evaluation (Pte) 22. What statement best represents the relationship between hearing threshold level and acoustic reflex?

a. The acoustic reflex threshold shows no change with age. It is a stable phenomenon.

b. The acoustic reflex threshold occurs at the same intensity for both contralateral and ispilateral ears.

c. The acoustic reflex threshold appears to be equivalent for pure tones and broadband noise stimuli.

d. There is a change in the critical bandwidth for loudness summation in the ear with sensorineural hearing loss.

e. The frequencies of 1000-2000 Hz require more intensity for the elicitation of the acoustic reflex.

A = Correct. You have identified the correct statement. Proceed to (EO) 14.

K = Incorrect. They require less. Review Jepsen (1963) then make another selection.

Q = Incorrect. It appears to be different. Review (Møller, 1961) and then make another selection.

J = Incorrect. There is a difference. Review (Jerger, 1975) and then make another selection.

T = Incorrect. It decreases systematically with increasing age. Make another selection.

Enabling objective (EO) 14

The reader will be able to identify statements which describe relationships between acoustic reflex and conductive loss.

The acoustic reflex seems to be much more sensitive to the presence of conductive loss than either static compliance measures of tympanometry. Jerger et al. (1974a), have found that the acoustic reflex is made significantly poorer by even the slightest degree of conductive loss. Because of this factor, it is usually safe to conclude that there is no conductive loss in either ear if reflex threshold levels are normal in both ears. Negative pressure in the middle ear where a very mild conductive loss may occur seems to constitute the only exception to this rule.

It should be stated now, however, that although normal reflex levels usually argue against a conductive loss, abnormal reflex findings do not necessarily always indicate the presence of conductive loss (Jerger, 1975). The reflex abnormalities can be symptoms of other cochlear or retrocochlear disorders.

When investigating specific conductive pathologies as they relate to the acoustic reflex, it is evident that the early disappearance of the acoustic reflex is the primary relationship between the two.

In the case of a unilateral conductive impairment, when the air conduction threshold is greater than 35 dB, one can not expect to obtain a reflex when testing either ear (Sheehy and Hughes, 1974). The reflex cannot be detected when the probe tip is in the conductively impaired ear and the stimulus is introduced to the normal ear because the conductive pathology (stapes fixation, ossicular discontinuity, serous otitis media, etc.) obscures the reflex if it, in fact, occurs. When the probe is placed in the normal ear and the stimulus is introduced to the impaired ear, an acoustic reflex cannot be obtained because of the elevated threshold in the test ear and the consequent inability to reach a sufficient intensity to elicit the stapedial reflex.

Otosclerosis. Sometimes in the very early stages of stapes fixation, the acoustic reflex may be elicited at relatively normal hearing levels (Jerger, 1975). These reflexes, however, are characterized by a negative deflection (decrease in impedance) at both the onset and offset of the eliciting signal (Djupesland, 1963, 1969; Terkildsen, Osterhammel, and Bretlau, 1973). Negative deflections at the onset of the eliciting signal are not abnormal, but negative deflections at the end of the eliciting signal are definitely abnormal (Jerger, 1975). Terkildsen, Osterhammel, and Bretlau (1973) state that in normal ears, the footplate is fastened at its anterior edge by looser ligaments than at its posterior end, such that movements will be rotational about a vertical axis at the posterior edge. In the presence of typical otosclerosis with an anterior locus, this situation is likely reversed. The posterior end becomes relatively more mobile and movements are hinged anteriorly. It appears that such a shift in the mode of stapes movement is a plausible explanation of the reflex pattern when the phenomenon is recorded as a change in eardrum impedance. Terkildsen, Osterhammel, and Bretlau (1973) state that such a mechanism would also provide a natural explanation for the negative reflex very early in the disease process and the gradual disappearance of the reflex as the fixation of the stapes becomes more pronounced.

Figure 27 is a comparison of the time course of a typical "normal" reflex and a typical "otosclerotic" reflex. Both show a negative deflection at the onset of the eliciting signal, but only the otosclerotic reflex shows a negative deflection at the terminus of the signal.

It should be noted that it is not otosclerosis per se that produces the abnormal temporal pattern, but rather ossicular fixation which may occur in other disorders which produce ossicular fixation. At this particular time there

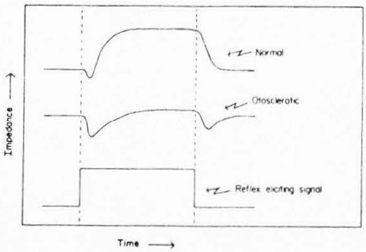


Figure 27. Time course of a typical normal and a typical otosclerotic reflex (Jerger, 1975, p. 154).

still is no satisfactory explanation of the on-off pattern characteristic of the otosclerotic reflex.

Ossicular discontinuity. In the presence of ossicular discontinuity, the acoustic reflex is usually absent. However, the reflex may be elicited when sound is presented to the opposite and normal ear when there is a functional connection between the stapedius tendon and that portion of the ossicular chain that is still attached to the tympanic membrane. Jerger (1975) sites an example of this phenomenon. When only the anterior crus of the stapes is fractured, there may be a significant air-bone gap, but the contraction of the stapedius muscle can alter the impedance of the chain still connected to the tympanic membrane.

Otitis media. The acoustic reflex usually disappears at a very early stage of otitis media due to the gross increase in impedance. It is often possible to elicit a reflex in the very early stage of the disease exemplified by a Type C tympanogram if one matches exactly the negative middle ear pressure. When the tympanogram is Type B, the acoustic reflex is virtually always absent.

If a middle ear disease creates an increase in impedance in the ossicular chain, there will be an elevation of the acoustic reflex threshold. If a tumor occupies the middle ear space such that tympanometry yields a Type B tympanogram, the acoustic reflex will be absent due to the gross increase in impedance. If, on the other hand, a small tumor creates minor effects such that a normal Type A tympanogram is obtained then the acoustic reflex threshold will usually simply be elevated.

In conclusion, if there is a change in middle ear impedance, there will be a change in the acoustic reflex threshold. In the presence of conductive loss, the change in impedance usually obliterates the acoustic reflex altogether.

Post-test evaluation (Pte) 23. What statement is most representative of the relationship between acoustic reflex and conductive loss?

a. Whenever ossicular discontinuity is present, the acoustic reflex is absent.

b. It is still possible to elicit the acoustic reflex in the very early stage of otitis media exemplified by the Type B tympanogram.

c. Abnormal reflex thresholds are a necessary indicator of conductive loss.

e. Negative middle ear pressure will not prevent the acoustic reflex.

A = Correct. This statement is true for this pathology. Proceed to (EO) 15, where loudness recruitment and the acoustic reflex will be investigated.

K = Incorrect. It can do so, especially with a significantly retracted tympanic membrane. Make another selection.

Q = Incorrect, but not all together wrong. It may also be the result of cochlear, retrocochlear, or facial nerve dysfunction.

J = Incorrect. This is not always the case. Review the section which covers this pathology and then make another selection.

T = Incorrect, but only for the reason of the tympanogram type. This answer is actually related to tympanometry. Make another selection.

