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An investigation of between-ear tympanometry measures in normal-hearing young adults

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Title: An Investigation of Between-Ear Tympanometry Measures in Normal-Hearing Young Adults.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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In recent years, tympanometry has been used to provide objective and definitive information regarding the status of middle ear conditions and functions. The present standard for tympanometric normalcy is based upon between-subject measures. This standard, however, does not allow precise differentiation between normal and pathological tympanometry curves. A within-subject comparison of right and left ear tympanometry curves of normal-hearing subjects could provide a narrow standard of tympanometric normalcy which would be more useful in differentiating between pathologic

and non-pathologic middle ear function. The within-subject relationship between tympanometry curves for right and left ears was investigated by comparing the individual right and left ear tympanometry curves at 220 and 660 Hz of 30 normal-hearing young adults. This was done to determine if a difference exists between within-subject right and left ear tympanometry curves. Three characteristics, curve peak amplitude, curve width, and pressure at curve peak, were measured and compared for each tympanometry curve. All tympanometry was conducted with a Grason-Stadler Otoadmittance Meter (Model 1720) utilizing a combined mode of conductance and susceptance. All tympanometry curves were graphically recorded on a Hewlitt-Packard X-Y plotter (Model 7035B). Statistical analysis and graphic illustration showed that for practical purposes no significant clinical difference exists between within-subject right and left ear tympanometry curves and that measurement variability is predominantly due to between-subject differences. The ranges of between-ear differences were much reduced in comparison to the computed ranges for between-subject measures. These findings would suggest that a definition of tympanometric normalcy should be based not only upon between-subject measures, but also upon between-ear comparisons.

AN INVESTIGATION OF BETWEEN-EAR TYMPANOMETRY MEASURES IN NORMAL-HEARING YOUNG ADULTS

by

BARRY LYNN KIMMEL

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CHAPTER I

INTRODUCTION

Audiology can be generally defined as the study of hearing concerned with the diagnosis and remediation of auditory dysfunction (O'Neill and Oyer, 1966). The audiologist is primarily concerned with the identification and measurement of hearing disorders as they relate to the habilitation or rehabilitation of the hearing impaired. Determination of the type and degree of hearing loss is prerequisite to selecting appropriate programs of habilitation, rehabilitation, or medical treatment in order to insure an optimal level of functioning for the hearing impaired individual.

Hearing loss is divided into two major categories, sensorineural and conductive. Sensorineural hearing loss results from cochlear or retrocochlear dysfunction and is considered to be a permanent type of hearing loss; however, through effective use of amplification and communication training, the handicapping effects of such a loss can be substantially reduced.

A conductive hearing loss, on the other hand, is due to the insufficient transmission of sound through the middle ear. This usually occurs as a result of obstruction or alterations of the mechanical properties of the middle ear sound transmission system. Through the use of medication and improved surgical technique, physicians have successfully treated middle ear conditions responsible for a vast number of conductive hearing losses. The audiologist has played a vital role as a major contributor of diagnostic information critical to the design of medical treatment programs for hearing disorders.

Included within the audiologist's repertoire are many tests for assessment of the auditory system. Basic audiometry involves the recording of behaviorial responses to pure tone stimuli. By varying the mode and manner of tonal stimulation, diagnostic information may be obtained to differentiate between conductive and sensorineural dysfunction and to identify the site of lesion. While most site-of-lesion testing has been directed toward the differential diagnosis of sensorineural pathologies, diagnostic tools for differentiating the various conductive or middle ear pathologies have been slow in development and less accurate. As a result, the audiologist has had to rely on less than ideal means to determine the status of the middle ear. The otological examination is greatly dependent upon the subjective impressions of the physician while the audiological evaluation depends on the subjective reporting and decisions by the patient. With the advent of instrumentation capable of recording changes in middle ear impedance,[1] however, objective methods of differentiating between middle ear pathologies have evolved.

[1]For purposes of this study, impedance is defined as resistivity to motion determining the vibrating efficiency of the middle ear system.

CHAPTER II

REVIEW OF LITERATURE AND STATEMENT OF PROBLEM

I. REVIEW OF LITERATURE

In recent years, impedance measurements have been used to provide more objective and definitive information regarding the status of middle ear conditions and functions (Liden, Peterson and Bjorkman, 1970 a and b; Lilly, 1970; Lamb, 1971; Jerger, 1970; Feldman, 1971 b; Alberti and Kristensen, 1970; Klockoff, 1971; Nilges, Northern, and Burke, 1969; Liden, Peterson and Harford, 1970; Zwislocki and Feldman, 1970; Brooks, 1968, 1969). How efficiently the middle ear transmits sound energy is dependent on its capability as a mechanical transducer for providing an acoustic impedance match between air and fluid filled structures of the cochlea (Feldman, 1971 a). Under normal conditions the air pressure in the tympanic cavity and the ear canal are equal. Alterations in middle ear volume and pressure, as well as in its various fibrous and ligamentous connections affect sound vibration transmitted through the middle ear system. Conditions which interfere with the normal function of any portion of the system ultimately alter the mobility and impedance of the tympanic membrane through its direct or indirect attachment to the entire system.

When sound strikes an object, a combination of three things occurs. The sound is: (a) reflected; (b) absorbed; and (c) transduced, depending upon the interplay between the various characteristics of the object and the sound itself. Specifically, the resistance,[2] reactance,[3] and compliance[4] of the object will determine how the sound will be affected. The tympanic membrane also operates acoustically according to these same principles. It is the effect the tympanic membrane has upon an incident sound wave that underlies the operation of impedance measuring instrumentation. Impedance measurements rely upon calculating the difference in SPL between a known incident sound wave and that portion which is reflected from the tympanic membrane. This difference is usually computed in arbitrary units or equivalent units of cubic centimeters, ohms, or millimhos (reciprocal of milliohms), depending upon the impedance measuring system being used.

[2] For purposes of this study, resistance is defined as an element of friction which tends to impede the passage of sound energy through the middle ear system.

[3] For purposes of this study, reactance may either be defined as elements of mass (positive reactance) or stiffness (negative reactance), determining the degree to which sound energy is allowed to pass through the middle ear system.

[4] For purposes of this study, compliance is defined as mobility of the middle ear system and is inversely related to stiffness. Stiffness is mainly due to the ligaments of the middle ear, the tympanic membrane, and the volume of air enclosed within the middle ear space.

The effects that elements of impedance have on the middle ear system for different frequencies were discussed by Feldman (1971). He noted that masses and resistances have little influence on the normal middle ear system in the low frequencies up to 500 Hz and the impedance is primarily an effect of the compliance or stiffness of the system. Above 500 Hz, however, resistances can be expected to exert more influence on the middle ear system, and at the resonsance point of the ear, approximately 1000-1500 Hz, the system becomes mass controlled. When the middle ear system becomes mass controlled, accurate measurements of compliance or resistance cannot be obtained.

According to Terkildsen and Nielsen (1960), the first systematic study of acoustic impedance of the human ear was made by Troger in 1934. Schuster invented an acoustic impedance bridge, instrumentation which was eventually modified by Metz (1946) and used to make impedance measurements in both normal and pathological ears. When utilizing the Metz equipment, however, wide variations in the impedance values were observed. Consequently, during the late 1940's and up through the early 1960's, it was felt by most investigators that standard otologic and audiologic procedures were of considerably more diagnostic value in determining middle ear pathology than were impedance measures.

Following Metz' (1946) work, other researchers (Terkildsen and Nielsen, 1960; Zwislocki, 1957, 1961, 1963; Moller, 1960; Feldman, 1964) continued the work on impedance measurement. Of the several methods available for the measurement of middle ear impedance, two have been applied clinically. The first of these is the mechanical acoustic bridge advanced by Metz (1946) and modified by Zwislocki (1961) for use on a broad clinical scale. The Zwislocki Acoustic Bridge allows compensation for variations in ear canal volume between the ear probe tip of the instrument and the tympanic membrane. Such compensation essentially eliminates errors in middle ear impedance measurement which might occur due to variations in ear canal volume. It also provides a stable matching impedance control over both resistance and reactance. The instrument obtains measures of resistance and reactance at the face of the tympanic membrane, thus providing absolute impedance[5] values. It also can be readily used for relative impedance[6] measurements to detect changes of impedance induced by contraction of one or both middle ear muscles.

A second clinical method of impedance measurement uses a modification of an electroacoustic impedance balancing system advanced originally by Terkildsen and Nielsen (1960). Such a system, the Madsen Acoustic Impedance Meter, has been used extensively in clinical and research settings over the past several

[5]For the purposes of this study, absolute impedance is defined as a measurement of middle ear impedance determined by comparing impedance of the artificially stiffened and maximally compliant tympanic membrane.

[6]For purposes of this study, relative impedance is defined as any change in middle ear impedance produced when either of the middle ear muscles contracts.

years (Lilly, 1970; Jerger, 1970; Alberti and Kristensen, 1970; Nilges, Northern and Burke, 1969; Brooks, 1968, 1969). Another commercially available electroacoustic impedance measuring system, the Grason-Stadler Otoadmittance Meter, has been recently developed. Both of these instruments, Madsen and Grason-Stadler, also permit absolute, as well as relative impedance measurements.

In principle, the Grason-Stadler Otoadmittance Meter is similar to the Zwislocki Acoustic Bridge in that it is designed to eliminate possible errors due to changes in ear canal volume so that impedance measurements are almost entirely associated with conditions existing at the plane of the tympanic membrane. By contrast, the Madsen Acoustic Impedance Meter lumps the conditions existing in the ear canal with the mixed conditions at the plane of the tympanic membrane, a method of measurement which does not compensate for the possible effects of the ear canal on impedance measurement or differentiate between the components of resistance and compliance contributing to middle ear impedance. While impedance measurement can be accomplished at several different frequencies with the Zwislocki Acoustic Bridge, the Grason-Stadler Otoadmittance Meter permits measurements at two different test tones (220 and 660 Hz) in contrast to the single test tone (220 Hz) capability of the Madsen Acoustic Impedance Meter.

Basically, the Grason-Stadler Otoadmittance Meter is designed to measure admittance.[7] Sound pressure and sound flow of the probe tone are electronically controlled so that pressure and flow can exist in either a 0 degree phase relationship or a phase relationship where flow precedes pressure by 90 degrees. The 0 degree phase condition obtains a component of admittance known as conductance[8] which is characterized by friction. When sound flow precedes sound pressure by 90 degrees, a component of admittance referred to as susceptance[9] is obtained which is characterized by compliance or stiffness. Electronic switching also allows conductance and susceptance to be combined, a condition when sound flow is neither exactly in phase nor 90 degrees out-of-phase with pressure. This latter condition closely approximates the method of measurement incorporated in the Madsen Acoustic Impedance Meter.

Electroacoustic impedance measuring systems introduce another concept, that of tympanometry. Tympanometry may be generally defined as a measurement of tympanic membrane compliance, or mobility, during artificially induced air pressure changes in

[7]The manufacturers of the Grason-Stadler Otoadmittance Meter refer to admittance as the reciprocal of impedance.

[8]The manufacturers of the Grason-Stadler Otoadmittance Meter refer to conductance as the reciprocal of resistance.

[9]The manufacturers of the Grason-Stadler Otoadmittance Meter refer to susceptance as the reciprocal of reactance.

the ear canal (Jerger, 1970; Liden, Peterson and Bjorkman, 1970 a; Lamb, 1971). It involves three essential measures: (1) the compliance of the tympanic membrane when air pressure conditions in the ear canal are optimum; (2) the degree of compliance change with only slight deviation from the optimal ear canal air pressure; (3) the amount of ear canal air pressure necessary to bring the tympanic membrane to its most compliant position (Lamb, 1971). The basic datum of tympanometry is a graphic recording of the pressure-compliance function relating compliance changes to air pressure variations.

Several characteristics which may be observed from tympanometric pressure-compliance function curves are shown in Figure 1 and depicted as follows: (1) effective middle ear compliance indicated by the height of the curves; (2) shape of the curves near their peaks, the gradient; and (3) air pressure within the middle ear cavity, shown by the point on the pressure continuum at which maximum compliance is attained (Liden, Peterson and Bjorkman, 1970 a; Lamb, 1971; Brooks, 1969).

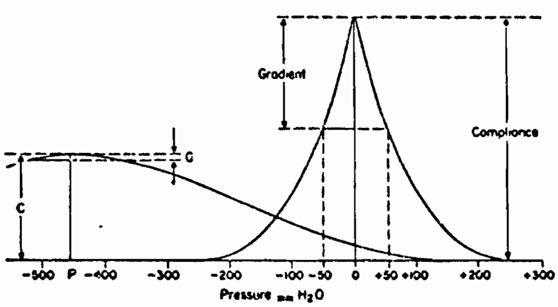

Figure 1. Idealized tympanometry curves for a normal middle ear and for a middle ear containing fluid (P). The degree of compliance and gradient is shown for each curve. (Brooks, 1969.)

In comparing tympanograms obtained at three different probe frequencies (220, 625 and 800 Hz) for their group of normal-hearing subjects, Liden, Peterson and Bjorkman (1970 b) observed statistically non-significant differences among the three frequencies to be in the shape of the tympanometry curve under positive air pressure and in the depth and position of the curve peak.

Jerger (1970) and Lamb (1971) described basic types of pressure-compliance functions. One type is characterized by a relatively sharp point of maximum compliance at or near 0 mm H_2O of air pressure. A relatively deep compliance function of this type is indicative of ossicular chain discontinuity, while a shallow rise in maximum compliance would be diagnostic of otosclerosis. A normal compliance maximum ranges between these two extremes. A second type shows little or no point of maximum compliance with compliance remaining essentially unchanged over a wide range of pressure variation. This second type usually indicates serous or adhesive otitis media. In a third type, the maximum is shifted to the left of 0 mm H_2O on the pressure continuum by negative pressure in the middle ear. A significant shift of 100 mm or more is commonly associated with Eustachian tube malfunction. These three basic types of tympanometry curves are illustrated in Figure 2.

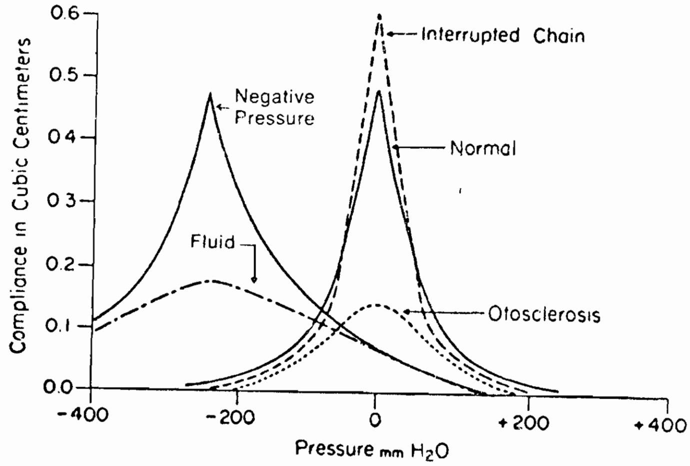

Figure 2. Idealized tympanometry curves showing pressure and compliance for five middle ear conditions. (Lamb, 1971.)

