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The present investigation was designed to explore the use of occluded forehead bone conduction in a clinical setting. Specifically, the present study investigated the equivalence of unoccluded mastoid (UM) and occluded forehead (OF) bone conduction thresholds, and the extent to which the occlusion effect compensates for the loss of sensitivity associated with forehead placement. Additionally, this investigation determined if the pattern demonstrated by comparison of air conduction and unoccluded mastoid bone conduction (AC-UM) was unchanged when occluded forehead thresholds were substituted for unoccluded mastoid thresholds (AC-OF) in an air conduction-bone conduction comparison in various types of hearing loss.

Thresholds were obtained at octave intervals between 250 and 4000 Hz under air conduction (AC), occluded forehead bone conduction (OF), unoccluded forehead bone conduction (UF), and unoccluded mastoid bone conduction (UM) for normal ears, conductive loss ears and sensorineural loss ears. A one-minute fixed frequency tracing was obtained with a Bekesy automatic audiometer at each frequency under each test condition. Experimental controls included standard instructions, a counterbalanced schedule of treatment conditions, constant

contralateral masking and a constant static vibrator pressure. Means were used as the basis of comparison of the OF and UM thresholds, the loss of sensitivity and the occlusion effect, and the (AC-UM) and (AC-OF). The significance of the differences was evaluated. The results of this analysis follow:

1) Comparison of the OF and UM thresholds at each of the test frequencies for the three diagnostic categories indicated differences no greater than five dB are present at six of the fifteen frequencies; these differences, however, were significant at five of the fifteen frequencies; 2) when all three diagnostic groups were combined, comparison of the occlusion effect and the loss of sensitivity indicated differences greater than five dB at nine of the fifteen test frequencies and these differences were significant in eight; 3) differences greater than five dB between the (AC-UM) and (AC-OF) scores were found at nine of the fifteen comparisons, and seven of these differences were significant.

An overview of the data shows that the OF method does not provide the same consistent baseline that the UM method provides. Additionally, the occlusion effect produces different effects in various types of hearing loss and is, therefore, not universally applicable.

AN INVESTIGATION OF THE USE OF THE OCCLUDED FOREHEAD BONE CONDUCTION METHOD IN A CLINICAL SETTING

by

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APPROVAL SHEET

This thesis has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

The behavioral sciences are presently engaged in a process of refining and evaluating the standardized tests and measurements available to quantify individual sensory behavior. The ability of an individual to control and manipulate his environment is often dependent upon the sensory information he receives. Because auditory sensitivity is the most essential sensory system in normal interpersonal communication, a deficiency in the sensitivity of the hearing sense can inhibit learning and normal function in the environment. Consequently, accurate assessment of auditory sensitivity is essential in the proper diagnosis and treatment of auditory deficiencies.

Modern methods of electroacoustic assessment provide the means to evaluate many aspects of hearing. The sensitivity and function of the hearing mechanism as a whole can be determined. If a deficiency is found, a lesion can be located in a segment of the mechanism. The present investigation is concerned with the method used for determining the function of one segment of the mechanism--the conductive mechanism of the middle ear. Determination of this function is accomplished by assessing acuity by air conduction and by bone conduction and comparing the obtained threshold values.

In the normal ear, these values are approximately equal when determined with a properly calibrated audiometer. If the middle ear is conducting the signal poorly, the air conduction threshold will be poorer than the bone conduction threshold. An estimate of the amount of middle ear interference can be determined by subtracting the bone conduction threshold from the air conduction threshold. In cases of conductive loss, the bone conduction threshold measurements are appreciably better than the threshold measurements of the air conduction mechanism. Information regarding the function of the conductive mechanism is essential in the diagnosis and evaluation of the progression of many diseases of the middle ear. Therefore, the method used for attaining thresholds by bone conduction must be accurate and reliable.

Bone conduction thresholds are obtained by measuring sensitivity to a signal produced by a vibrator attached to the skull. The vibrator sets the bones and cartilaginous structures of the skull into vibration and these structures in turn vibrate the fluid of the cochlea. The mode of vibration and efficiency of transmission of the test signal depend upon a variety of factors: the frequency of the test tone; the ambient noise level in the test room; middle and external ear conditions; and the transmissional characteristics of the placement site.