Enabling objective (EO) 15

The reader will be able to identify statements characteristic of the relationship between loudness recruitment and acoustic reflex.

Evidence for recruitment is obtained when it can be shown that the loudness of a given tone increases more rapidly than normal as the sensation level (SL) of the tone is increased. It has been shown that the acoustic reflex is loudness governed (Metz, 1946; Ross, 1968; Flottrop, Djupesland, and Winther, 1971) and, therefore, provides an objective method of measuring loudness recruitment. If, in a patient with hearing impairment, an acoustic stimulus less than 60-70 dB above the threshold of hearing elicits an acoustic reflex, it must with great probability signify the presence of recruitment.

As Jerger (1975) states, the arguments against the acoustic reflex being a measure of recruitment on the basis of the fact that it does not always agree with results from the ABLB (Fowler) test are largely irrelevant to the clinical task of differentiating cochlear from eighth nerve site. For this purpose, one needs only to consider the clinical observation that the acoustic reflex is characteristically present in ears with cochlear disorder for a limited degree of hearing loss, and either elevated or absent in ears with eighth nerve disorder.

In the ear with cochlear disorder, the reflex SL for pure tones in the 500-4000 Hz region declines in exact proportion to the degree of hearing loss (Jerger, Jerger, and Mauldin, 1972). Data are based on the reflex thresholds from a sample of 515 patients with varying degrees of cochlear hearing loss.

When the pure tone air conduction threshold was 0 dB, the average reflex SL was 85 dB. At 40 dB hearing loss, however, the average reflex SL was only 45 dB. Jerger, Jerger, and Mauldin (1972) continue to state that the function decelerates and levels off at an average limiting SL of 25 dB. This, in turn, sets an upper limit on the degree of cochlear loss that will still show a reflex. If the upper limit of the audiometer is 110 dB, then the maximum cochlear loss still showing a reflex will be, on the average, 85 dB (110 minus 25).

Absence of the acoustic reflex should always raise the suspicion of eighth nerve disorder, since a patient with a cochlear loss not exceeding 85-100 dB, ought to show a reflex when a sufficiently intense sound is introduced to that ear (Jerger, 1975).

In summary, it can be stated the loudness level required to elicit the acoustic reflex will be reached at a mUch lower than normal sensation level in cochlear pathology. The use of the acoustic reflex test as a measure of recruitment has a definite advantage in that it can be used in binaural hearing loss where the ABLB cannot be utilized. Furthermore, the acoustic reflex technique is purely objective and only requires normal middle ear function.

Post-test evaluation (Pte) 24. What statement is most representative of how loudness recruitment is related to the acoustic reflex?

a. If, in a patient with hearing impairment, the acoustic stimulus is not 85-100 dB above 0 dB HL, it likely signifies the presence of recruitment.

b. The loudness level required to elicit the acoustic reflex will be reached at a much higher level for the recruiting ear.

c. The determination of recruitment through acoustic reflex measures has the disadvantage of being only a unilateral test for recruitment.

d. The acoustic reflex is characteristically absent in ears with cochlear loss.

e. The reflex SL for pure tones 500-4000 Hz declines in exact proportion to the degree of cochlear hearing loss.

A = Correct. The statement is as described. Proceed to (EO) 16 where we will investigate (SPAR) measures.

K = Incorrect, and yet partially correct. It is usually defined as 60-70 dB and a reflex SL of 80 dB for example, would not indicate recruitment. Make another selection.

Q = Incorrect. Review the last paragraph of this section and make another selection.

J = Incorrect. The opposite of this statement is true. Review the first paragraph of this section and make another selection.

T = Incorrect. The opposite of this statement is true. Review Jerger (1975) and make another selection.

Enabling objective (EO) 16

The reader will be able to identify concepts of critical bandwidth in the associated technique for predicting sensitivity from acoustic reflex measures (SPAR).

When reconsidering the concept of "loudness summation" briefly discussed in enabling objective 13, it is evident that the acoustic reflex is dependent upon the status of the cochlea and the neural activity at the superior olivary complex since "loudness summation" is dependent upon the neural integrity up to and including the brain stem. The effect of loudness summation on the acoustic reflex can be seen directly in acoustic reflex measurements for pure tones and for broadband noise. The acoustic reflex threshold for broadband noise is typically obtained at a significantly lower overall intensity than is the case for pure tones. The measurement of the acoustic reflex threshold by observation of stimulation for pure tones and broadband noise in impedance changes should indirectly demonstrate the existence of critical bandwidth in loudness summation.

The clinical application of the phenomenon is seen in sensitivity predictions from acoustic reflex measures. Niemeyer and Sesterhenn (1974) developed a technique for the prediction of degree of hearing loss by demonstrating that sensorineural hearing loss systematically reduces the difference between acoustic reflex thresholds for pure tones and for broadband noise. As stated previously, there seems to be an increase in the width of the critical band for loudness summation in the ear with sensorineural hearing loss due to cochlear pathology.

In the normal ear, the acoustic reflex is elicited when any signal exceeds a critical loudness. By definition, the critical "loudness" for pure tones and broadband noise is equal for all ears at the acoustic reflex. The summation of loudness for each of several critical bands accounts for the fact that the critical loudness for broadness noise is reached at a lower physical intensity than is the case for a pure tone. Stated differently, since the pure tone is confined in a single critical band and the broadband noise derives loudness from "X" critical bands, it takes less noise intensity than tone intensity to produce a reflex-eliciting signal (Jerger, 1975).

In the case of sensorineural hearing loss, because of the widening of each critical band, the number of critical bands available for loudness summation is reduced. In addition the sloping frequency responses so characteristic of the sensorineural ear attenuates the relative loudness contributions of the critical bands in the high frequency region (Jerger, 1975). The result is a noise-tone reflex threshold difference that is much smaller than the normal difference.

The test for predicting hearing sensitivity from acoustic reflex thresholds for pure tones and broadband noise has been designated the "differential loudness summation test." It is based on two phenomena: (1) in the normal ear, the sound intensity required to elicit the acoustic reflex is about 25 dB less for broadband white noise than for pure tones within the band; (2) sensorineural hearing loss has the effect of reducing the difference. By comparing the patient's noise-tone difference with the normal-tone difference, one may predict the approximate degree of sensorineural hearing loss.

Jerger et al. (1974b), placed sensitivity predictions of 1,156 patients in four categories: grossly normal; mild to moderate loss; severe loss; and profound loss. The basis for prediction was a combination of: (1) differences between reflex thresholds for pure tones and white noise; and (2) the absolute SPL of the reflex threshold for noise.

The slope of loss was predicted from the difference between reflex thresholds for low-pass filtered and a high-pass filtered noise (filter cut-off at 2,600 Hz).

Table 8 shows the criteria for SPAR prediction of sensitivity loss. Jerger et al. (1974b) found their predictions were excellent in 60 percent of the ears tested, errors were moderate in 36 percent of ear, and serious in only 4 percent.