Not only has tympanometry been shown to be a practical, expedient clinical test of tympanic membrane and specific middle ear conditions (Liden, Peterson and Bjorkman, 1970 a and b; Alberti and Kristensen, 1970; Jerger, 1970), but it also has the advantage of being an objective measure of these conditions in contrast to the subjectivity of standard otological and audiological evaluations of general middle ear function. Because tympanometry does not require the patient to be cooperative and respond voluntarily, it has been utilized in unique clinical situations. When hearing thresholds cannot be validly determined through conventional pure-tone audiometry, as the case may be with a yound child (Jerger, 1970; Alberti and Kristensen, 1970) or mentally retarded individual (Lamb, 1971), tympanometry may be used to confirm the presence of conductive pathology. Tympanometry also is helpful in providing information about middle ear function when the hearing loss is of such magnitude that bone conduction thresholds cannot be measured within the limits of the audiometer (Jerger, 1970). Brooks (1968) advocated the use of tympanometry in school screening programs to detect children with middle ear disease who otherwise would have passed an audiometric screening test. Since its recent inception, tympanometry has been recognized as an objective measure of middle ear function. Narrowly defined, tympanometric standards must be established before its maximum potential, as a diagnostic tool, can be realized.

Several researchers have described idealized "normal" tympanometry curves, but have failed to establish useful clinical norms for distinguishing between normal and pathological middle ears when comparing within-subject right and left ear tympanometry curves (Jerger, 1970; Liden, Peterson and Bjorkman, 1970 a; Lamb, 1971). Liden, Peterson and Bjorkman obtained data on four tympanometric curve characteristics for their group of otologically and audiologically normal-hearing subjects. According to these investigators, the data showed little spread around the obtained means for these measured characteristics, indicating good between-subject stability for normal tympanometry curves. The standard deviations from the means, however, showed a range of variation which could be rather inconclusive diagnostically when comparing within-subject right and left ear tympanometry curves that are significantly different but still within the range of tympanometric normalcy based on between-subject measures. The task of differentiating between a normal and pathological middle ear becomes more difficult when tympanometry curves indicative of ossicular chain discontinuity and otosclerosis are of the same type as normal tympanometry curves; the only major feature distinguishing these three curves from one another being relatively different points of maximum compliance along a compliance continuum (Lamb, 1971; Jerger, 1970). Further, Liden (1970 b) showed that there was no statistically significant difference between the means for tympanometry curve measurements for his normal and otosclerotic groups.

A number of variables may account for the observed range of between-subject variation in normal tympanometry curves. Lilly (1970) compared two tympanometry curves measured on the same ear of one of his normal-hearing subjects. Using a Madsen Acoustic Impedance Meter, the first measurement was accomplished with the Madsen ear canal probe tip inserted in a conventional manner while the second measurement was recorded with the probe tip intentionally pushed deeper into the ear canal reducing the volume of air within the ear canal. By comparing the two curves, Lilly noted that a reduction of the volume of air within the ear canal moved the tympanometry curve upward and also changed its shape. This observation seemed to suggest that the shape of a "normal tympanometry curve" and its relative position on the form is dependent upon several factors which are: (1) the cross-sectional area of the eardrum and the external auditory meatus; (2) the volume of air between the tip of the probe and the ear drum; and (3) the acoustic conditions that exist at the surface of the eardrum. These variables are highly individualized and, as such, provide a possible explanation for the wide variation in between-subject tympanometric normalcy.

By measuring both the right and left ear canal volumes of his subjects, Feldman (1967) learned that although there was a considerable range of individual differences, a strong correlation existed between the within-subject right and left ear canal volumes. His data implied that the measured ear canal volume for one ear can be used for the second ear with a fair degree of confidence and that the difference between volumes would not be expected to exceed 0.1 cubic centimeters. This is in contrast to Feldman's anticipated ear canal volume range for 80 percent of an adult population which showed between-subject ear canal volume differences to vary as much as 0.4 cubic centimeters. It may be inferred from Feldman's observations that within-subject anatomical symmetry allows some degree of control over variables which affect tympanometry curves, i.e., ear canal volume, cross-sectional area of the eardrum and external auditory meatus.

Another anatomical structure controlling ear canal volume during tympanometry is the cartilaginous margin of the external auditory meatus which limits the insertion depth of the ear probe tip used with the electroacoustic impedance measuring systems (Lilly, 1970). While this cartilaginous margin would be expected to be anatomically similar for an individual's right and left ears, it could vary considerably between persons. Between-subject anatomical variation in this margin, to the extent that it regulates ear canal volume during tympanometry, may then be partly responsible for the wide range of between-subject variation seen in tympanometry curves considered to be normal.

Because of within-subject anatomical symmetry, the previously mentioned anatomical variables are reduced when comparing an individual's right and left ears. Right and left ear tympanometry curves for an otologically and audiologically normal individual, therefore, would be expected to be in very close agreement in contrast to the range of variation observed for between-subject normal ear measurements. The present range of tympanometric normalcy based on between-subject measures permits within-subject right and left ear tympanometry curves to be significantly different and still be contained within normal limits. By obtaining strictly delimited within-subject agreement between right and left ear tympanometry curves, a range of within-subject normalcy may be defined which could be diagnostically more useful for differentiating between pathologic and non-pathologic ears than the present standard based upon between-subject measures. Such a within-subject definition of normalcy may provide a more efficient and reliable method of evaluating an individual's middle ear function even though his hearing is audiometrically normal. While between-subject variations in the "normal tympanometry curve" appear non-significant, these same variations in within-subject measurements could be diagnostically indicative of existing middle ear pathology.

II. STATEMENT OF THE PROBLEM AND THE PURPOSE

Before one can realize the maximum potential of tympanometry as a diagnostic tool on a broad clinical basis, the "normal" tympanometry curve must be made more definitive for distinguishing between normal and pathological middle ears. Review of the literature has shown that no attempts have been made to establish a range of normalcy for within-subject tympanometry curves. A more narrowly defined within-subject range of normalcy derived from a comparison of right and left ear tympanometry curves could provide diagnostically useful information for differentiating between pathologic and non-pathologic middle ear function.

The purpose of this study was to investigate the within-subject relationship between tympanometry curves for right and left ears in a sample of normal-hearing subjects. The following question was investigated: Is there a difference between within-subject right and left ear tympanometry curves? If a difference does not exist between within-subject right and left ear tympanometry curves a narrowly defined range of normalcy could be derived from these within-subject measurements which would allow precise differentiation between normal and pathological middle ears.

Such information should improve the diagnostic usefulness of tympanometry.

CHAPTER III

METHOD

To compare the relationship between within-subject right and left ear tympanometry curves in a sample of normal-hearing subjects, the following methods and procedures were used.

I. SUBJECTS

Thirty normal-hearing young adults were selected to serve as subjects for this experiment. In order to control for possible effects of age or auditory pathologies, subjects were chosen according to the following criteria: (1) be 18-30 years of age; (2) present a negative history of middle ear pathology, noise exposure or hereditary deafness; (3) have normal ears by otologic examination (otologic screening was conducted in the Ear, Nose, Throat Clinic, Veterans Administration Hospital); (4) have normal hearing as indicated by pure-tone sensitivity of 10 dB (ISO, 1964) or better for the frequencies of 250, 500, 1000 and 2000 Hz. Otologic and audiologic examinations were administered immediately prior to tympanometric evaluation.

Of the thirty-six individuals who received otologic and audiologic examinations, six individuals did not qualify as subjects for this experiment. Three of these six individuals presented a positive history of middle ear pathology, one did not pass the otologic examination, one did not have normal pure-tone hearing sensitivity, and one did not have normal pure-tone hearing sensitivity or pass the otologic examinations. It should be noted that for two of the individuals presenting positive histories of middle ear pathology, tympanometry curves were obtained which were consistant with scarred tympanic membranes (Liden, Peterson, Bjorkman, 1970 b) although otologic examination did not provide such evidence.

II. TESTING ENVIRONMENT

Although tympanometry need not be administered in a special acoustically treated room, the use of a single-walled Industrial Acoustics Company (IAC) sound treated room (Model 404) located in the Veterans Administration Hospital Audiology Clinic, Portland, Oregon, allowed a more controlled environment for test purposes. This room provided a quiet atmosphere, relatively devoid of potential environmental distractions which might interfere with test administration.

III. ADMINISTRATION OF TYMPANOMETRY

A Grason-Stadler Otoadmittance Meter (Model 1720) was used to administer tympanometry. Figure 3 illustrates the basic components of this instrument. The Grason-Stadler Otoadmittance Meter system utilizes an optional X-Y plotter (Hewlitt Packard,

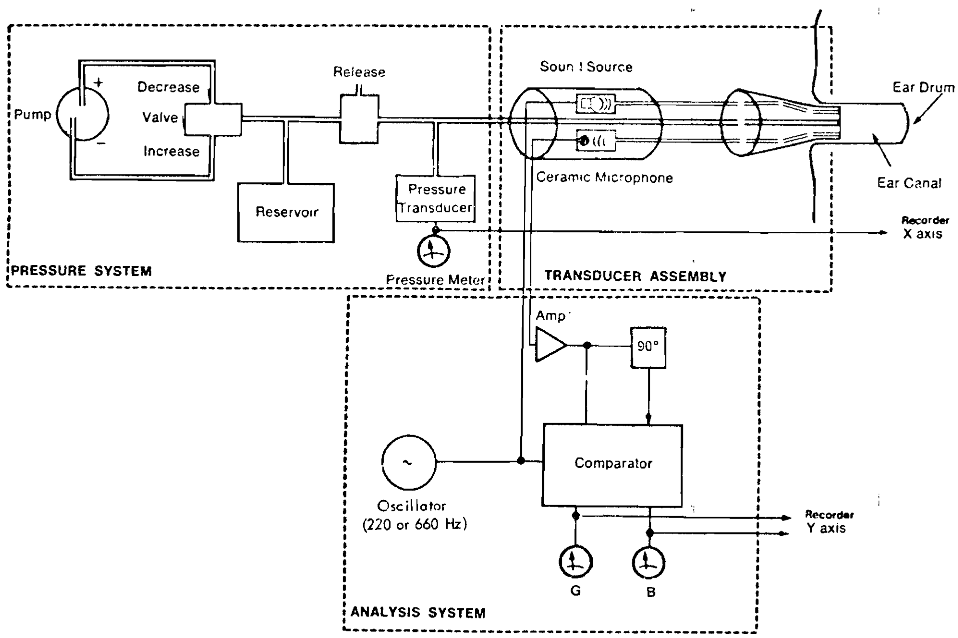

Figure 3. Basic components of the Grason-Stadler Otoadmittance Meter (Model 1720). (Grason-Stadler Company, 1971).

Model 7035B), which allowed a graphic recording of tympanometry curves (see Appendix B, Figure 1). An adjustable headband held the earpiece in position on the subject and an inflatable rubber cuff surrounding the ear probe tip was adaptable for all subjects (see Appendix B, Figure 2). The ear probe tip terminates in three capillary tubes that feed into the ear canal. One leads to a microphone and registers the sound pressure level, a second leads from a sound source generating the probe tone, and the third supplies a variable static air pressure that can be superimposed on the sound pressure for tympanometry.

The Otoadmittance Meter system is fully automated and automatically adjusts the intensity of the test tone until a reference level of 85 dB SPL within the ear canal is achieved. Once a seal was achieved with the ear probe tip in the ear canal, tympanometry was conducted (Appendix B, Figure 3). All tympanometry testing was administered under a condition of decreasing air pressure from +200 to -200 mm H_2O over a period of 27 seconds for each test trial. Changes in admittance under a condition of continuously decreasing air pressure were automatically recorded on the X-Y plotter.

Prior to tympanometric evaluation, each subject received a basic orientation to tympanometry as a method of evaluating middle ear function. For ease of test administration, subjects were seated in a comfortable chair facing away from the tympanometry instrumentation while being evaluated. Subjects were further instructed to refrain as much as possible from making head movements and swallowing during test administration since such motion may cause large irregularities in the tympanometry curve configuration. (See Appendix A for Subject Instructions.)

Prior to each period of testing, the Otoadmittance Meter was checked for calibration with the test cavity supplied by the manufacturers. Before each test the ear probe tip was inspected and any cerumen occluding the capillary tubes of the probe tip was removed. Probe tones were monitored with a Hewlitt-Packard

Frequency Counter (Model 5326A) and probe tone wave configurations were displayed on a Tektronix Dual-Beam Storage Oscilloscope (Model 5103N/D13). (See Appendix B, Figure 1.) Probe tones monitored at the level of the ear probe tip were found to be 218.5 Hz with the Otoadmittance Meter frequency selector switch set at 220 Hz and 659.2 Hz with the frequency selector switch set at 660 Hz. Wave configurations for both probe tones displayed on the oscilloscope were sinusoidal.

Tympanometry curves were obtained for both right and left ears of each subject utilizing a combined mode of conductance and susceptance. Tympanometry was also conducted at both the 220 and 660 Hz probe tones in this experiment to determine the possible effects of probe tone frequency on tympanometric curve configurations (Appendix C).

For between-ear statistical comparisons, all tympanometry curves were labeled for right and left ears. To balance the effects of ordering, testing was alternated so that the right ear of each even-numbered subject and the left ear of each odd-numbered subject were the first ears tested for right and left ear measurements. Existing research did not indicate that artificially induced displacement of the tympanic membrane during tympanometry is physiologically fatiguing to the middle ear system. Therefore, ordering effects of the testing sequence for probe tones was not a concern, and tympanometry was first administered at 220 Hz and then at 660 Hz for all subjects.

IV. ADDITIONAL TESTING

Five subjects were retested within two weeks after initial evaluation for a reliability check of tympanometric measures. None of these subjects reported any conditions suggestive of middle ear pathology occuring between test-retest. Test administration for retest was the same as that used for initial testing.

V. MEASUREMENTS

Three curve characteristics, curve peak amplitude, curve width, and pressure at the curve peak, were measured for each tympanometry curve according to a method suggested by Liden (1970 a). Liden described curve peak amplitude as being the measured difference between the level of the lowest point on the tympanometry curve and the level of the curve peak. Liden calculated curve width by determining half the curve peak amplitude and projecting this point to the intersection with each half of the tympanometry curve, the width being the measured distance between these two points of intersection. Pressure at curve peak was characterized as the position of the curve peak relative to zero air pressure. Units of measurement for curve peak amplitude were millimhos and curve width and pressure at the curve peak were calculated in millimeters H_2O of air pressure (Appendix C). A millimeter ruler was used to extrapolate pressure and millimhos measurements.

Measurements in millimhos were accurate to the nearest .1 millimho and pressure measurements were judged to be accurate within ± 2 millimeters H_2O.

CHAPTER IV

RESULTS

I. COMPARISON OF RIGHT AND LEFT EARS FOR CURVE PEAK AMPLITUDE, CURVE WIDTH, AND PRESSURE AT CURVE PEAK

The relationship between each subject's right and left ear tympanometry curve measurements was investigated using the Pearson Product-Moment Correlation (Bruning and Kintz, 1968). Correlations were computed for measurements of curve peak amplitude, curve width, and pressure at curve peak at both test frequencies under investigation in order to determine if a relationship existed between right and left ear tympanometry curves.

Curve Peak Amplitude

Right ear versus left ear correlations for measurements of curve peak amplitude are shown in Table I. Correlations of +.88 at 220 Hz and +.90 at 660 Hz were significant at the .05 and .01 confidence levels. (See Appendix D, Table I for measurements of curve peak amplitude for each subject.)

Curve Width

Table II displays the between-ear correlations for measurements of curve width at 220 and 660 Hz. Correlations for measurements of curve width listed in Table II are +.88 at 220 Hz and

TABLE I

CORRELATION (PEARSON r) * BETWEEN RIGHT AND LEFT EAR MEASUREMENTS OF CURVE PEAK AMPLITUDE

Curve Peak Amplitude for Right Ears vs Curve Peak Amplitude for Left Ears	
220 Hz	660 Hz
+.88	+.90

* rs necessary for significance;
at .05 = .30; at .01 = .42.

TABLE II

CORRELATION (PEARSON r) * BETWEEN RIGHT AND LEFT EAR MEASUREMENTS OF CURVE WIDTH

Curve Width for Right Ears vs Curve Width for left Ears	
220 Hz	660 Hz
+.82	+.70

* rs necessary for significance; at .05 = .30, at .01 = .42.

+.70 at 660 Hz. Similar to correlations for measurements of curve peak amplitude, correlations for curve width are significant at the .05 and .01 confidence levels. (See Appendix D, Table II for measurements of curve width for each subject.)

Pressure at Curve Peak

Correlations for right ear versus left ear measurements of pressure at curve peak at 220 and 660 Hz are shown in Table III. As indicated by Table III, correlations for measurements of pressure at curve peak are +.39 at 220 Hz and +.24 at 660 Hz. In contrast to the .05 and .01 levels of significance obtained for between-ear correlations for both measurements of curve peak amplitude and curve width, only the correlation for measurements of pressure at curve peak at 220 Hz was significant at the .05 level. (See Appendix D, Table III for measurements of pressure at curve peak for each subject.)

II. REGRESSION LINES AND CONFIDENCE INTERVALS FOR TYMPANOMETRY CURVE MEASUREMENTS

Tympanometry curve measurements for each subject were examined by computing regression line coefficients and constructing regression lines with confidence intervals for measurements of curve peak amplitude, curve width, and pressure at curve peak at 220 and 660 Hz. Confidence intervals of 95 percent were computed in order to determine the degree of accuracy with which left ear

TABLE III

CORRELATION (PEARSON r) * BETWEEN RIGHT AND LEFT EAR MEASUREMENTS OF PRESSURE AT CURVE PEAK

Pressure At Curve Peak For Right Ears vs Curve Peak For Left Ears	
220 Hz	660 Hz
+.39	+.24

* rs necessary for significance; at .05 = .30; at .01 = .42.

measurements may be predicted from right ear measurements according to linear regression.

Curve Peak Amplitude

Regression line coefficients for right and left ear measurements of curve peak amplitude were found to be .856 and .060 at 220 Hz and .860 and .198 at 660 Hz. Regression lines with confidence intervals for measurements of curve peak amplitude at both test frequencies are shown in Figures 4 and 5. The distributions of individual right and left ear measurements of curve peak amplitude depicted in Figures 4 and 5 show that all individual measurements are clustered rather closely around the regression lines. If lines were to be drawn parallel to and outside the confidence intervals at a distance of .07 mmhos for curve peak amplitude measurements at 220 Hz and .4 mmhos at 660 Hz, almost the entire number of right and left ear measurements would be confined within a narrow set of boundaries.

Curve Width

Regression line coefficients of .756 and 22.367 at 220 Hz and .722 and 30.772 at 660 Hz were computed for right and left ear measurements of curve width. Figures 6 and 7 display the regression lines with confidence intervals for curve width measurements at both test frequencies. Similar to the distributions of right and left ear measurements of curve peak amplitude, the

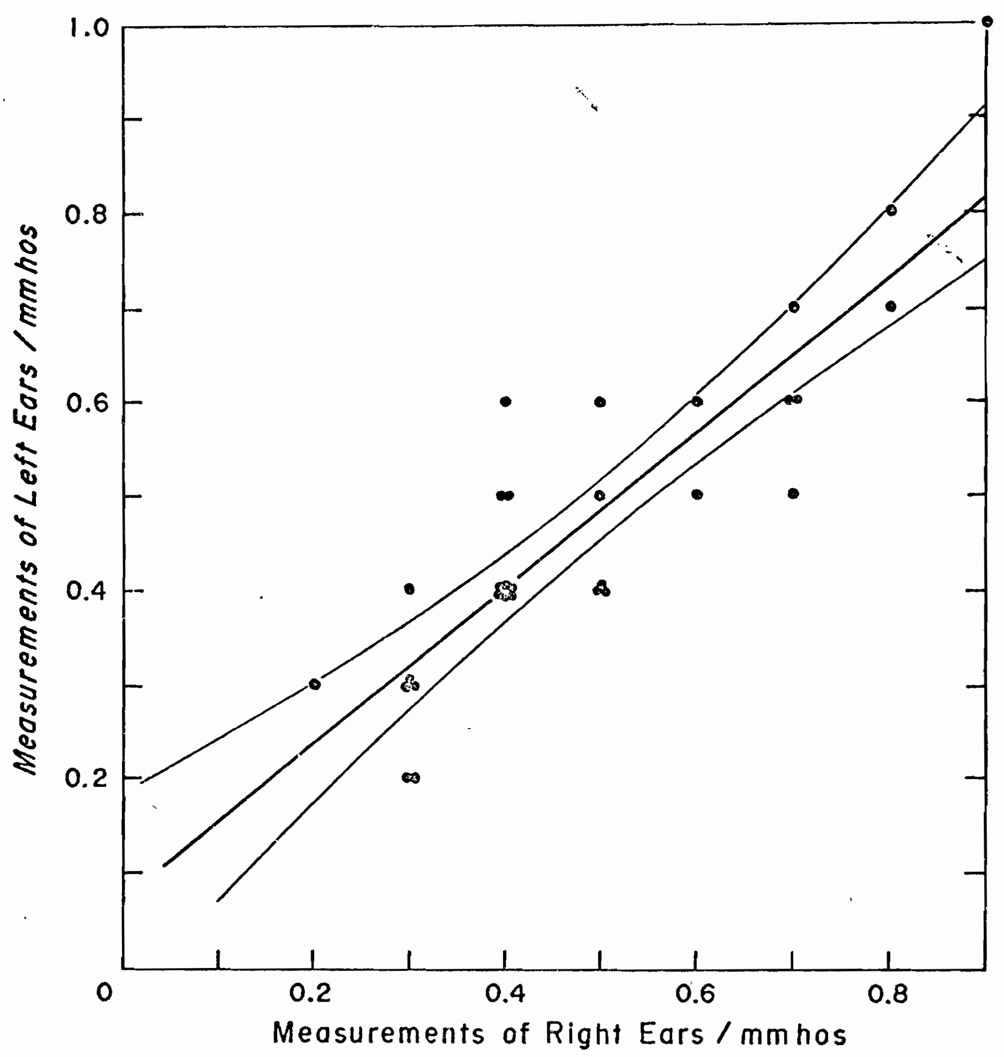

FIGURE 4. REGRESSION LINE AND 95% CONFIDENCE INTERVAL FOR INDIVIDUAL RIGHT AND LEFT EAR MEASUREMENTS OF CURVE PEAK AMPLITUDE AT 220 Hz.

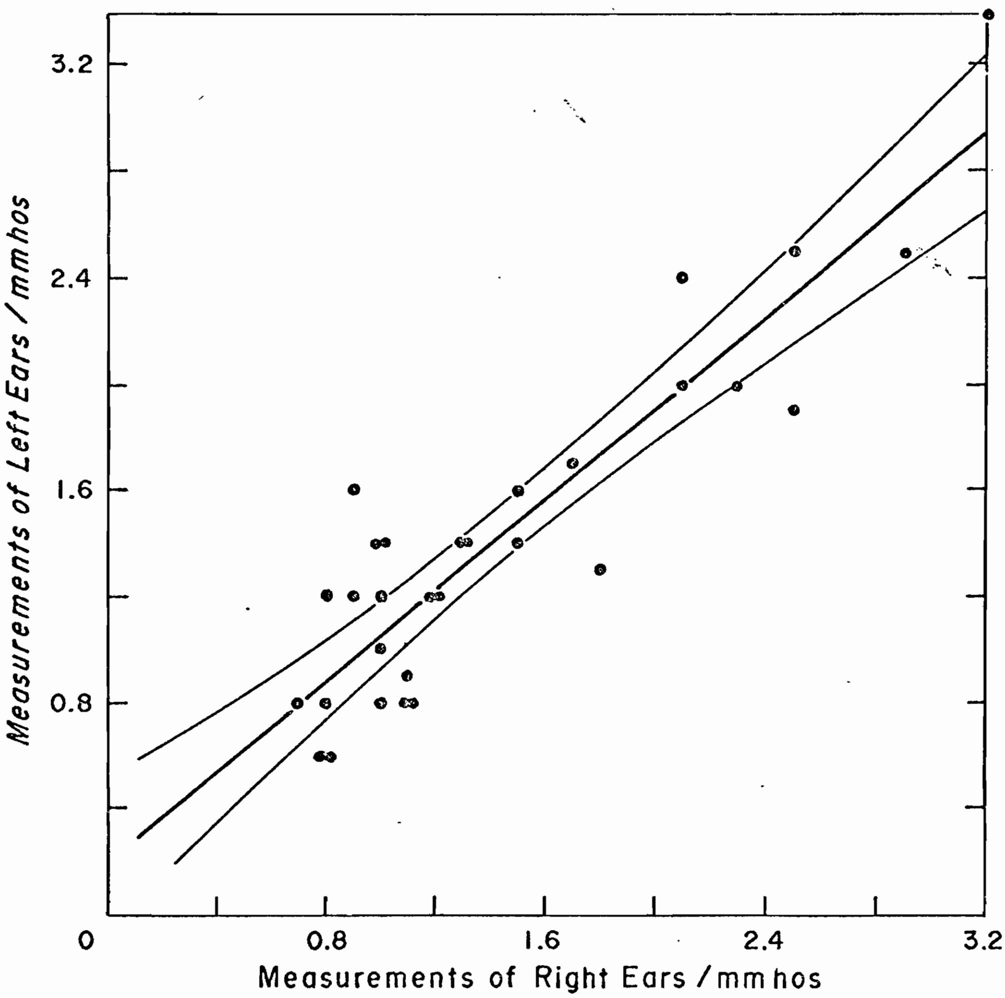

FIGURE 5. REGRESSION LINE AND 95% CONFIDENCE INTERVAL FOR INDIVIDUAL RIGHT AND LEFT EAR MEASUREMENTS OF CURVE PEAK AMPLITUDE AT 660 Hz.

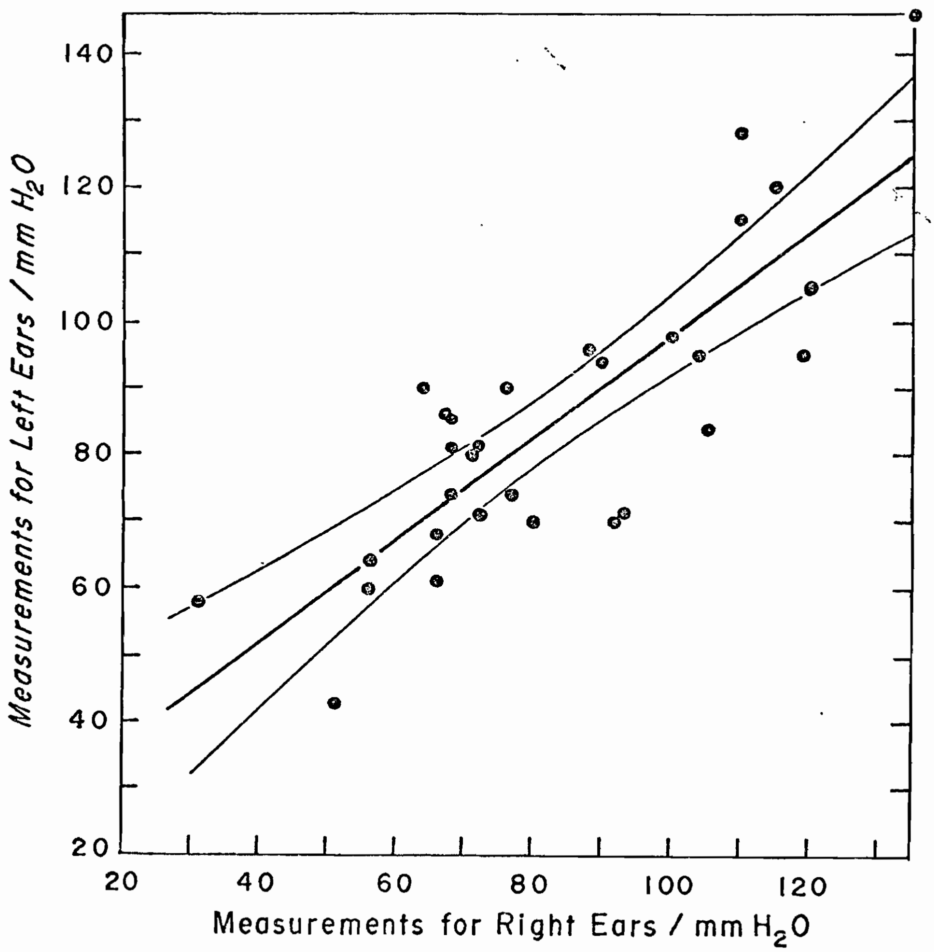

FIGURE 6. REGRESSION LINE AND 95% CONFIDENCE INTERVAL FOR INDIVIDUAL RIGHT AND LEFT EAR MEASUREMENTS OF CURVE WIDTH AT 220 Hz.