TABLE 8.--Criteria for SPAR prediction of sensitivity loss (Jerger et al., 1974b)

D	If	BBN SPL	Prediction
20 or larger		anywhere	normal
15-19		80 dB or less	normal
15-19		81 dB or more	mild-moderate
10-14		anywhere	mild-moderate
less than 10		89 dB or less	mild-moderate
less than 10		90 dB or more	severe
	reflexes not observed		

The clinical value of the SPAR technique can not be over-estimated where behavioral responses are unobtainable in the difficult to test patient and in infants.

Post-test evaluation (Pte) 25. How is critical band related to the technique for predicting sensitivity from acoustic reflex measures (SPAR)?

a. For the sensorineural ear there is a noise-tone reflex threshold difference that is much larger than the normal difference.

b. Although it is possible to predict sensitivity using SPAR procedures, it is not possible to predict the slope of the loss.

c. In the case of sensorineural hearing loss, because the narrowing of each critical band, the number for loudness summation is increased.

d. There is no actual change in the critical bandwidth for loudness summation in the ear with sensorineural hearing loss.

e. Sensorineural hearing loss systematically reduces the differences between acoustic reflex thresholds for pure tones and broadband noise.

A = Correct. It is obvious you understand the relationship. Proceed to (EO) 17 for a discussion of acoustic reflex delay.

K = Incorrect. Review Niemeyer and Sesterhenn (1974) and make another selection.

Q = Incorrect. There is a decrease. Review Niemeyer and Sesterhenn (1974), and then make another selection.

J = Incorrect. It appears that there is. Review the second paragraph of this section and make another selection.

T = Incorrect. One can do this. Review (Jerger, 1975) then make another selection.

Enabling objective (EO) 17

The reader will isolate statements which describe the relationship between reflex decay and retrocochlear lesions.

In 1969, Anderson, Barr and Wedenberg, added a clinical dimension to the Metz test or acoustic reflex test by measuring decay of the acoustic reflex amplitude when the sound stimulation was sustained for some time.

Anderson, Barr, and Wedenberg (1969), reported that decay of the acoustic reflex was not observed for normal ears in response to 500 and 1000 Hz stimulation, but was observed for 2000 and 4000 Hz stimulus frequencies. In addition, they reported that in seventeen cases of confirmed intracranial tumors that affected the eighth nerve, acoustic reflexes could not be elicited from seven of the cases with intense stimulation of the impaired ear. Acoustic reflexes were elicited from the other ten subjects but when the 500 or 1000 Hz stimulus was raised 10 dB above the acoustic reflex threshold and sustained for some time, the magnitude of the observed reflex response amplitude diminished to less than half of its original amplitude in less than 10 seconds.

Jerger and Jerger (1974) in a study of twenty-six of thirty patients who had retrocochlear lesions found absences of either the acoustic reflex or reflex decay, or both. Only four patients in the sample revealed reflex decay. Acoustic reflex findings in acoustic tumors will ultimately relate closely to the stage of which the tumor is detected.

In a study by Sanders, Josey, and Glasscock (1974) it was reported that the acoustic stapedial reflex decay test was used with six neural ears. Reflex decay suggested abnormal adaptation for two eighth nerve tumors in which the abnormality was not disclosed by tone decay or Bekesy audiometry.

Reflex decay is common in many normal ears at 2000 and especially at 4000 Hz (Jerger, 1975). Because of this fact, the presence of reflex decay in this frequency region has significance. At 500 and 1000 Hz, however, such decay is very rare in normal ears and its appearance at either of these frequencies is a strong indicator of eighth nerve lesion.

Olsen, Noffsinger, and Kurdziel (1975), report data which indicates that approximately 20 percent of ears having cochlear lesion due to noise trauma and Meniere's disease may also fail to yield an acoustic reflex and show reflex decay that is suggestive of retrocochlear involvement.

Jerger and Jerger (1974) recently cautioned that the reflex decay phenomenon, like the threshold tone decay test, may produce a high number of false positives (i.e., reflex decay in a significant proportion of patients without eighth nerve disorders).

The technique for measuring reflex decay is described by Anderson (1969). One sustains a 500 or 1000 Hz test signal for 10 seconds at a reflex SL of 10 dB (i.e., 10 dB above acoustic reflex threshold). If the amplitude of the reflex declines to less than one-half of its initial value within the 10 second test period, abnormal reflex decay is present. Some kind of graphic write-out system to record reflex as a function of time is essential in order to carry out reflex decay testing.

Post-test evaluation (Pte) 26. What statement shows best the relationship between acoustic reflex decay and retrocochlear lesions?

a. The reflex decay test is administered at the level of the initial reflex response to the acoustic stimulus or, in other words at a sensation level re the acoustic reflex threshold of 0 dB.

b. The normal ear does not typically show reflex decay at 500 and 1000 Hz, but reflex decay is observed in normal ears at 2000 and 4000 Hz.

c. If the reflex decay is total, it is of no particular significance in the diagnosis of retrocochlear lesions.

d. The normal ear shows pronounced decay at 5000 and 1000 Hz.

e. The major advantage of the acoustic reflex decay phenomenon is that there are literally no false positives.

A = Correct. This is important to know and remember. Proceed to (EO) 18 for a discussion of "elevated" reflex thresholds.

K = Incorrect. It is. Review Sanders, Josey, and Glasscock (1974) then make another selection.

Q = Incorrect. There are. Review Jerger and Jerger (1974c) and make another selection.

J = Incorrect. This would indicate retrocochlear lesion. Review Anderson (1969) and make another selection.

T = Incorrect. At 10 dB above the reflex threshold. Make another selection.

Enabling objective (EO) 18

The reader will be able to identify statements describing the phenomenon of "elevated" acoustic reflex and retrocochlear lesions in relation to normal and cochlear ears.

Elevated reflex threshold in eighth nerve disorders refer to the elevation of the reflex threshold above the levels observed in relation to normal and cochlear ears. In terms of reflex SL, the acoustic reflex threshold is the same as observed in a normal ear, but increasing hearing loss will eventually drive the reflex threshold HL beyond the upper limit of the audiometer (Jerger, 1975). Jerger et al. (1974c) states that presence of the acoustic reflex is the exception rather than the rule in VIIIn lesion, since a hearing loss of greater than 25 dB would preclude measuring a reflex when using an audiometer with a 110 dB HL limit as the stimulus source. Unless the pure tone A/C hearing loss is very slight, the acoustic reflex usually can not be elicited in eighth nerve disorders. When it does appear, it may or may not show abnormal reflex decay (Jerger et al., 1974c). If reflex decay does occur at 500 or 1000 Hz, however, the audiologist should suspect VIII nerve lesion.

In Table 9, Jerger (1975) presents hypothetical reflex data illustrating the presence of a normal reflex threshold level (re 0 dB HL) and a reduced reflex SL in an ear with cochlear disorder and an "elevated" reflex threshold level in an ear with eighth nerve disorder. Note that the reflex SL is the same in the ear with VIIIn disorder as it is in the normal ear.