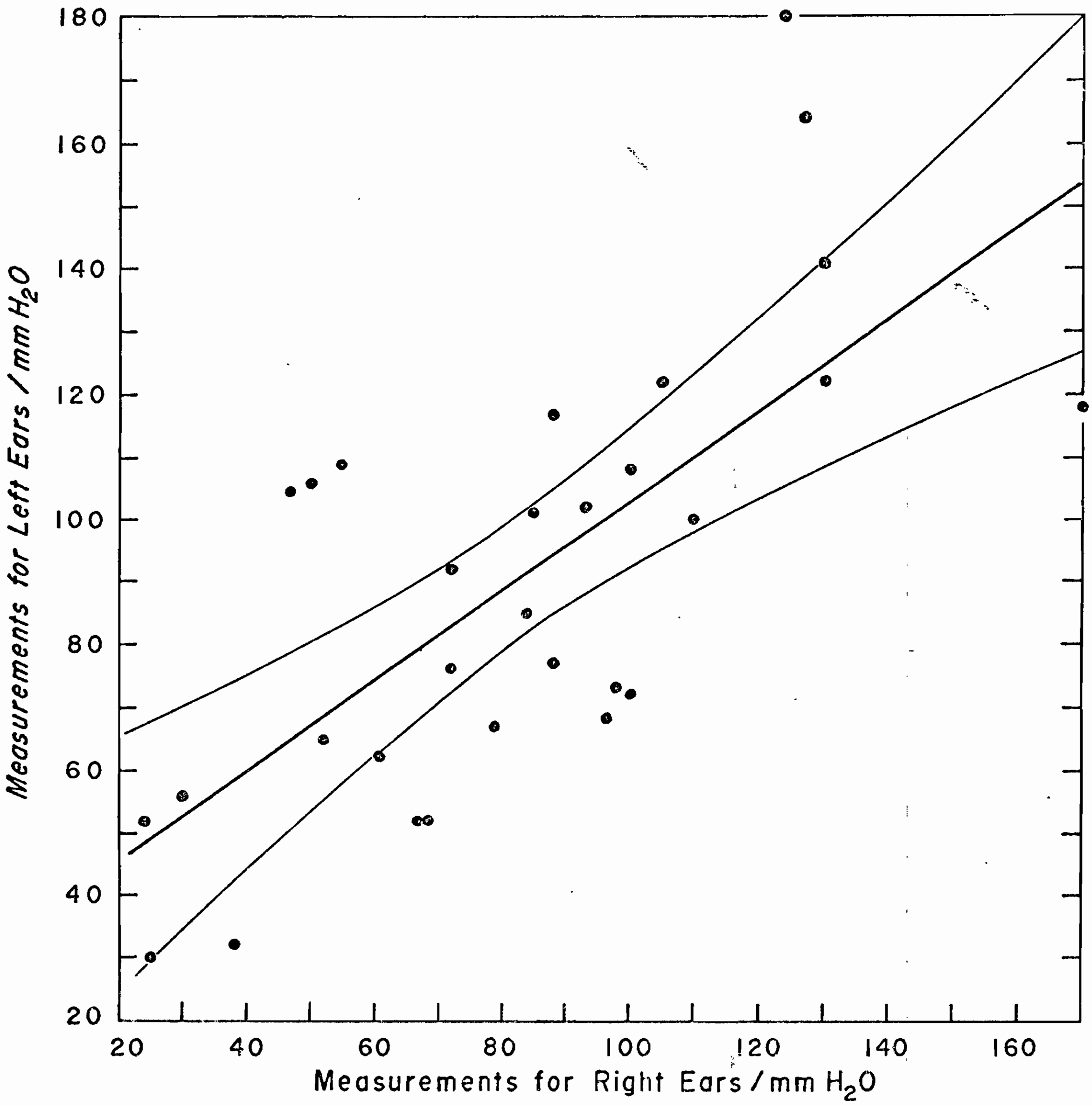

FIGURE 7. REGRESSION LINE AND 95% CONFIDENCE INTERVAL FOR INDIVIDUAL RIGHT AND LEFT EAR MEASUREMENTS OF CURVE WIDTH AT 660 Hz.

distribution of curve width measurements at 220 Hz (Figure 6) is concentrated near the regression line. The confidence interval in Figure 6 is also shown to deviate minimally from the regression line. Should this confidence interval be extended outward in both directions from the regression line an additional 11 mm H_2O, the right and left ear curve width measurements at 220 Hz for all but two subjects would be encompassed within this interval.

Measurements of curve width at 660 Hz shown in Figure 7 are more widely distributed than the same measurements at 220 Hz. The confidence interval in Figure 7 also deviates considerably more from the regression line than that observed for curve width measurements at 220 Hz indicating that a greater degree of variance exists for predicted left ear curve width measurements at 660 Hz. The confidence interval for curve width measurements at 660 Hz would need to be expanded an additional 23 mm H_2O on both sides of the regression line to include 29 of the 30 subjects.

Pressure at Curve Peak

Regression lines for right and left ear measurements of pressure at curve peak were drawn according to regression line coefficients of .327 and 1.007 at 220 Hz and .229 and 3.979 at 660 Hz. Regression lines with confidence intervals for measurements of pressure at curve peak at both test frequencies are shown in Figures 8 and 9. The most obvious descriptive feature of Figures 8 and 9 is the wide distribution of individual right and left ear

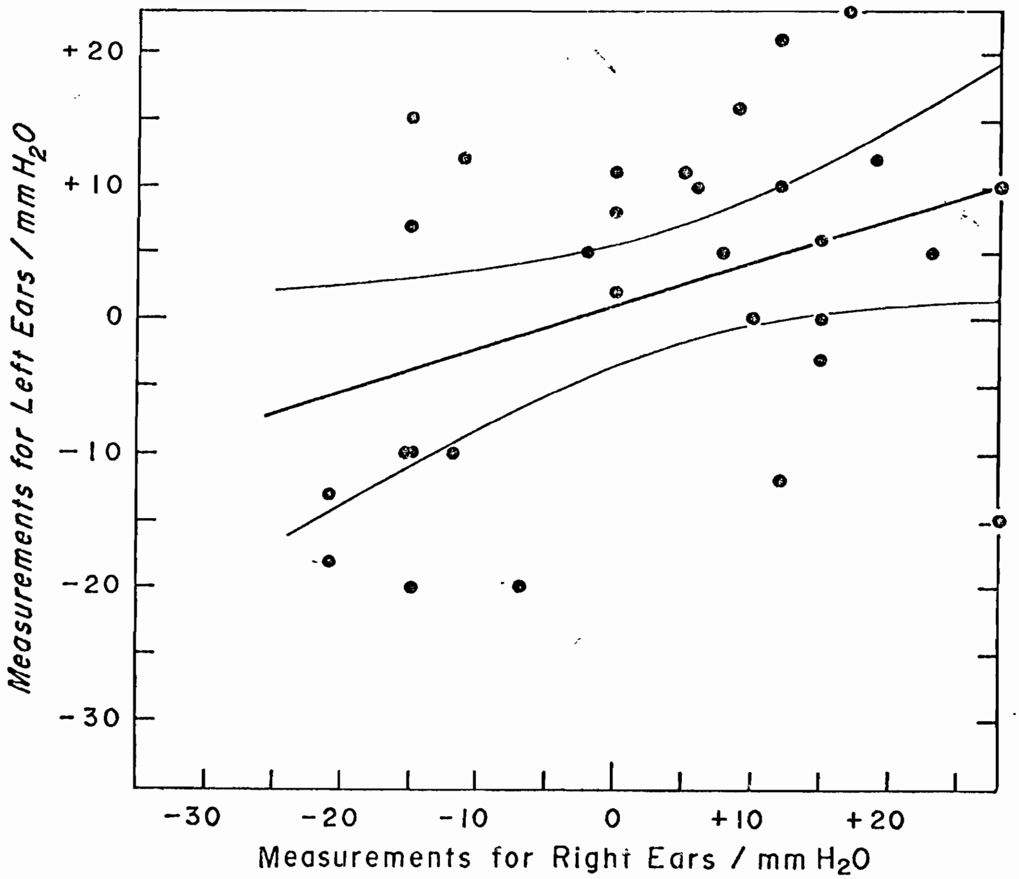

FIGURE 8. REGRESSION LINE AND 95% CONFIDENCE INTERVAL FOR INDIVIDUAL RIGHT AND LEFT EAR MEASUREMENTS OF PRESSURE AT CURVE PEAK AT 220 Hz.

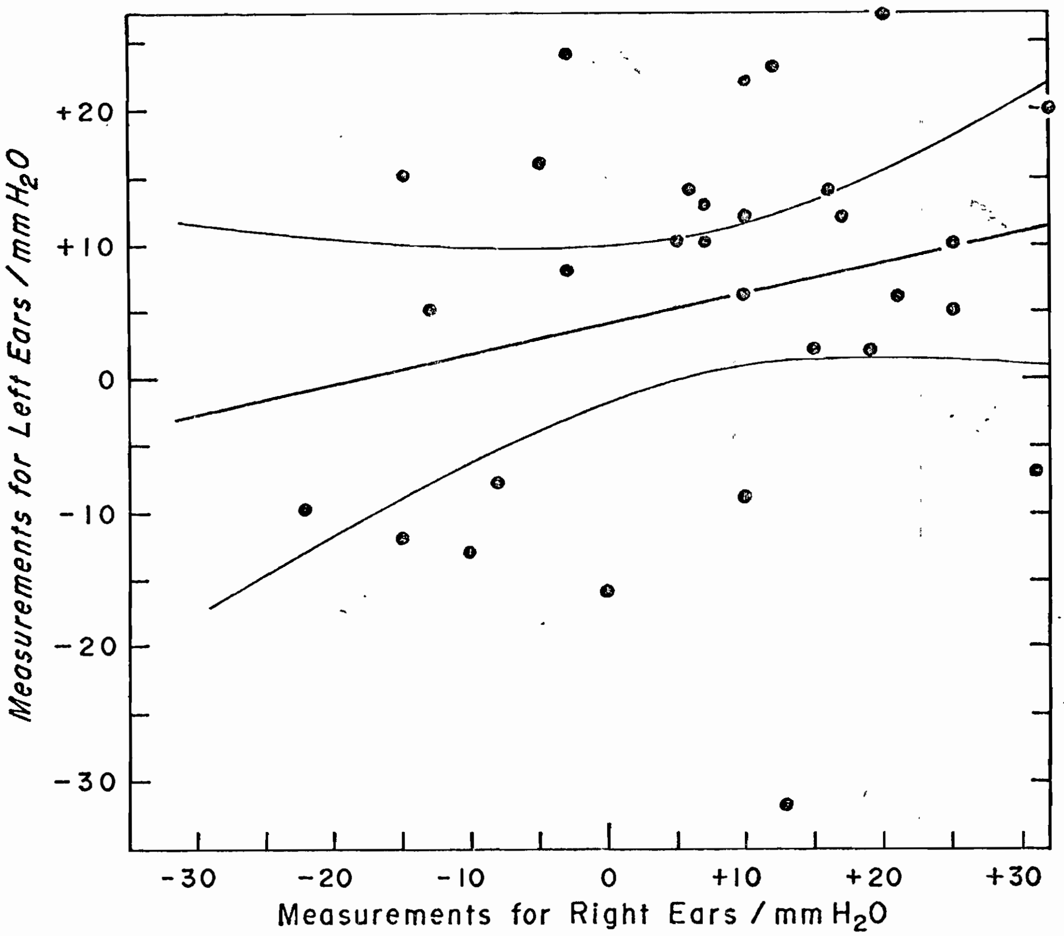

FIGURE 9. REGRESSION LINE AND 95% CONFIDENCE INTERVAL FOR INDIVIDUAL RIGHT AND LEFT EAR MEASUREMENTS OF PRESSURE AT CURVE PEAK AT 660 Hz.

pressure at curve peak measurements through the entire range limits for pressure at curve peak measurements. Confidence intervals for these measurements allow a considerable amount of variance for predicted left ear pressure at curve peak measurements.

III. PERCENTAGES OF MEASUREMENT VARIABILITY DUE TO BETWEEN-SUBJECT DIFFERENCES, BETWEEN-EAR DIFFERENCES, AND ERROR OF MEASUREMENT

Analysis of variance was used to determine the amount that each of three sources of measurement variability (differences between subjects, differences between individual right and left ears, and error of measurement) contributed to the total measurement variability for tympanometry curve measurements at 220 and 660 Hz. The sum of squares for each source of measurement variability was divided into the total sum of squares for all three sources of measurement variability. This was done to determine the percentage that each source of measurement variability contributed to the total measurement variability for the measures under investigation.

Curve Peak Amplitude

Table IV shows the percentage of total measurement variability due to between-subject differences, between-ear differences, and error of measurement for measurements of curve peak amplitude at 220 and 660 Hz. As indicated by Table IV, 100 percent of the measurement variability for measurements of curve peak

TABLE IV

PERCENTAGES OF VARIATION IN MEASUREMENTS OF CURVE PEAK AMPLITUDE DUE TO DIFFERENCES BETWEEN RIGHT AND LEFT EARS, DIFFERENCES BETWEEN SUBJECTS, AND ERROR OF MEASUREMENT

Curve Peak Amplitude			
Frequencies	Differences Between Ears	Differences Between Subjects	Error of Measurement
220 Hz	0%	100%	0%
660 Hz	0%	95.15%	4.85%

amplitude at 220 Hz is ascribed to between-subject differences with no measurement variability due to between-ear differences or error of measurement. At 660 Hz, 95.15 percent of the total measurement variability for curve peak amplitude measurements was explained by between-subject differences with 4.85 percent of the total measurement variability being attributed to error of measurement. Table IV also indicates that none of the total measurement variability at 660 Hz is attributed to between-ear differences.

Curve Width

The percentages of total measurement variability due to between-subject differences, between-ear differences, and error or measurement for measurements of curve width at 220 and 660 Hz are listed in Table V. According to Table V between-subject differences account for 90.61 percent of the total measurement variability occurring at 220 Hz and 83.93 percent at 660 Hz. Of the remaining measurement variability for curve width measurements, variability was largely due to error of measurement which accounts for 9.21 percent of the total measurement variability at 220 Hz and 14.78 percent at 660 Hz. Only a slight percentage of the total measurement variability, 0.18 percent at 220 Hz and 1.29 percent at 660 Hz, was due to between-ear differences.

TABLE V

PERCENTAGES OF VARIATION IN MEASUREMENTS OF CURVE WIDTH DUE TO DIFFERENCES BETWEEN RIGHT AND LEFT EARS, DIFFERENCES BETWEEN SUBJECTS AND ERROR OF MEASUREMENT

Curve Width			
Frequencies	Differences Between Ears	Differences Between Subjects	Error of measurement
220 Hz	0.18%	90.61%	9.21%
660 Hz	1.29%	83.93%	14.78%

Pressure at Curve Peak

Table VI displays the percentages of total measurement variability due to between-subject differences, between-ear differences, and error of measurement for measurements of pressure at curve peak at 220 and 660 Hz. As listed in Table VI, the percentages of total measurement variability attributed to between-subject differences are 66.72 percent at 220 Hz and 63.69 percent at 660 Hz. The second largest contributor to total measurement variability for measurements of pressure at curve peak was error of measurement, accounting for 33.16 percent of the total measurement variability at 220 Hz and 35.98 percent at 660 Hz. As was the case with percentages of total measurement variability due to between-ear differences recorded for measurements of curve peak amplitude and curve width, the percentages of measurement variability due to between-ear differences for measurements of pressure at curve peak at both test frequencies were minimal, .12 percent at 220 Hz and 0.33 percent at 660 Hz. In contrast to the percentages of total measurement variability due to between-subject differences and error of measurement recorded for curve peak amplitude and curve width measurements, the percentages of total measurement variability for pressure at curve peak measurements were substantially reduced for measurement variability due to between-subject differences and increased for measurement variability explained by error of measurement.

TABLE VI

PERCENTAGES OF VARIATION IN MEASUREMENT OF PRESSURE AT CURVE PEAK DUE TO DIFFERENCES BETWEEN RIGHT AND LEFT EARS, DIFFERENCES BETWEEN SUBJECTS, AND ERROR OF MEASUREMENT

Pressure at Curve Peak			
Frequencies	Differences Between Ears	Differences Between Subjects	Error of Measurement
220 Hz	0.12%	66.72%	33.16%
660 Hz	0.33%	63.69%	35.98%

IV. RELATIONSHIPS BETWEEN INDIVIDUAL RIGHT AND LEFT EAR MEASUREMENTS

Differences between individual right and left ear measurements of curve peak amplitude, curve width, and pressure at curve peak at 220 and 660 Hz were computed. Using all right ear measurements as a baseline, the amount that left ear measurements differed from right ear measurements was calculated as a positive or negative deviation to demonstrate between-ear measurement relationships for each subject. The mean amount of between-ear measurement differences was computed for all subjects for the measurements under investigation.