TABLE 9.--Hypothetical reflex data illustrating concept of normal reflex threshold (abnormally small reflex SL) in cochlear disorder and "elevated" reflex threshold (normal reflex SL) in eighth nerve disorder (Jerger, 1975)

	Type of Ear		
	Normal	Cochlear	Eighth Nerve
Threshold HL	0	30	30
Reflex HL	85	85	115
Reflex SL	85	55	85

Post-test evaluation (Pte) 27. What statement best describes the diagnostic significance of "elevated" reflex?

a. In terms of HL, the threshold is quite normal for retrocochlear pathology.

b. Unless the audiometric loss is very slight, the acoustic reflex is usually not elicited in cochlear disorders.

c. When the "elevated" reflex is present, it is always accompanied by reflex decay.

d. Elevated reflex thresholds in eighth nerve disorders refers to the dB reduction between 0 dB HL and the acoustic reflex threshold.

e. Elevated reflex thresholds in eighth nerve disorders refers to the elevation of the reflex HL in relation to normal and cochlear ears.

A = Correct. This is the best description. Proceed to (EO) 19 for a discussion of ipsilateral and contralateral reflexes.

K = Incorrect. Review the first paragraph of this (EO) then make another selection.

Q = Incorrect. It is elevated. Make another selection.

J = Incorrect. This is more true for retrocochlear disorders. Review Jerger et al. (1974c) and make another selection.

T = Incorrect. Review paragraph one of this (EO) and then make another selection.

Enabling objective (EO) 19

The reader will be able to isolate diagnostic differences in ipsilateral and contralateral reflexes.

In measuring the ipsilateral acoustic reflex the stimulus is presented to an ear and the response is monitored in the same ear. As noted earlier, when doing contralateral acoustic reflex testing, the acoustic stimulus is presented to one ear and the probe tip is placed in the opposite ear for purposes of monitoring the response.

Greisen and Rasmussen (1970) found that in cases of brain stem lesion, ipsilateral stimulation excites acoustic reflex activity, but that stimuli presented contralaterally fail to elicit the reflex. Thus, a lesion which cuts the reflex arc between the cochlear nuclei on one side and the facial nucleus of the other is detectable on the basis of comparison of reflex data obtained ispilaterally and contralaterally. For illustration of the reflex arc, return to (EO) 12.

It is evident that greater diagnostic precision exists with the possibility of recording both ipsilateral and contralateral reflexes. Instrumentation is now available which permits recording of both ipsilateral and contralateral reflexes.

Figure 28 is a schematic showing expected contralateral and ipsilateral reflex findings in a patient with normal sensitivity in both ears, but a central auditory disorder at the level of the brain stem. As can be seen, reflexes are characteristically present with ipsilateral stimulation. Figure 29 shows the probable location of the lesion.

Post-test evaluation (Pte) 28. What statement is most representative of the diagnostic significance of ispilateral and contralateral reflexes?

a. The acoustic reflex is bilateral, and a patient with a brain stem lesion will routinely show contralateral reflexes.

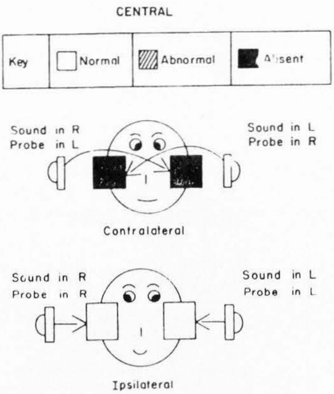


Figure 28. Contralateral and ipsilateral reflexes for a patient with normal sensitivity in both ears, but a central auditory disorder at the level of the brainstem (Jerger, 1975, p. 166).

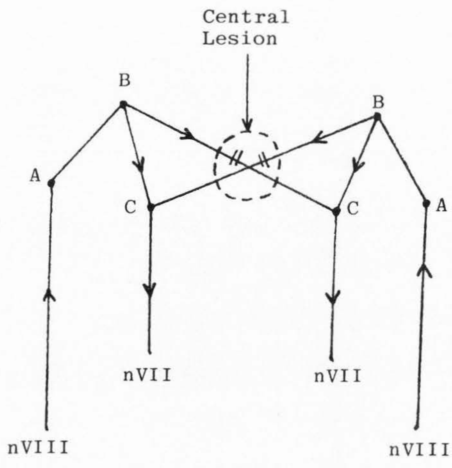


Figure 29. The probable location of the central lesion, where A represents the dorsal and ventral cochlear nuclei, B is the superior olivary complex, and C represents the motor nuclei of the VII or facial nerve.

b. The acoustic reflex is bilateral, but a brain stem lesion may prohibit the contralateral reflex while the ipsilateral reflex arc remains intact.

c. What the ipsilateral reflex is present and the contralateral reflex is not absent a central disorder is indicated.

d. Instrumentation is not yet available to record both ipsilateral and contralateral reflexes.

e. If the facial nerve of the ipsilateral ear is damaged, one will be unable to elicit contralateral reflexes.

A = Correct. Proceed to (EO) 20 for a discussion of p sychogenic deafness and malingering.

K = Incorrect. It is. Make another selection.

Q = Incorrect. Return to Figure 26 and eliminate one of the nVII lines and observe whether or not a contralateral arc still exists. Make another selection.

J = Incorrect. An absent reflex could signify conductive cochlear retrocochlear loss.

T = Incorrect. They will characteristically be absent. Review Greisen and Rasmussen (1970).

Enabling objective (EO) 20

The reader will know and identify the implication of acoustic reflex testing in psychogenic deafness and malingering.

Employment of the acoustic reflex has been used and described by Jepsen (1953, 1963), Terkildsen (1964), and Lamb, Peterson, and Hansen (1968) in the determination of the presence and magnitude of nonorganic hearing impairment.

If pure tone or speech thresholds cannot be obtained at maximum equipment limits in a given patient, hearing is usually considered as being non-existent for practical purposes in the ear(s) concerned. If, upon further investigation, it is found that acoustic reflex thresholds can be obtained from the ear(s), the audiologist can use this information as positive proof that the ear is in fact capable of hearing (Thomsen, 1955). As mentioned earlier, the acoustic reflex is "loudness" mediated. If a pure tone air conduction threshold is, in fact, not present at maximum equipment limits, it will be impossible to obtain an acoustic reflex threshold. If, on the other hand, an acoustic reflex is obtained, the audiologist can be certain that the stimulus was heard and that the "loudness" experience was sufficiently great to elicit the acoustic reflex.

In cases where hearing is not completely lost but merely impaired, a psychogenic factor cannot be determined unless the acoustic reflex threshold is better than the admitted behavioral pure tone threshold. It is possible that recruitment may play a significant role in sensorineural loss such that acoustic reflex thresholds are obtained at "normal" levels.

It is important to note that the acoustic reflex can be used diagnostically in cases of psychogenic deafness to confirm or contradict findings from other audiometric tests. Since the reflex arc does not extend beyond the pons, the presence of an acoustic reflex does not require the patient's behavioral response. The acoustic reflex test is an objective test for detection of non-organic hearing loss.

Post-test evaluation (Pte) 29. What statement best reveals the diagnostic usefulness of the acoustic reflex in nonorganic hearing loss?

a. If the acoustic reflex is absent, then the patient indeed has a total hearing loss.

b. An ear showing normal reflex thresholds is an ear with normal hearing.

c. If an acoustic reflex is present, it is proof that the ear is capable of hearing.

d. The acoustic reflex is not truly objective, since one can inhibit the reflex by conscious effort.

e. One can determine the existence of the acoustic reflex but the magnitude of the hearing threshold cannot be estimated with any degree of accuracy or reliability.

A = Correct. This statement confirms the objectivity of the measure. Proceed to (EO) 21 for a discussion of the acoustic reflex in relation to facial nerve dysfunction.

K = Incorrect. What about the absence due to conductive factors? Make another selection.

Q = Incorrect. This can be estimated through knowledge of normal reflex SL. Make another selection.

J = Incorrect. Remember that the arc does not extendbeyond the pons. Review this (EO) and make another selection.

T = Incorrect. What about recruitment? Review this (EO) and make another selection.

Enabling objective (EO) 21

The reader will be able to identify statements which are characteristic of the diagnostic significance of the acoustic reflex in facial nerve site of lesion testing.

Before proceeding with enabling objective 21, the reader should study Figure 30 which is a schematic illustration of the facial nerve and its branches.

The particular point of involvement along the facial nerve in facial palsy can be determined by three tests. First, electrogustometry can be used in assessment of taste function. Specifically, if taste is absent or impaired, the lesion involves or is proximal to the chorda tympani. Second, Schirmer's test can be used in measuring lachrimation. Litmus paper is placed under the lower eye lid. If the facial nerve lesion involves or is proximal to the greater superficial petrosal nerve, or involves the geniculate ganglion, tear volume will be reduced. Application of the acoustic reflex test in the typical diagnosis of site of lesion along the facial nerve will be considered in more detail presently. The third test is the acoustic reflex test as described earlier.

At this point in time the student should be well aware that the stapedius muscle contracts reflexively in response to loud sound and that the reflex is bilateral. Also, when the stapedius muscle contracts, it alters the impedance of the middle ear.

To administer the test, the probe tip of the impedance bridge is sealed in the external auditory meatus of the ear under test; then sound is presented to the opposite ear at an intensity sufficient to elicit reflex contractions of both stapedial muscles. If the facial nerve is intact proximal to the stapedius branch, the muscles will contract, the ossicular chain will stiffen and the result will be a simultaneous increase in impedance. In this case, the

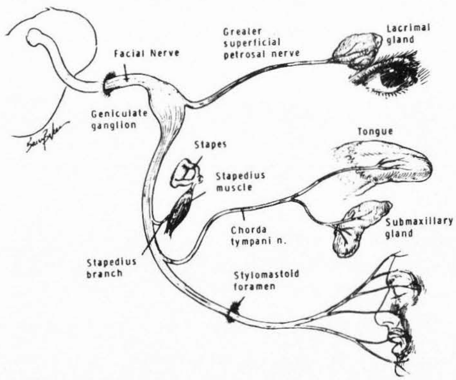


Figure 30. Schematic anatomical illustration of the facial nerve and its branches (Alford et al., 1973, p. 215).

lesion must be distal to the stapedial branch of the facial nerve. On the other hand, if innervation to the stapedius muscle of the ear under test is interrupted because of facial nerve disorder proximal or central to the stapedial branch, the muscle will not contract and no change in impedance will be detected (Alford et al., 1973).

Table 10 shows the typical results of stapedial reflex testing in a patient with left facial paralysis. No reflex is present in the left ear as a consequence of the facial nerve lesion.

TABLE 10.--Results of stapedius reflex measurements in a patient with left facial paralysis (Alford et al., 1973, p. 334)

Ear under test	Sound in	Probe in	Stapedius reflex observed
Right	Left	Right	Yes
Left	Right	Left	No

It is important to emphasize that the presence of some kinds of hearing loss in either ear may invalidate the interpretation of facial nerve lesion function. Specifically, the acoustic reflex test cannot be used in testing for facial nerve function in the presence of a conductive loss in the test ear or a severe hearing loss in the non-test ear.

Post-test evaluation (Pte) 30. What statement is characteristics of the stapedius reflex in facial nerve site of lesion testing?

a. The test ear is the ear contralateral to the facial paralysis.

b. If the facial nerve is intact proximal to the stapedius branch, the muscle will contract.

c. If the facial nerve disorder is proximal to the chorda tympani, the stapedius muscle will contract.

d. If the facial nerve disorder is distal to the stylomastoid foramen, the stapedial reflex will be affected.

e. If lachrymation is reduced, there will probably be no effect on the stapedius reflex.

A = Correct. You have handled this technical question well. This is the last enabling objective, but proceed to the last chapter for some concluding remarks.

K = Incorrect. Review Figure 30 and make another selection.

Q = Incorrect. Reread the third paragraph of this (EO) and make another selection.

J = Incorrect. Review Figure 30 and make another selection.

T = Incorrect. Review Figure 30 and Alford et al. (1973), then make another selection.

References

Anderson, H., Barr, B., and Wedenberg, E. 1969. Intra-aural reflexes in retrocochlear lesions, pp. 49-55. In C. A. Hamberger and J. Wersail (Eds.). Disorders of the skull base region. Nobel Symposium 10. Stockholm. Almquist and Wiksel.

Alford, B. R., Jerger, J. F., Coats, A. C. Peterson, C. R., and Weber, S. C. 1973. Neurophysiology of facial nerve testing. Archives of Otolaryngology 97:214-219.

Dallos, P. J. 1973. The auditory periphery. Academic Press, New York.

Deutsch, L. 1972. The threshold of the stapedius reflex for pure tone and noise stimuli. Acta Otolaryngologia 74:248-251.

Djupesland, G. 1962. Preliminary report on the intra-aural muscular reflexes elicited by air current stimulation of the external ear. Acta Otolaryngologica 54:143-153.

Djupesland, G. 1964. Middle ear muscle reflexes elicited by acoustic and non-acoustic stimulation. Acta Otolaryngologica, Supplement No. 188, 287-292.

Djupesland, G. 1969. Use of impedance indicator in diagnosis of middle ear pathology. Journal of International Audiology 8:570-579.

Djupesland, G., Flottorp, G., and Winther, F. O. 1967. Size and duration of acoustically elicited impedance changes in man. Acta Otolaryngologica, Supplement No. 224.

Feldtkeller, R. 1955. Uber die Zerlegung des Schallspektrums in Frequenzgruppen durch das Genor, Elektron. Rundschau 9:387-389.

Feldtkeller, R., and Zwicker, E. 1956. E Das Ohr als Nachrichtenempfanger. S. Hirzel Verlag, Stuttgart. 42-44.

Flottorp, G., Djupesland, G., and Winther, F. 1971. The acoustic stapedius reflex in relation to critical bandwidth. Journal of the Acoustic Society of America 49(2):457-461.

Greisen, O., and Rasmussen, P. E. 1970. Stapedius muscle reflexes and otoneurological examinations in brainstem tumor. Acta Otolaryngologica 70:366-370.

Jepsen, O. 1953. Intratympanic muscle reflexes in psychogenic deafness. Acta Otolaryngologica, Supplement No. 109, 61.

Jepsen, O. 1955. Studies on the acoustic stapedius reflex in man. Unpublished thesis, University of Aarhus, Denmark.