Curve Peak Amplitude

Between-ear relationships for measurements of curve peak amplitude at 220 and 660 Hz (Figures 10 and 11) show a general tendency for the number of left ear measurements to be equally placed above and below the baseline for right ear measurements. These relationships also indicate that the magnitudes of differences between right and left ears for measurements of curve peak amplitude are fairly normally distributed with between-ear differences ranging from 0.0 to 0.2 mmhos at 220 Hz and from 0.0 to 0.7 mmhos at 660 Hz. No between-ear differences are demonstrated by 43 percent of the subjects represented in Figure 10 and 20 percent of the subjects in Figure 11. The mean differences between right and left ear measurements for all subjects were .063 at 220 Hz and .223 at 660 Hz.

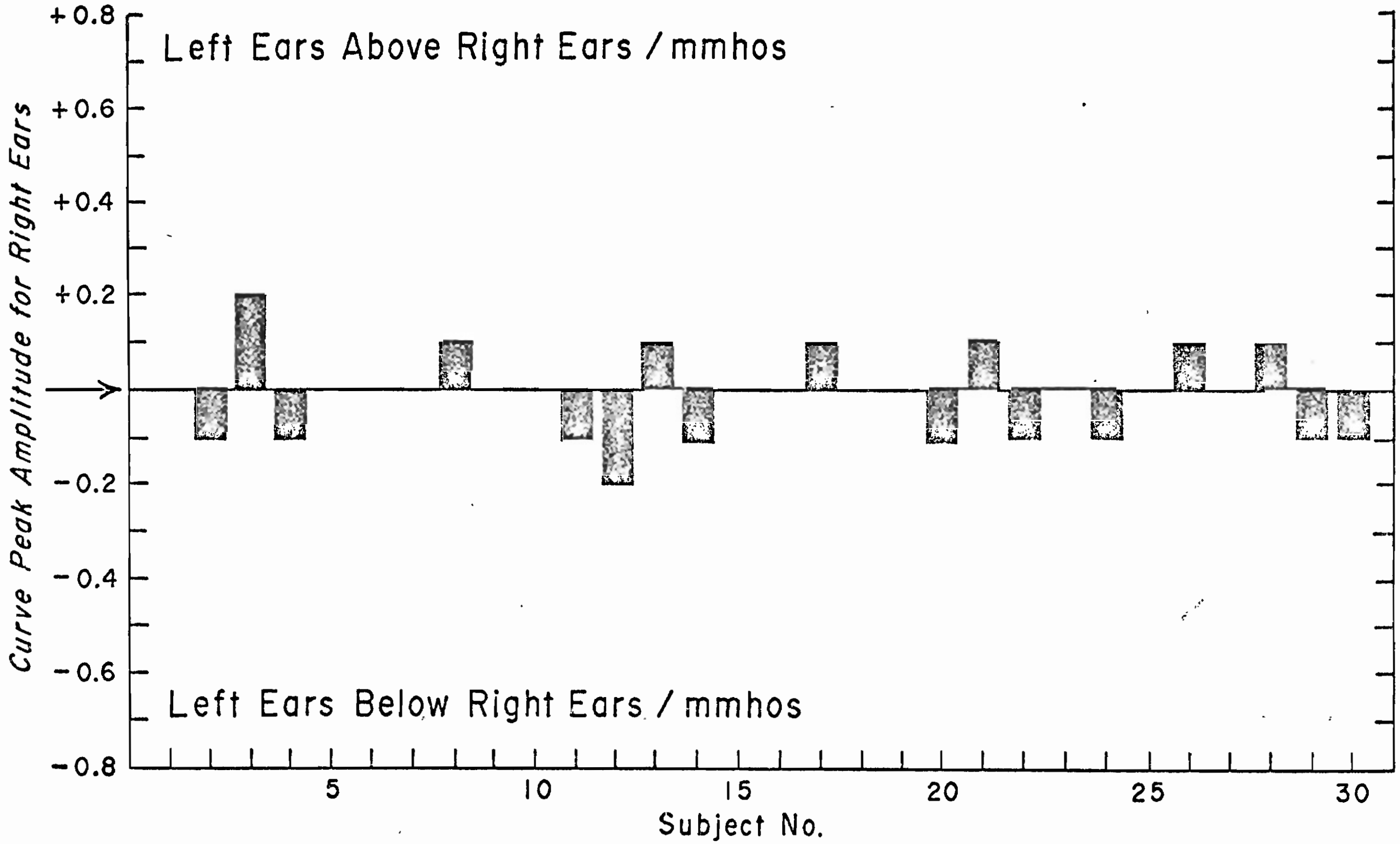

FIGURE 10. RELATIONSHIPS BETWEEN RIGHT AND LEFT EARS FOR MEASUREMENTS OF CURVE PEAK AMPLITUDE AT 220 Hz.

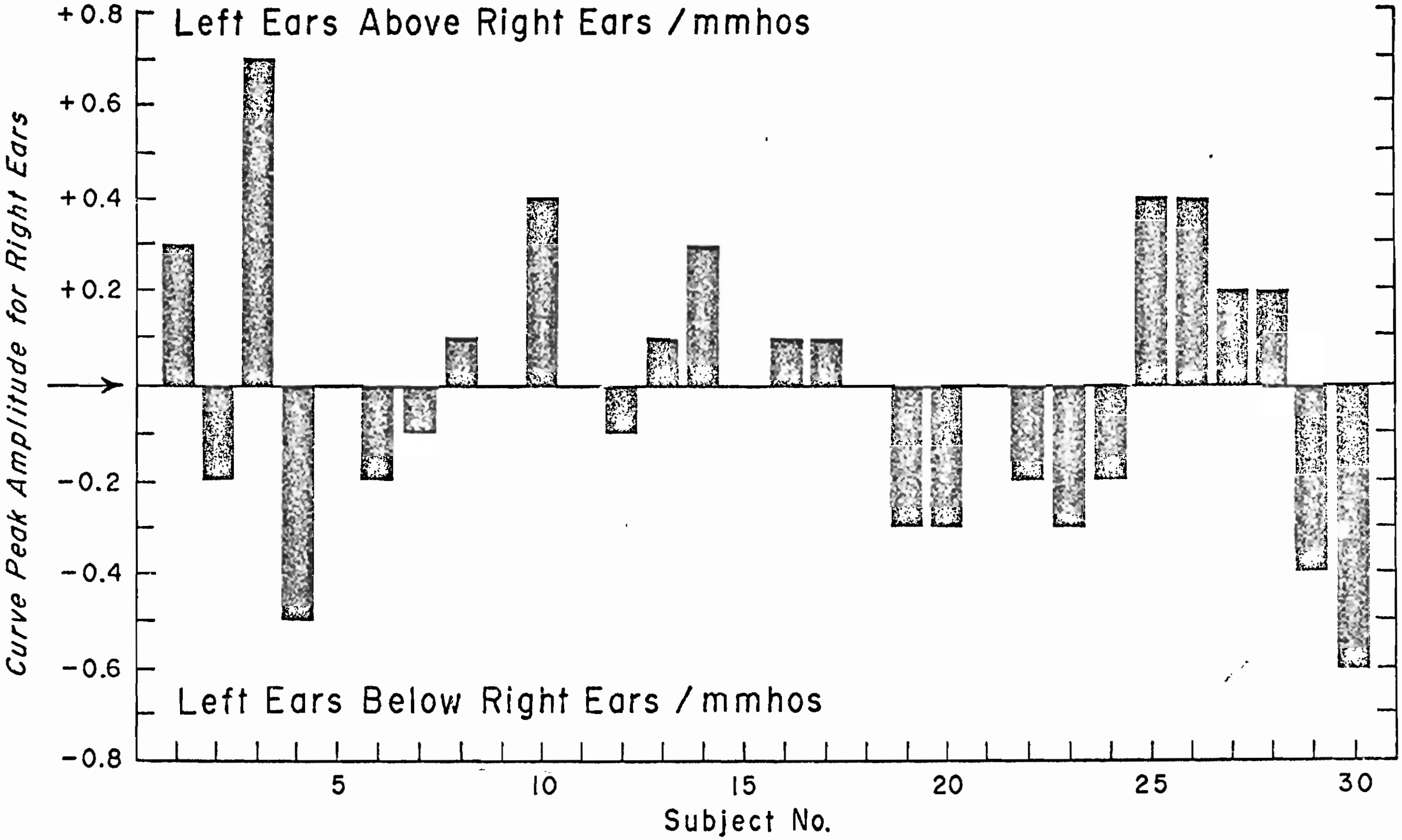

FIGURE 11. RELATIONSHIPS BETWEEN RIGHT AND LEFT EARS FOR MEASUREMENTS OF CURVE PEAK AMPLITUDE AT 660 Hz.

Curve Width

As illustrated by Figures 12 and 13, there is a slight tendency for left ear measurements to differ in a positive direction from the baseline for right ear measurements of curve width at 220 and 660 Hz. Figure 12 shows that between-ear differences range from 0 to 27 mm H_2O for measurements of curve width at 220 Hz with half of these differences being grouped between 0 and 9 mm H_2O. Between-ear differences range from 1 to 58 mm H_2O for measurements of curve width at 660 Hz according to Figure 13 and half of these differences are contained within a range of 1 to 17 mm H_2O. Computed means for differences between right and left ear measurements of curve width were 11.23 mm H_2O at 220 H_z and 22 mm H_2O at 660 Hz.

Pressure at Curve Peak

The relationships between right and left ear measurements of pressure at curve peak at 220 and 660 Hz (Figures 14 and 15) indicate that about an equal number of left ear measurements deviate in both a positive and negative direction from the baseline for right ear measurements. The magnitude of differences between right and left ear measurements of pressure at curve peak ranged from 2 to 43 mm H_2O at 220 Hz (Figure 14) and from 0 to 45 mm H_2O at 660 Hz (Figure 15). Figures 14 and 15 show that half of the between-ear differences range between 2 and 9 mm H_2O at 220 Hz and that two-thirds of the between-ear differences at

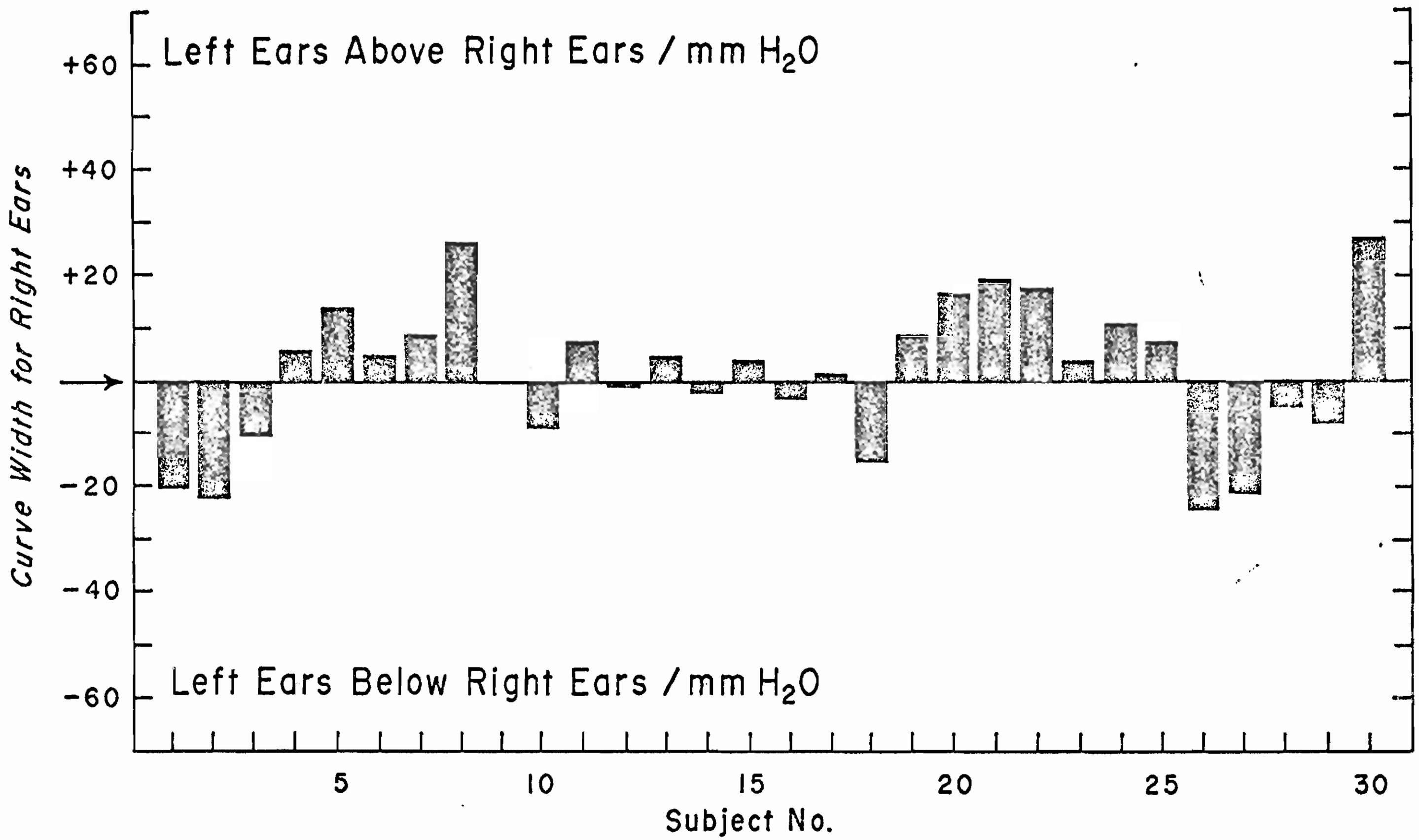

FIGURE 12. RELATIONSHIPS BETWEEN RIGHT AND LEFT EARS FOR MEASUREMENTS OF CURVE WIDTH AT 220 Hz.