Jepsen, O. 1963. Middle ear muscle reflexes in man. In James Jerger (Ed.). Modern development in audiology, Chapter 6. Academic Press, New York.

Jerger, J. 1970. Clinical experience with impedance audiometry. Archives of Otolaryngology 92:311-324.

Jerger, J. 1975. Diagnostic use of impedance measures. In James Jerger (Ed.). Handbook of clinical impedance audiometry. American Electromedics Corporation, Dobbs Ferry, New York.

Jerger, J., Anthony, L., Jerger, S., and Mauldin, L. 1974a. Studies in impedance audiometry: II. Middle ear disorders. Archives of Otolaryngology 99:165-171.

Jerger, J., Burney, P., Mauldin, L., and Crump, B. 1974b. Predicting hearing loss from the acoustic reflex. Journal of Speech and Hearing Disorders 39:11-22.

Jerger, J., Harford, E., Clemis, J., and Alford, B. 1974c. The acoustic reflex in eighth nerve disorders. Archives of Otolaryngology 99: 409-413.

Jerger, J., and Jerger, S. 1974. Audiological comparison of cochlear and and eighth nerve disorders. Annals of Otology, Rhinology and Laryngology 83:275-286.

Jerger, J., Jerger, S. J., and Mauldin, L. 1972. Studies in impedance audiometry: I. Normal and Sensorineural ears. Archives of Otolaryngology 99:1-9.

Jerger, S., Jerger, J., Mauldin, L., and Segal, P. 1974d. Studies in impedance audiometry: II. Children less than six years old. Archives of Otolaryngology 99:1-9.

Klockhoff, I. 1961. Middle ear reflexes in man: A clinical and experimental study with special reference to diagnostic problems in hearing impairment. Acta Otolaryngologica, Supplement No. 164:1-9.

Klockhoff, I., and Anderson, H. 1959. Recording of the stapedius reflex elicited by cutaneous stimulation. Acta Otolaryngologica 50:451-454.

Klockhoff, I., and Anderson, H. 1960. Reflex activity in the tensor tympanic muscle recorded in man: A preliminary report. Acta Otolaryngologica 51:184-189.

Lamb, L., Peterson, J., and Hansen, S. 1968. Application of stapedius muscle reflex measures in the diagnosis of audiotry problems. Journal of International Audiology 7:188-199.

Licklider, J. C. R. 1951. Basic correlates of the auditory stimulus. In S. S. Stevens (Ed.). Handbook of experimental psychology, Chapter 25. John Wiley and Sons, Inc., New York.

Luscher, E. 1929. Die Funktion des musculus stapedius beim menschen, I. Z. Hals----, Nas---u. Ohrenheilk 23:105-132.

Metz, O. 1946. The acoustic impedance measured on normal and pathological ears. Acta Otolaryngologica, Supplement 63.

Møller, A. R. 1961. Network model of the middle ear. Journal of the Acoustical Society of America 33:168-176.

Møller, A. R. 1962. Acoustic reflex in man. Journal in the Acoustical Society of America 34:1524-1534.

Niemeyer, W., and Sesterhenn. 1974. Calculating the hearing threshold from the stapedius reflex threshold for different sound stimuli. Audiology 13:421-427.

Olsen, W. O., Noffsinger, D., and Kurdziel, S. 1975. Acoustic reflex and reflex decay. Archives of Otolaryngology 101(10):622-625.

Rasmussen, G. L. 1946. The olivary peduncle and other fiber projections of the superior olivary complex. Journal of Comparative Neurology 84:141-219.

Ross, S. 1968. On the relation between the acoustic reflex and loudness. Journal of the Acoustical Society of America 43:768-779.

Sanders, J. S., Josey, A. F., and Glasscock, M. E. 1974. Audiologic evaluation in cochlear and eighth nerve disorders. Archives of Otolaryngology 100:283.

Sheehy, J. L., and Hughes, R. L. 1974. The ABC's of impedance audiometry. Laryngoscope 84(11):1935-1949.

Terkildsen, K. 1962. Intra-aural muscle reflex testing. Journal of International Audiology 1:228.

Terkildsen, K. 1964. Clinical application of impedance measurements with a fixed frequency technique. Journal of International Audiology 3:123.

Terkildsen, K., and Nielsen, S. 1960. An electroacoustic impedance bridge of clinical use. Archives of Otolaryngology 72:339-346.

Terkildsen, K., Osterhammel, P., and Bretlau, P. 1973. Acoustic middle ear reflexes in patients with otosclerosis. Archives of Otolaryngology 98:152-155.

Thomsen, K. A. 1955. Employment of impedance measurements in otologic and otoneurologic diagnostics. Acta Otolaryngologica 45:159-167.

Zwicker, E. 1960. Uber die Rolle der Frequenzgruppe beim Horen. Ergeb. Biol. 23:187-203.

Zwicker, E., Flottorp, G., and Stevens, S. S. 1957. Critical bandwidth in loudness summation. Journal of the Acoustical Society of America 29:548-557.

CONCLUSION

It has been the attempt to present as concisely as possible with an instructional format the clinical information necessary to the interpretation of electroacoustic impedance measurements. Due to the goal for conciseness and to the limitation of the paper, it was necessary to eliminate valuable research findings which aid in the understanding of a complete picture of impedance audiometry.

It was a goal that the reader would be knowledgeable of the various concepts used in the description of the impedance/admittance relationship. It is the hope that the paper helped to clarify the differences between impedance and admittance and their various components. Impedance and admittance are terms which represent the same acoustic phenomena. It is important to remember that they are merely reciprocals of one another and that their complex differences appear confusing only through differences in terminology.

Static acoustic impedance measurements are perhaps the least useful clinically since there is much overlap among normal and pathological ears. It was the goal, however, that the reader be knowledgeable of terminology, normative data and clinical interpretation of static impedance measurements. Perhaps future research will further refine normative values establishing static measures as a more consistent and reliable clinical tool.

It was the goal of the tympanometry section that the reader would be able to identify diagnostically significant variables of the tympanogram and relate them to the audiometric-medical status of the patient upon the completion of the section. Various tympanometric shapes and their particular clinical meanings were presented. It is important to remember that in evaluating any conductive loss, impedance results reflect middle ear physics and not the etiology of the disease. It is the hope that the reader has the conceptual tools for the evaluation of tympanometric tracings. Tympanometry remains an extremely useful clinical tool.

The goal of acoustic reflex section was that the reader be knowledgeable of the diagnostic significance of the acoustic reflex. It was beyond the scope of this paper to present the clinical findings of the "tactile stapedius reflex" and other nonacoustic middle ear muscle reflexes. In order to avoid serious error in the interpretation of acoustic reflex abnormalities, it is critical that one remember that in order to elicit an acoustic reflex, certain conditions must be met. It must be possible for the reflex eliciting signal to evoke a sufficient sensation of loudness in the ear to which it is introduced. Next, the motor pathways in the brain stem must be intact without facial nerve involvement. Finally, the middle ear on the probe side must be normal. The acoustic reflex is probably the most powerful diagnostic tool in impedance audiometry.

LITERATURE CITED

Alberti, P. W., and Jerger, J. F. 1974. Probe-tone frequency and the diagnostic value of tympanometry. Archives of Otolaryngology 99:206-210.

Alberti, P., and Kristensen, R. 1970. The clinical application of impedance audiometry. Laryngoscope 80:735-746.

Alford, B. R., Jerger, J. F., Coats, A. C., Peterson, C. R., and Weber, C. S. 1973. Neurophysiology of facial nerve testing. Archives of Otolaryngology 97:214-219.

Anderson, H., Barr, B., and Wedenberg, E. 1969. Intra-aural reflexes in retrocochlear lesions, pp. 49-55. In C. A. Hamberger and J. Wersail (Eds.). Disorders of the skull base region. Nobel Symposium 10. Stockholm. Almquist and Wiksel.

Berlin, I., and Cullen, J. K. 1975. The physical basis of impedance measurements. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 1. American Electromedics Corporation, Dobbs Ferry, New York.

Bicknell, M., and Morgan, N. A. 1968. A clinical evaluation of the Zwislocki acoustic bridge. Journal of Laryngology Otology 82:673-692.

Bluestone, C. D. 1975. Assessment of Eustachian tube function. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 6. American Electromedics Corporation, Dobbs Ferry, New York.

Bluestone, C., Berry, Q., and Paradise, J. 1973. Audiometry and tympanometry in relation to middle ear effusions in children. Laryngoscope 83:594-604.

Bluestone, C. D., Paradise, J. L., and Beery, Q. 1972. Physiology of the Eustachian tube in the pathogenesis and management of middle ear effusions. Laryngoscope 84:247-255.

Brooks, D. N., 1968. An objective method detecting fluid in the middle ear. Journal of International Audiology 7:280-286.

Brooks, D. N. 1969. The use of the electro-acoustic impedance bridge in the assessment of middle ear function. Journal of International Audiology 8:563-569.

Burke, K. S., Herer, G. R., and McPherson, D. L. 1970. Middle ear impedance measurement: Acoustic and electroacoustic comparisons. Acta Otolaryngologica 70:29-34.

Dallos, P. J. 1973. The auditory periphery. Academic Press, New York, New York.

Dempsey, C. 1975. Static compliance. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 4. American Electromedics Corporation, Dobbs Ferry, New York.

Deutsch, L. 1972. The threshold of the stapedius reflex for pure tone and noise stimuli. Acta Otolaryngologia 74:248-251.

Djupesland, G. 1962. Preliminary report on the intra-aural muscular reflexes elicited by air current stimulation of the external ear. Acta Otolaryngologica 54:143-153.

Djupesland, G. 1964. Middle ear muscle reflexes elicited by acoustic and non-acoustic stimulation. Acta Otolaryngologica, Supplement No. 188: 287-292.

Djupesland, G. 1969. Use of impedance indicator in diagnosis of middle ear pathology. Journal of International Audiology 8:570-579.

Djupesland, G., Flottorp, G., and Winther, F. O. 1967. Size and duration of acoustically elicited impedance changes in man. Acta Otolaryngologica, Supplement No. 224.

Espich, James E., and Williams Bill. 1967. Developing programmed materials: A handbook for program writers. Lear Siegler, Inc./Fearon Publishers, Belmont, California.

Feldman, A. 1963. Impedance measurements at the eardrum as an aid to diagnosis. Journal of Speech and Hearing Research 6:315-327.

Feldman, A. 1964. Acoustic impedance measures as a clinical procedure. Journal of International Audiology 3:1-11.

Feldman, A. 1967. Acoustic impedance studies of the normal ear. Journal of Speech and Hearing Research 10:165-176.

Feldman, A., Djupesland, G., and Grunes, C. 1971. A comparison of impedance measurements. Archives of Otolaryngology 93:416-418.

Feldtkeller, R. 1955. Uber die Ferlegung des Schallspektrums in Frequenzgruppen durch das Genor, Elektron. Rundschau 9:387-389.

Feldtkeller, R., and Zwicker, E. 1956. E Das Ohr als Nachrichtenempfanger. S. Hirzel Verlag, Stuttgart. 42-44.

Flisberg, K., Inglestedt, S., and Ortegren, U. 1963. Controlled "ear aspiration" of air: A "physiological test of tubal function." Acta Otolaryngologica, Supplement No. 182.

Flottorp, G., Djupesland, G., and Winther, F. 1971. The acoustic stapedius reflex in relation to critical bandwidth. Journal of the Acoustic Society of America 49(2):457-461.

Goodhill, V. 1958. Auditory response in relation to viscosity of tympanic fluids. Acta Otolaryngologica 49:38.

Greisen, O., and Rasmussen, P. E. 1970. Stapedius muscle reflexes and otoneurological examinations in brainstem tumor. Acta Otolaryngologica 70:366-370.

Harford, E. R. 1975. Tympanometry. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 3. American Electromedics Corporation, Dobbs Ferry, New York.

Jacobson, J. T., Kimmel, B. L., and Fausti, S. A. 1975. Clinical application of the Grason-Stadler Otoadmittance meter. A Journal of the American Speech and Hearing Association 17(1)11-16.

Jepsen, O. 1953. Intratympanic muscle reflexes in psychogenic deafness. Acta Otolaryngologica, Supplement No. 109:61.

Jepsen, O. 1955. Studies on the acoustic stapedius reflex in man. Unpublished thesis, University of Aarhus, Denmark.

Jepsen, O. 1963. Middle ear muscle reflexes in man. In James Jerger (Ed.). Modern development in audiology, Chapter 6. Academic Press, New York.

Jerger, J. 1970. Clinical experience with impedance audiometry. Archives of Otolaryngology 92:311-324.

Jerger, J. 1972. Suggested nomenclature for impedance audiometry. Archives of Otolaryngology 96:1-3

Jerger, J. 1975. Diagnostic use of impedance measures. In James Jerger (Ed.). Handbook of clinical impedance audiometry, Chapter 7. American Electromedics Corporation, Dobbs Ferry, New York.

Jerger, J. 1975. Impedance terminology. Archives of Otolaryngology 101:589-590.

Jerger, J., Anthony, L.,Jerger, S., and Mauldin, L. 1974. Studies in impedance audiometry: III. Middle ear disorders. Archives of Otolaryngology 99:165-171.

Jerger, J., Burney, P., Mauldin, L., and Crump, B. 1974. Predicting hearing loss from the acoustic reflex. Journal of Speech and Hearing Disorders 39:11-22.

Jerger, J., Harford, E., Clemis, J., and Alford, B. 1974. The acoustic reflex in eighth nerve disorders. Archives of Otolaryngology 99:409-413.

Jerger, J., and Jerger S. 1974. Audiological comparison of cochlear and eighth nerve disorders. Annals of Otology, Rhinology and Laryngology 83:275-286.

Jerger, J., Jerger, S. J., and Mauldin, L. 1972. Studies in impedance audiometry: I. Normal and sensorineural ears. Archives of Otolaryngology 99:1-9.

Jerger, S., Jerger, J., Mauldin, L., and Segal, P. 1974. Studies in impedance audiometry: II. Children less than six years old. Archives of Otolaryngology 99:1-9.

Keith, R. 1973. Impedance audiometry with neonates. Archives of Otolaryngology 97:465-467.