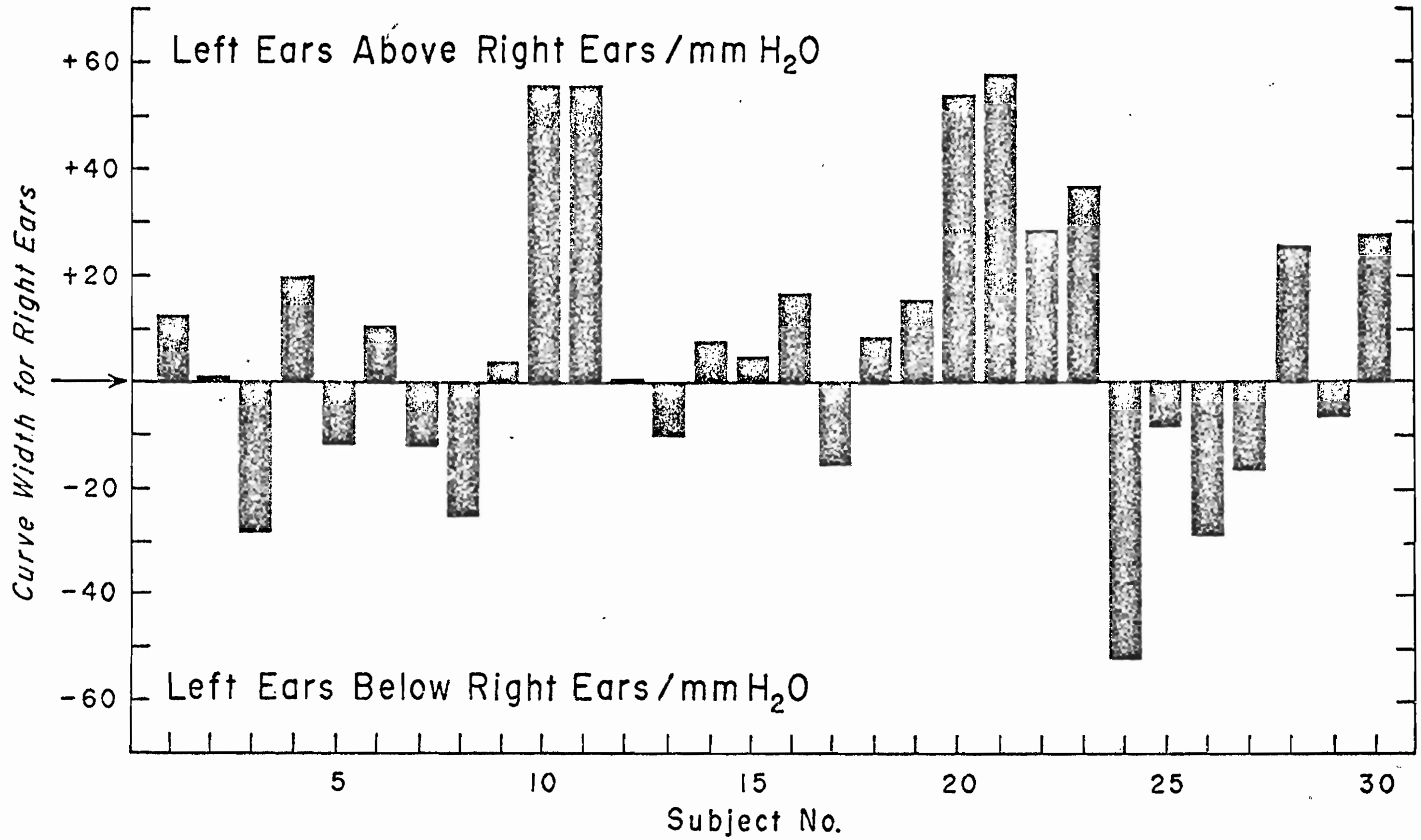

FIGURE 13. RELATIONSHIPS BETWEEN RIGHT AND LEFT EARS FOR MEASUREMENTS OF CURVE WIDTH AT 660 Hz.

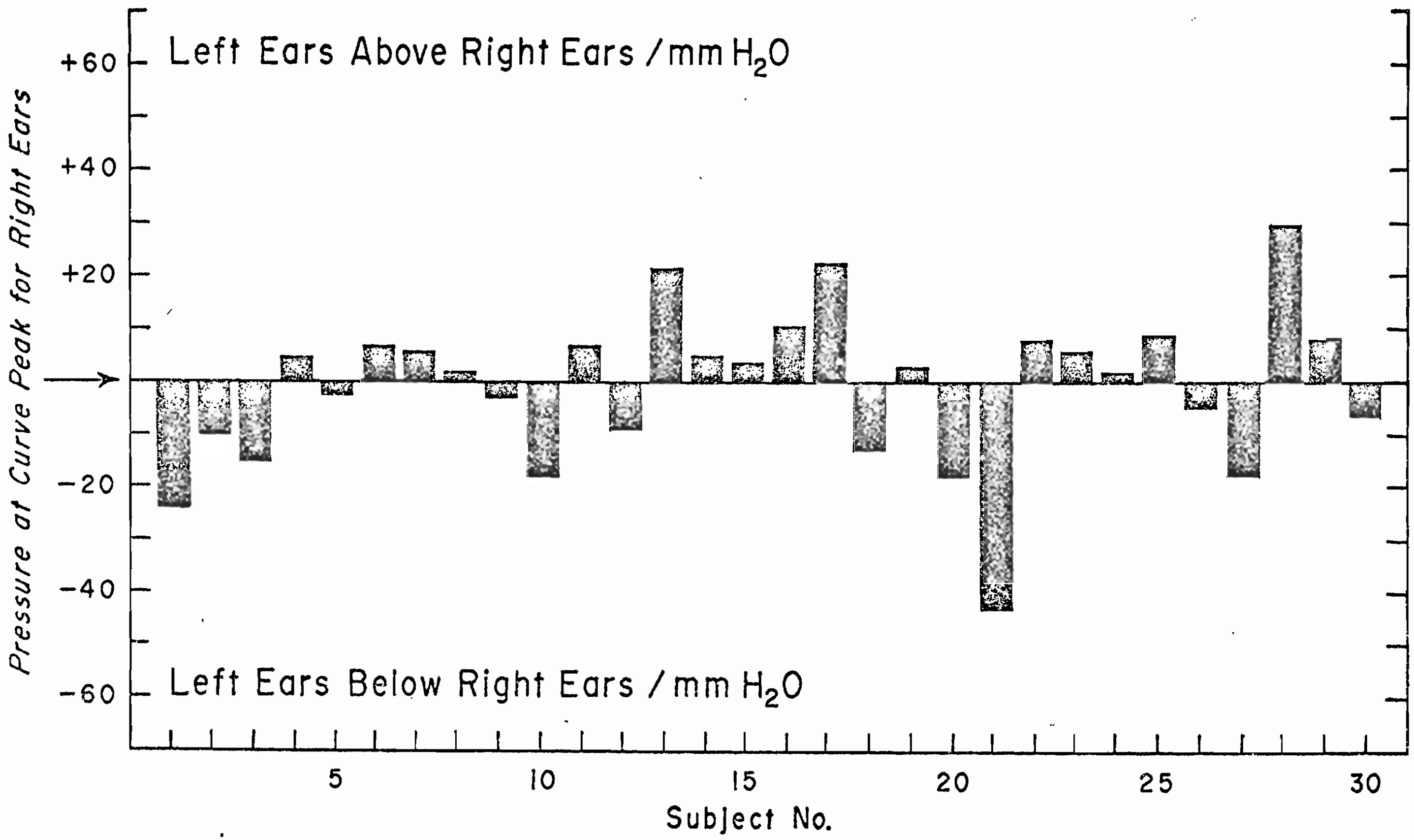

FIGURE 14. RELATIONSHIPS BETWEEN RIGHT AND LEFT EARS FOR MEASUREMENTS OF PRESSURE AT CURVE PEAK AT 220 Hz.

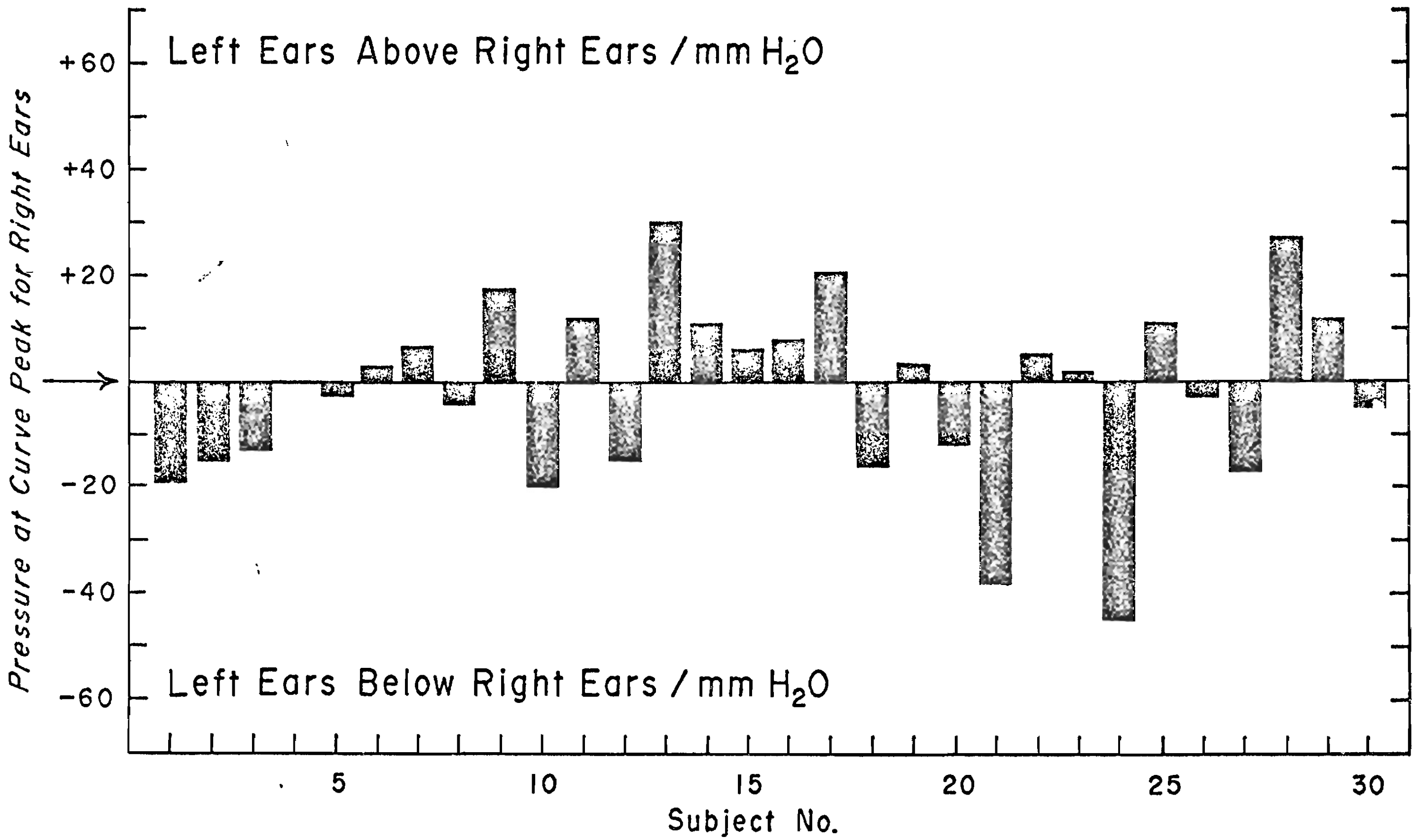

FIGURE 15. RELATIONSHIPS BETWEEN RIGHT AND LEFT EARS FOR MEASUREMENTS OF PRESSURE AT CURVE PEAK AT 660 Hz.

660 Hz are contained within a range of 0 to 15 mm H_2O. Means for differences between right and left ear measurements of pressure at curve peak for all subjects were 11.43 mm H_2O at 220 Hz and 13.33 mm H_2O at 660 Hz.

V. RESULTS OF ADDITIONAL TESTING

Five of the thirty subjects were retested within two weeks after their initial testing session. None of these subjects subjectively noticed any change in hearing sensitivity or experienced anything suggestive of middle ear pathology during the interim between initial testing and retest. The test procedure for retest was the same as that used in the original testing session. This was done as a check on the reliability of the measures obtained in the main study.

A comparison of initial and retest measures of curve peak amplitude for the same subject yielded differences that ranged from 0.0 to 0.1 mmhos at 220 Hz for right and left ears and from 0.0 to 0.2 mmhos for right ears and 0.0 to 0.1 mmhos for left ears at 660 Hz for the five subjects tested. The mean of the differences for measures of curve peak amplitude for the two testing sessions was 0.02 mmhos for right and left ears at 220 Hz and 0.10 mmhos for right ears and 0.06 mmhos for left ears at 660 Hz (Appendix E, Tables IV and V).

Differences ranging from 0 to 22 mm H_2O for right ears and 1 to 13 mm H_2O for left ears at 220 Hz and from 2 to 25 mm H_2O for right ears and 0 to 9 mm H_2O for left ears at 660 Hz were obtained between initial and retest measures of curve width for the five subjects tested. The means for these differences were 10.60 mm H_2O for right ears and 6.40 mm H_2O for left ears at 220 Hz and 11.20 mm H_2O for right ears and 5.40 mm H_2O for left ears at 660 Hz (Appendix E, Tables IV and V).

Differences obtained between initial and retest measures of pressure at curve peak for the five subjects tested ranged from 3 to 16 mm H_2O for right ears and 0 to 13 mm H_2O for left ears at 220 Hz and from 2 to 31 mm H_2O for right ears and 2 to 13 mm H_2O for left ears at 660 Hz. The means for these differences for measures of pressure at curve peak were 8.80 mm H_2O for right ears and 4.20 mm H_2O for left ears at 220 Hz and 15.00 mm H_2O for right ears and 6.20 mm H_2O for left ears at 660 Hz (Appendix E, Tables IV and V).

VI. BETWEEN-SUBJECT MEASUREMENTS

Table VII lists ranges, means, and standard deviations computed for tympanometry curve measurements on all 60 normal ears under investigation. According to Table VII, measurements of curve peak amplitude for all ears range from 0.2 to 1.0 mmhos at 220 Hz and from 0.6 to 3.4 mmhos at 660 Hz. Means for all measurements of curve peak amplitude are 0.48 mmhos at 220 Hz and 1.40 mmhos at 660 Hz with corresponding standard deviations of .17 and .72 mmhos.

TABLE VII

BETWEEN-SUBJECT RANGES, MEANS, AND STANDARD DEVIATIONS FOR MEASUREMENTS OF CURVE PEAK AMPLITUDE, CURVE WIDTH, AND PRESSURE AT CURVE PEAK AT 220 AND 660 HZ

	Curve Peak Amplitude (mmhos)		Curve Width ($mm\ H_20$)		Pressure at Curve Peak (mmH_20)	
	220 Hz	660 Hz	220 Hz	660 Hz	220 Hz	660 Hz
RANGE	0.8	2.8	115	156	49	64
MEAN	0.48	1.40	84.92	86.23	+2.38	+6.43
S.D.	0.17	0.72	22.21	34.57	12.69	13.42

Measurements of curve width for all ears ranged from 31 to 146 mm H_2O at 220 Hz and from 24 to 180 mm H_2O at 660 Hz (Table VII). Means and standard deviations for all measurements of curve width as listed in Table VII are 84.92 and 22.21 mm H_2O at 220 Hz and 86.23 and 34.57 mm H_2O at 660 Hz.

As indicated by Table VII, all measurements of pressure at curve peak range from -21 to +28 mm H_2O at 220 Hz and from -32 to +32 mm H_2O at 660 Hz. Means for these measurements are +2.38 mm H_2O at 220 Hz and +6.43 mm H_2O at 660 Hz. Corresponding standard deviations are shown in Table VII to be 12.69 and 13.42 mm H_2O.

CHAPTER V

DISCUSSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

The results of the Pearson Product-Moment Correlations between right and left ear tympanometry curve measurements show that, under the conditions of this study, significant correlations exist between right and left ear tympanometry curve measurements for the normal-hearing subjects utilized in this study. Of the three tympanometry curve measurements investigated, only the between-ear correlation for tympanometry curve measurements of pressure at curve peak at 660 Hz did not demonstrate correlative significance.