Klockhoff, I. 1961. Middle ear reflexes in man: A clinical and experimental study with special reference to diagnostic problems in hearing impairment. Acta Otolaryngologica, Supplement No. 164:1-9.

Klockhoff, I., and Anderson, H. 1959. Recording of the stapedius reflex elicited by cutaneous stimulation. Acta Otolaryngologica 50:451-454.

Klockhoff, I., and Anderson, H. 1960. Reflex activity in the tensor tympanic muscle recorded in Man: A preliminary report. Acta Otolaryngologica 51:184-189.

Lamb, L., Peterson, J., and Hansen, S. 1968. Application of stapedius muscle reflex measures in the diagnosis of auditory problems. Journal of International Audiology 7:188-189.

Licklider, J. C. R. 1951. Basic correlates of the auditory stimulus. In S. S. Stevens (Ed.). Handbook of experimental psychology, Chapter 25. John Wiley and Sons, Inc., New York.

Liden, G., Harford, E., and Hallen, O. 1974. Tympanometry for the diagnosis of ossicular disruption. Archives of Otolaryngology 99: 23-29.

Liden, G., Peterson, J., and Bjorkman, G. 1970. Tympanometry. Archives of Otolaryngology 99:23-29.

Lilly, D. J. 1973. Measurement of acoustic impedance at the tympanic membrane. In James Jerger (Ed.). Modern developments in audiology, Edition 2. Academic Press, New York.

Luscher, E. 1929. Die Funktion des Musculus Stapedius beim Menschen, I.A. Hals---, Nas---u. Ohrenheilk 23:105-132.

McCandless, G. A., and Thomas, G. K. 1974. Impedance audiometry as a screening procedure for middle ear disease. Transactions of the American Academy of Opthalmology and Otolaryngology 78:2.

Madsen Electromedics Corporation. Madsen Model Z070 electroacoustic impedance bridge: Applications and instructions for use. Madsen Electromedics, Denmark.

Martin, F. N., Butler, E. C., and Burns, P. 1973. A variation of the Type B tympanogram. Laryngoscope 83(11):1783-1785.

Metz, O. 1946. The acoustic impedance measured on normal and pathological ears. Acta Otolaryngologica, Supplement No. 63.

Møller, A. R. 1961. Network model of the middle ear. Journal of the Acoustical Society of America 33:168-176.

Møller, A. R. 1962. Acoustic reflex in man. Journal of the Acoustical Society of America 34:1524-1534.

Møller, A. R. 1964. The acoustic impedance in experimental studies on the middle ear. Journal of International Audiology 2:123-135.

Newman, B. T., and Fanger, D. M. 1973. Otoadmittance handbook 2. Grason-Stadler, Concord, Massachusetts.

Niemeyer, W., and Sesterhenn. 1974. Calculating the hearing threshold from the stapedius reflex threshold for different sound stimuli. Audiology 13:421-427.

Olsen, W. O., Noffsinger, D., and Kurdziel, S. 1975. Acoustic reflex and reflex decay. Archives of Otolaryngology 101(10):622-625.

Priede, V. M. 1970. Acoustic impedance in two cases of ossicular discontinuity. Journal of International Audiology 9:127-136.

Porter, Thomas. 1972. Normal Otoadmittance values for three populations. Journal of Auditory Research 12(1):53-58.

Rasmussen, G. L. 1946. The olivary peduncle and other fiber projections of the superior olivary complex. Journal of Comparative Neurology 84:141-219.

Rock, E. H. 1972. Electroacoustic impedance measurements in clinical otology. Impedance newsletter. American Electromedics Corporation. 1:Revised.

Ross, S. 1968. On the relation between the acoustic reflex and loudness. Journal of the Acoustical Society of America 43:768-779.

Sanders, J. W., Josey, A. F., and Glasscock, M. E. 1974. Audiologic evaluation in cochlear and eighth nerve disorders. Archives of Otolaryngology 100:283.

Sheehy, J. L., and Hughes, R. L. 1974. The ABC's of impedance audiometry. Laryngoscope 84(11):1935-1949.

Terkildsen, K. 1962. Aural muscle reflex testing. Journal of International Audiology 1:228.

Terkildsen, K. 1964. Clinical application of impedance measurements with a fixed frequency technique. Journal of International Audiology 3:123.

Terkildsen, K., and Nielsen, S. 1960. An electroacoustic impedance bridge of clinical use. Archives of Otolaryngology 72:339-346.

Terkildsen, K., Osterhammel, P., and Bretlaw, P. 1973. Acoustic middle ear reflexes in patients with otosclerosis. Archives of Otolaryngology 98:152-155.

Thomsen, K. A. 1955. Employment of impedance measurements in otologic and otoneurologic diagnostics. Acta Otolaryngologica 45:159-167.

Zwicker, E. 1960. Uber die Rolle der Frequenzgruppe beim Horen. Ergeb. Biol. 23:187-203.

Zwicker, E., Flottorp, G., and Stevens, S. S. 1957. Critical bandwidth in loudness summation. Journal of the Acoustical Society of America 29:548-557.

Zwislocki, J. 1963. An acoustic method for clinical examination of the ear. Journal of Speech and Hearing Research 6:303-314.

Zwislocki, J. 1964. Summary by the moderator. The Acoustic impedance of the ear. Journal of International Audiology 4:18-19.

Zwislocki, J. J., and Feldman, A. S. 1970. Acoustic impedance of pathological ears. ASHA Monograph No. 15. American Speech and Hearing Association, Washington, D. C.

APPENDIX

The Multiple Purpose Self Trainer

THE MULTIPLE PURPOSE
SELF TRAINER

Developed by
Charles W. Nelson, PH.D.
Formerly Associate Professor
The University of Chicago

Example	a.	b.	c.	d.	e.
1	a.	b.	c.	d.	e.
2	a.	b.	c.	d.	e.
3	a.	b.	c.	d.	e.
4	a.	b.	c.	d.	e.
5	a.	b.	c.	d.	e.
6	a.	b.	c.	d.	e.
7	a.	b.	c.	d.	e.
8	a.	b.	c.	d.	e.
9	a.	b.	c.	d.	e.
10	a.	b.	c.	d.	e.
11	a.	b.	c.	d.	e.
12	a.	b.	c.	d.	e.
13	a.	b.	c.	d.	e.
14	a.	b.	c.	d.	e.
15	a.	b.	c.	d.	e.
16	a.	b.	c.	d.	e.
17	a.	b.	c.	d.	e.
18	a.	b.	c.	d.	e.
19	a.	b.	c.	d.	e.
20	a.	b.	c.	d.	e.
21	a.	b.	c.	d.	e.
22	a.	b.	c.	d.	e.
23	a.	b.	c.	d.	e.
24	a.	b.	c.	d.	e.
25	a.	b.	c.	d.	e.
26	a.	b.	c.	d.	e.
27	a.	b.	c.	d.	e.
28	a.	b.	c.	d.	e.
29	a.	b.	c.	d.	e.
30	a.	b.	c.	d.	e.

Score key	Ace	King	Queen	Jack	Ten	Total

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VITA

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