According to the results of analysis of variance, the total measurement variability observed for the tympanometry curve measurements is predominantly due to differences between subjects with little or no measurement variability due to differences between each subject's right and left ears. Error of measurement contributed minimally to total measurement variability for measurements of curve peak amplitude and curve width, but accounted for a larger percentage of total measurement variability for measurements of pressure at curve peak. Although the percentage of total measurement variability due to between-subject differences and error of measurement was proportionately different for all tympanometry curve measurements, the percentage of total measurement variability attributed to between-ear differences was consistantly negligible.

Regression lines and confidence intervals for the right and left ear measurements of curve peak amplitude and curve width for each subject at 220 and 660 Hz (Figures 4, 5, 6 and 7) showed that most of these measurements were concentrated near the regression lines and that almost the entire number of these measurements could be confined within relatively narrow sets of boundaries. These observations are consistant with the obtained high correlations between right and left ear measurements of curve peak amplitude and curve width.

Individual right and left ear measurements of pressure at curve peak at 220 and 660 Hz were widely distributed around their respective regression lines (Figure 8 and 9). This would indicate that a lesser degree of interdependency exists between these individual right and left ear measurements within the established ranges for all pressure at curve peak measurements at 220 and 660 Hz.

Between-subject data yielded results which show that measurements of curve peak amplitude at 660 Hz are larger than the same measurements at 220 Hz for all subjects in this study. While curve peak amplitude measurements are larger at 660 Hz than at 220 Hz, mean measurements of curve width are similar for both test frequencies. As such, curve width decreases relative to increases in curve peak amplitude. Means for all measurements of pressure at curve peak at 220 and 660 Hz indicate a minor positive deviation of the curve peak from 0 mm H_2O. This deviation is slightly more for measurements at 660 Hz. These findings agree with those of Liden, Peterson and Bjorkman (1970 b). Liden, Peterson and Bjorkman also suggest that a hysteresis effect of the impedance of the tympanic membrane to applied air pressure may be responsible for some of the observed shifts of the peak of the tympanometry curve. All deviations of pressure at curve peak observed for the subjects in the present study, however, fell within a range of plus and minus 32 mm H_2O from 0 mm H_2O. The total sample produced tympanometry curve measurements which conform to what has been described as normal tympanometry curves (Liden, 1970 a and b; Jerger, 1970).

An equal number of left ear tympanometry curve measurements differ in both positive and negative directions from right ear measurements. It also has been shown that the ranges of these between-ear differences are consistently greater for tympanometry curve measurements at 660 Hz than at 220 Hz (Figures 10, 11, 12, 13, 14 and 15). All ranges of between-ear differences, especially for measurements of curve peak amplitude and curve width, however, are much reduced in comparison to the ranges of differences between subjects for the same measurements (Table VII). This illustrates that a much closer relationship exists between individual right and left ear tympanometry curve measurements than between the measurements for all subjects in this study.

The results of repeat testing (Appendix E, Tables IV and V) show a high degree of consistency for measurements of curve peak amplitude with less test-retest consistency being observed for measurements of curve width and pressure at curve peak. Test-retest comparisons also show that measurements of curve peak amplitude, curve width, and pressure at curve peak are generally not as consistent at 660 Hz as they are at 220 Hz. This lesser degree of test-retest consistency for measurements of curve peak amplitude at 660 Hz may be explained partially by the fact that millimho values are doubled for each division unit on the tympanogram for measurements at 660 Hz in comparison to values for measurements at 220 Hz. Test-retest variations of the same magnitude would result in curve peak amplitude values at 660 Hz being twice as large as those at 220 Hz. Reduced test-retest consistency for pressure at curve peak measurements at 660 Hz may be in part due to an increased influence of a hysteresis affect upon these measurements compared to the impact of such an affect upon the same measurements at 220 Hz.

Of the three tympanometry curve characteristics investigated, curve peak amplitude and curve width describe tympanometry curve configurations while pressure at curve peak locates tympanometry curves on the tympanogram relative to 0 mm H_2O. As mentioned earlier the only major feature distinguishing tympanometry curves indicative of ossicular chain discontinuity or otosclerosis from normal tympanometry curves is relatively different points of maximum compliance (curve peak amplitude) on a compliance continuum. Although measurements of curve width have been shown to vary relative to increases and decreases in measurements of curve peak amplitude (Liden, Peterson and Bjorkman, 1970 b), the measurement of curve peak amplitude is the single tympanometry curve characteristic which can best differentiate between a pathologically mobile or stiff middle ear and a normal middle ear (Jerger, 1970; Liden, Peterson and Bjorkman, 1970 a and b; Lamb, 1971).

It has been suggested that due to individual anatomical symmetry, within-subject right and left ear tympanometry curves for normal-hearing subjects should be in very close agreement in contrast to a range of normalcy based on between-subject measures. The results of this investigation have demonstrated that for practical purposes, no significant difference exists between right and left ear tympanometry curve measurements of curve peak amplitude and curve width, while a wide range of between-subject variation is shown for these same measurements under the conditions of this study.

The close between-ear relationships for tympanometry curve measurements demonstrated by this study provide a basis for developing a more narrowly defined range of normalcy. Such a definition of tympanometric normalcy would specify that not only must individual right and left ear tympanometry curves fall within the range of normalcy established on between-subject tympanometry curve measurements, but also must not differ significantly. If some difference should exist between right and left ear measurements, it would be expected that this difference would be minimal and would not exceed the ranges established for normal between-ear differences. This definition of tympanometric normalcy should allow more precise clinical differentiation between normal and pathological middle ears than that standard provided by the present range of normalcy derived from between-subject tympanometry curve measurements. Should a difference between within-subject right and left ear tympanometry curves exceed the ranges established for normal between-ear differences, the clinician would be alerted to the possibility of middle ear pathology. Further clinical follow-up could then confirm the presence or absence of middle ear pathology, the side affected, and the type and degree of existing pathology.

Because of its recent production, the Grason-Stadler Otoadmittance Meter has not been used extensively in clinical and research settings. As such, normative standards for measurements obtained with this instrument have not yet been established. Although the results of the present investigation provide normative tympanometric data for a small number of subjects, additional research encompassing a larger population of normal-hearing individuals must be conducted with the Otoadmittance Meter before standards for tympanometric normalcy can be established for broad clinical application.

Normative tympanometric standards need to be established for various age groups. The middle ear undergoes a certain amount of anatomical and physiological change due to the aging process. This has been referred to as "conductive presbycusis" by Goodhill (1969). Such modifications of the middle ear system would suggest the necessity for further research designed to investigate possible between-subject and between-ear variations in tympanometry curve configurations due to age.

Another possible area of research could be directed towards the development of normative standards for between-subject and between-ear measurements of absolute impedance. Such research utilizing the Otoadmittance Meter would need to be conducted on a large population of normal-hearing individuals in order to establish such standards for general clinical use.

Absolute admittance measurements in millimhos may be converted to values in acoustic ohms. This conversion would allow absolute admittance measurements for normal-hearing subjects obtained with the Otoadmittance Meter to be compared to absolute impedance measurements acquired with the Madsen Acoustic Impedance Meter. The results of such a comparison would be useful for interpreting similar clinical data generated from both the Otoadmittance Meter and the Madsen Acoustic Impedance Meter.

A number of factors may be responsible for the percentage of total measurement variability due to error of measurement observed for the tympanometry curve measurements in this study. An investigation to determine these factors could provide information which would facilitate a better understanding of the variables inherent to the administration of tympanometry.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Tympanometry has been used for a number of years as a method for measuring middle ear function. Not only may tympanometry be used to distinguish between normal and pathological middle ears, but it also provides a means of making differential diagnoses of middle ear pathology. Tympanometric standards based upon between-subject measures for normal-hearing individuals have been established in order to differentiate normal tympanometry curves from pathological curves. These standards fail, however, to provide useful clinical norms for comparing within-subject right and left ear tympanometry curves contained within the range of normalcy established for between-subject measures. During this study interest was directed to the investigation of differences between right and left ear tympanometry curves for normal-hearing individuals. The broad purpose of this investigation was to provide information regarding the within-subject relationship between tympanometry curves for right and left ears in a sample of normal-hearing subjects. This was done in an attempt to define a within-subject range of tympanometric normalcy.

The question investigated by this study was as follows: Is there a difference between within-subject right and left ear tympanometry curves? To answer this question thirty normal-hearing individuals, 18 to 30 years of age, were used as subjects. Both ears of each subject were tested individually. To balance the effects of ordering, the right ears of all even-numbered subjects and the left ears of all odd-numbered subjects were the first ears tested. For all subjects, however, tympanometry was administered first at 220 Hz and then at 660 Hz for each ear tested. All tympanometry testing was conducted utilizing a combined mode of conductance and susceptance. Three characteristics, curve peak amplitude, curve width, and pressure at curve peak, were measured and compared for each tympanometry curve.

An analysis of the data obtained for the right and left ear tympanometry curve measurements led to the following conclusions:

1. Under the conditions of this investigation significant correlations were shown between right and left ear tympanometry curve measurements at both 220 and 660 Hz with the exception of pressure at curve peak measurements for 660 Hz. The proximities of individual right and left ear tympanometry curve measurements to their respective regression lines were consistent with these correlations.

2. Results of analysis of variance for the tympanometry curve measurements under investigation showed that total measurement variability was predominantly due to differences between subjects with only a slight amount of total measurement variability being attributed to differences between within-subject right and left ears.

3. Graphic representations of between-ear differences for all measurements under investigation illustrated that ranges of between-ear differences were much reduced in comparison to the computed ranges for between-subject measures. These representations also showed that approximately an equal number of left ear measurements deviated in both positive and negative directions from the baseline for right ear measurements.

In conclusion, the results obtained under the conditions of this investigation demonstrated that for practical purposes no significant clinical difference exists between within-subject right and left ear tympanometry curves. These findings would suggest that a definition of tympanometric normalcy should be based not only upon between-subject measures, but also upon between-ear comparisons. Such a definition of tympanometric normalcy would specify that not only must within-subject right and left ear tympanometry curves fall within the range of normalcy established for between-subject measures, but also that these between-ear measures must not be significantly different. This definition would narrow the standard for tympanometric normalcy allowing precise differentiation between normal and pathological middle ears when comparing within-subject right and left ear tympanometry curves.

The outcome of this study clearly demonstrated that significant correlations exist between individual right and left ear tympanometry curve configurations at both test frequencies. Reasons for these correlations were discussed. Areas of possible future investigation also were suggested.

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A P P E N D I X E S

APPENDIX A

SUBJECT INSTRUCTIONS

SUBJECT INSTRUCTIONS FOR TYMPANOMETRY TESTING

The following test is a method used for measuring middle ear function. You will hear two different test tones during the test administration. Please do not talk, remain quietly seated, and refrain as much as possible from making head movements and swallowing while testing is in process. Should you become uncomfortable during the testing procedure, please advise me of your discomfort so that I make whatever alterations are necessary. Are there any questions?

If you have any questions regarding the test results or how they relate to the measure of middle ear function, please feel free to ask those questions following test administration.

APPENDIX B

INSTRUMENTATION

Oscilloscope Frequency Counter X-Y Plotter Otoadmittance Meter

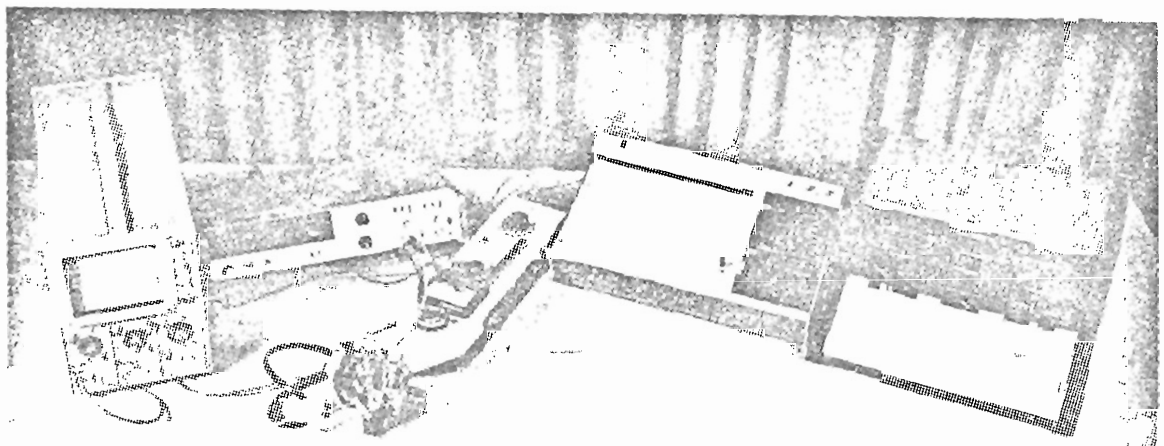


FIGURE 1. INSTRUMENTATION FOR TYMPANOMETRY TESTING.

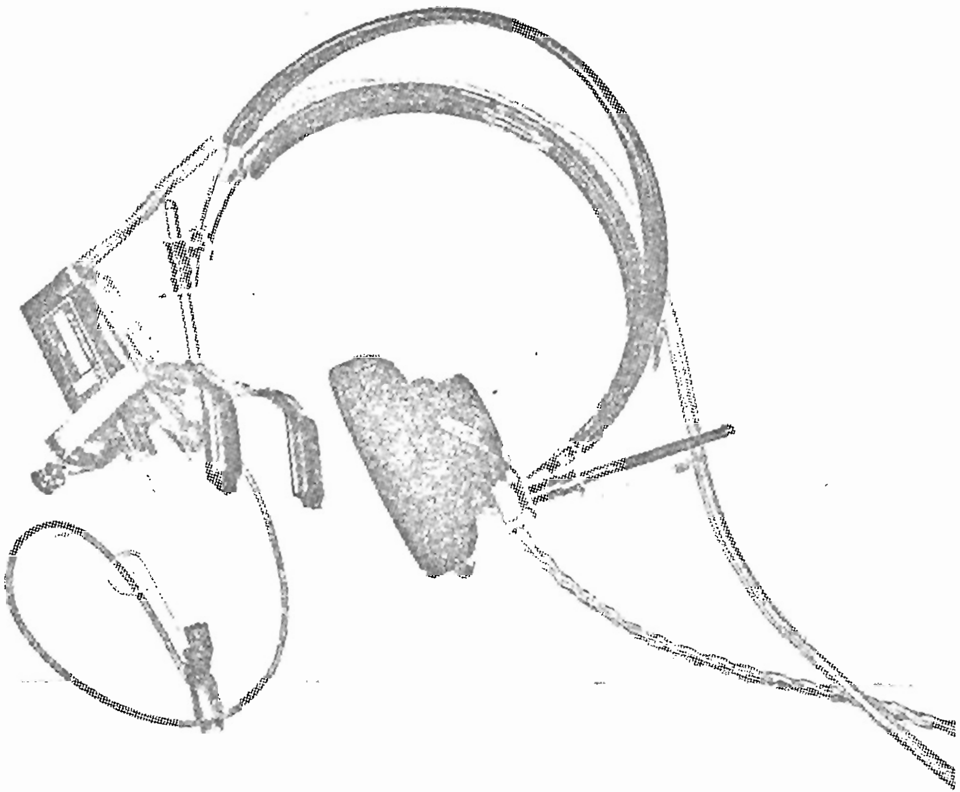


FIGURE 2. GRASON-STADLER OTOADMITTANCE METER HEADSET.

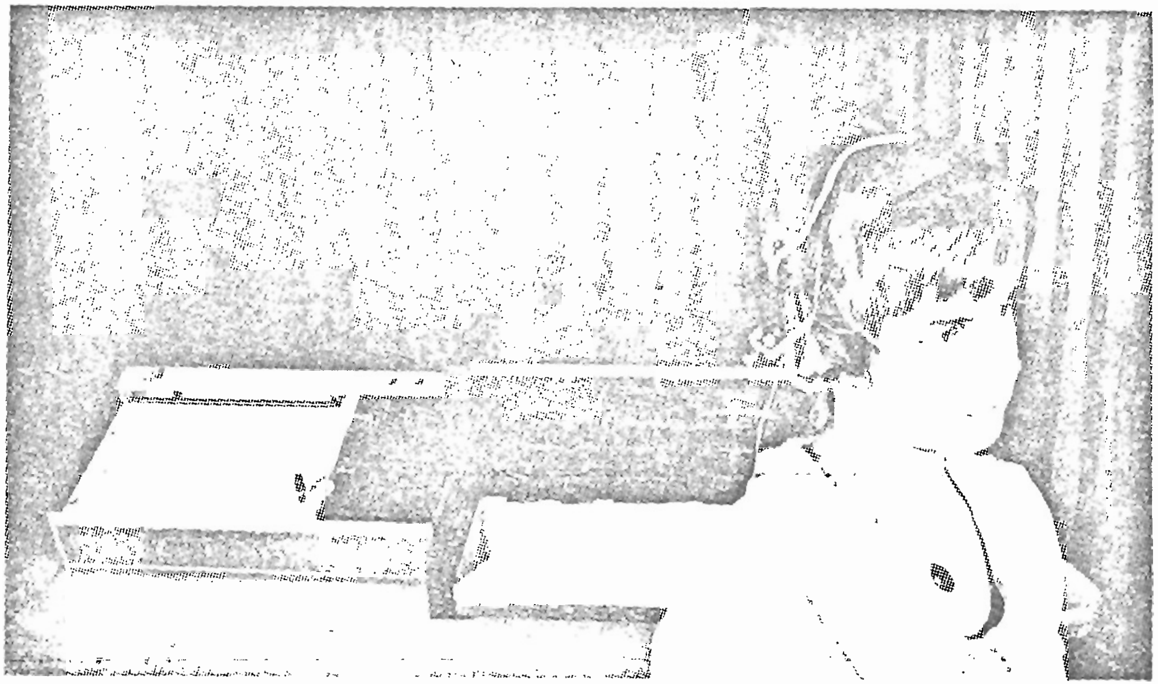
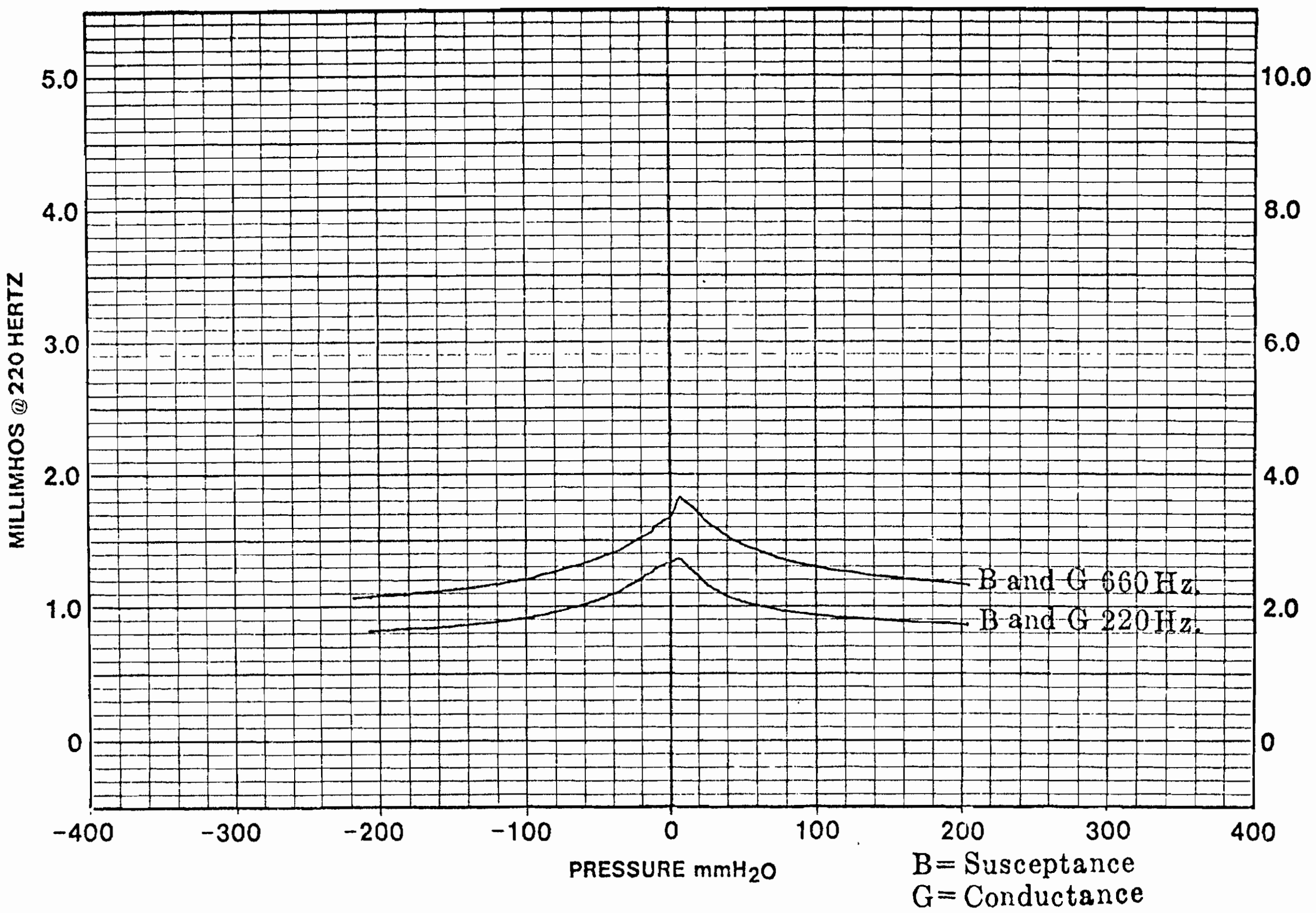


FIGURE 3. GRASON-STADLER OTOADMITTANCE METER HEADSET IN PLACE ON SUBJECT WITH EAR PROBE TIP INSERTED.

APPENDIX C

TYMPANOGRAM

SHOWN BELOW IS AN EXAMPLE OF SUBJECT TYMPANOMETRY CURVES ON A TYMPANOGRAM



APPENDIX D

INDIVIDUAL TYMPANOMETRY CURVE MEASUREMENTS

TABLE I

INDIVIDUAL MEASUREMENTS OF CURVE PEAK AMPLITUDE
FOR RIGHT AND LEFT EARS
AT 220 AND 600 HZ
IN mmhos*

Subject # Sex Age	Curve Peak Amplitude At 220 Hz		Curve Peak Amplitude At 660 Hz	
	R	L	R	L
1-M-25	.8	.8	2.1	2.4
2-F-26	.5	.4	1.1	.9
3-M-28	.4	.6	.9	1.6
4-F-21	.5	.4	1.8	1.3
5-F-21	.5	.5	1.2	1.2
6-F-22	.3	.3	.8	.6
7-M-21	.6	.6	2.1	2.0
8-F-25	.4	.5	1.5	1.6
9-F-26	.3	.3	1.2	1.2
10-F-21	.4	.4	.8	1.2
11-F-21	.6	.5	1.0	1.0
12-M-27	.7	.5	1.5	1.4
13-F-22	.2	.3	.7	.8
14-F-23	.5	.4	.9	1.2
15-F-28	.7	.7	2.5	2.5
16-M-28	.4	.4	1.3	1.4
17-F-23	.4	.5	1.3	1.4
18-F-26	.3	.3	.8	.8
19-F-27	.4	.4	1.1	.8
20-M-21	.7	.6	2.3	2.0
21-M-29	.5	.6	1.7	1.7
22-F-23	.3	.2	1.0	.8
23-F-28	.4	.4	1.1	.8
24-F-25	.3	.2	.8	.6
25-M-23	.4	.4	1.0	1.4
26-F-23	.3	.4	1.0	1.4
27-F-25	.4	.4	1.0	1.2
28-M-30	.9	1.0	3.2	3.4
29-F-28	.7	.6	2.9	2.5
30-F-26	.8	.7	2.5	1.9

* All measurements obtained using a combined mode of conductance and susceptance.

TABLE II
INDIVIDUAL MEASUREMENTS OF CURVE WIDTH
FOR RIGHT AND LEFT EARS
AT 220 AND 660 HZ
IN mmH_2O *

Subject # Sex Age	Curve Width At 220 Hz		Curve Width At 660 Hz	
	R	L	R	L
1-M-25	93	73	52	65
2-F-26	92	70	84	85
3-M-28	80	70	100	72
4-F-21	68	74	72	92
5-F-21	76	90	88	77
6-F-22	115	120	130	141
7-M-21	71	80	79	67
8-F-25	64	90	98	73
9-F-26	85	85	72	76
10-F-21	104	95	124	180
11-F-21	68	81	50	106
12-M-27	72	71	61	62
13-F-22	110	115	110	100
14-F-22	100	98	100	108
15-F-28	56	60	25	30
16-M-28	77	74	105	122
17-F-23	66	68	67	52
18-F-26	120	105	93	102
19-F-27	72	81	85	101
20-M-21	68	85	55	109
21-M-29	67	86	47	105
22-F-23	110	128	88	117
23-F-28	90	94	127	164
24-F-25	135	146	170	118
25-M-23	88	96	130	122
26-F-23	119	95	96	68
27-F-25	105	84	68	52
28-M-30	66	61	30	56
29-F-28	51	43	38	32
30-F-26	31	58	24	52

* All measurements obtained using a combined mode of conductance and susceptance.

TABLE III

INDIVIDUAL MEASUREMENTS OF PRESSURE AT CURVE PEAK
FOR RIGHT AND LEFT EARS
AT 220 AND 660 HZ
IN mmH_20*

Subject # Sex Age	Pressure At Curve Peak At 220 Hz		Pressure At Curve Peak At 660 Hz	
	R	L	R	L
1-M-25	+12	-12	+10	- 9
2-F-26	+10	0	+25	+10
3-M-28	+15	0	+15	+ 2
4-F-21	-15	-10	- 8	- 8
5-F-21	+12	+10	+16	+14
6-F-22	- 2	+ 5	+ 7	+10
7-M-21	+17	+23	+20	+27
8-F-25	0	+ 2	+10	+ 6
9-F-26	+ 8	+ 5	-13	+ 5
10-F-21	+23	+ 5	+25	+ 5
11-F-21	+ 9	+16	+10	+22
12-M-27	+15	+ 6	+21	+ 6
13-F-22	-15	+ 7	-15	+15
14-F-23	-15	-10	- 3	+ 8
15-F-28	+ 6	+10	+ 7	+13
16-M-28	0	+11	+ 6	+14
17-F-23	-11	+12	- 5	+16
18-F-26	- 7	-20	0	-16
19-F-27	-21	-18	-15	-12
20-M-21	+28	+10	+32	+20
21-M-29	+28	-15	+31	- 7
22-F-23	0	+ 8	+ 5	+10
23-F-28	+ 5	+11	+10	+12
24-F-25	-12	-10	+13	-32
25-M-23	+12	+21	+12	+23
26-F-23	-15	-20	-10	-13
27-F-25	+15	- 3	+19	+ 2
28-M-30	-15	+15	- 3	+24
29-F-28	-21	-13	-22	-10
30-F-26	+19	+12	+17	+12

* All measurements obtained using a combined mode of conductance and susceptance

APPENDIX E

RESULTS OF ADDITIONAL TESTING

TABLE IV

COMPARISON OF TEST RETEST RESULTS AT 220 Hz.

Subject No.	Test Curve Peak Ampl. (mmhos) EARS		Retest Curve Peak Ampl. (mmhos) EARS		Difference Between Test-Retest Curve Peak Ampl. (mmhos) EARS		Test Curve Width (mmH_2O) EARS		Retest Curve Width (mmH_2O) EARS		Diff. Between Test-Retest Curve Width (mmH_2O) EARS		Test Press. at Curve Peak Ampl. (mmH_2O) EARS		Retest Press. at Curve Peak Ampl. (mmH_2O) EARS		Diff. Between Test-Retest Press. at Curve Peak (mmH_2O) EARS	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
3	.4	.6	.4	.6	.0	.0	80	70	80	65	0	5	+15	0	+25	+13	10	13
14	.5	.4	.5	.4	.0	.0	100	98	90	97	10	1	-15	-10	-5	-15	10	5
18	.3	.3	.3	.3	.0	.0	120	105	100	92	20	13	-7	-20	-10	-20	3	0
21	.5	.6	.5	.6	.0	.0	67	86	66	85	1	1	+28	-15	+12	-15	16	0
27	.4	.4	.3	.3	.1	.1	105	84	83	72	22	12	+12	-3	+7	0	5	3
				Mean	0.02	0.02				Mean	10.60	6.40				Mean	8.80	4.20

TABLE V

COMPARISON OF TEST RETEST RESULTS AT 660 Hz.

Subject No.	Test Curve Peak Ampl. (mmhos)		Retest Curve Peak Ampl. (mmhos)		Difference Between Test-Retest Curve Peak Ampl. (mmhos)		Test Curve Width (mmH_2O)		Retest Curve Width (mmH_2O)		Diff. Between Test-Retest Curve Width (mmH_2O)		Test Press. at Curve Peak Ampl. (mmH_2O)		Retest Press. at Curve Peak Ampl. (mmH_2O)		Diff. Between Test-Retest Press. at Curve Peak (mmH_2O)	
	EARS R	L	EARS R	L	EARS R	L	EARS R	L	EARS R	L	EARS R	L	EARS R	L	EARS R	L	EARS R	L
3	.9	1.6	1.0	1.6	.1	.0	100	72	95	75	5	3	+15	+2	+25	+15	10	13
14	.9	1.2	1.1	1.1	.2	.1	100	108	125	117	25	9	- 3	+8	+ 5	+10	8	2
18	.8	.8	.9	.8	.1	.0	93	102	108	95	15	7	0	-16	- 2	-20	2	4
21	1.7	1.7	1.8	1.6	.1	.1	47	105	56	105	9	0	+31	-7	0	-11	31	4
27	1.0	1.2	1.0	1.1	.0	.1	68	52	70	60	2	8	+19	+2	-5	- 6	24	8
				Mean	.10	.06				Mean	11.20	5.40				Mean	15.00	6.20