Each point on the skull is a potential placement site for the vibrator. Traditionally, the vibrator has been placed on the mastoid process of the temporal bone or the frontal bone of the forehead. Advantages and disadvantages associated with homogeneity of the structure of the bone, the tactile sensitivity of the area, and calibration of the output of the vibrator are attributed to both sites. The mastoid site is considered poorer because of variance in contour and density of the bone and its approximation to cartilaginous structures. These factors cause variation in the amplitude of the test signal from closely-separated points of contact. Vibro-tactile sensitivity is slightly greater at the mastoid site than at the forehead site. However, the signal is transmitted from the mastoid to the cochlea with less attenuation than from the forehead. The forehead site, over a wide area, is consistent in density and contour with minimal interference from cartilaginous structures and vibro-tactile sensitivity. The greater attenuation of the signal or the loss of intensity in transmission to the cochlea requires an additional output from the vibrator to reach normal threshold.

There are two factors regardless of placement site and frequency of the test signal that influence bone conduction thresholds--ambient noise in the test room and the condition of the external and middle ear. Ambient noise in the test area can mask the test signal and, therefore, must be controlled. Natural and artificial occlusion of the external auditory meatus can influence the threshold values obtained through bone conduction measurements. Various writers (Goldstein, 1963; Kelly and Reger, 1957; Naunton and Fernandez, 1961; Studebaker, 1960) have demonstrated an apparent improvement in bone conduction thresholds for normal hearing subjects by occlusion of the external auditory meatus with standard clinical earphones. The apparent improvement in threshold sensitivity is designated the "occlusion effect."

The method used for assessing bone conduction sensitivity must take these factors into account. Martin (1969) suggests that a method utilizing the occlusion effect and forehead placement of the vibrator will yield thresholds equivalent to those obtained with unoccluded mastoid bone conduction and overcome the variance of the mastoid site and the attenuation of the test signal encountered with forehead placement. After reviewing recent pertinent literature, he concludes that the increase in sensation resulting from the occlusion of the ear can be used to compensate for the loss of sensitivity noted when thresholds are measured at the forehead. By occluding the ears, the ambient noise in the room is controlled and masking can easily be introduced.

Conley and Elpern (1969) investigated Martin's proposal and present evidence that occluded forehead bone conduction thresholds and air conduction thresholds are approximately equal in normal hearing subjects. Based on this evidence, they conclude that the method proposed by Martin is clinically feasible in normal hearing subjects.

The present study was designed to investigate further the occlusion effect and its relationship to the loss of sensitivity noted with forehead placement. Specifically, this study was designed to answer the following questions:

1. Are occluded forehead bone conduction thresholds equivalent to unoccluded mastoid bone conduction thresholds?

2. To what extent does the occlusion effect compensate for the loss of sensitivity noted when bone conduction thresholds are measured from the forehead?

3. Is the pattern demonstrated by comparison of air conduction thresholds and unoccluded mastoid bone conduction thresholds in various types of hearing loss unchanged when air conduction thresholds are compared with occluded forehead bone conduction thresholds?

For the purposes of discussion and comparison, two threshold values will be considered equal if the difference between them is no greater than five decibels. Chapter II presents a review of the literature pertinent to an investigation of occluded forehead bone conduction.

CHAPTER II

REVIEW OF THE LITERATURE

Bone Conduction Defined

A pressure wave or displacement which evokes an auditory response is designated as sound. The end organ for human hearing is stimulated via two routes--air conduction and bone conduction. Normally, sounds are transmitted through the air conduction mechanism of the outer and middle ear to the fluids of the inner ear. When a vibrating object is placed in contact with the head, however, the wave motion is conducted through the bone and cartilaginous structures of the head to the fluid of the inner ear, by-passing the middle ear route. Sound that is transmitted through the bone is said to be bone conducted. Therefore, bone conduction is the process by which sound is transmitted from a vibrator through the bone and cartilaginous structures of the head to the fluid of the cochlea.

Threshold measurement via bone conduction is used routinely to assess the sensitivity of the inner ear unconfounded by defects of the air conduction mechanism. If the conductive mechanism of the outer and middle ear is not functioning efficiently, the bone conduction thresholds will be appreciably better than the air conduction thresholds. When the external auditory canal is patent and the tympanic membrane and ossicular chain are free from defects, the air and bone conduction thresholds are theoretically equal.

History of Measurement of Bone Conduction Sensitivity

Capivacci (1589) was the first investigator to use the phenomenon of hearing by bone conduction as a diagnostic tool. By transmitting the sound through the bone by placing a vibrator on the teeth, he was able to assess 'labyrinthine hearing loss.' Capivacci reasoned that if the subject did not hear the signal, the sensitivity of the labyrinthe was defective because the conductive mechanism was by-passed. Wheatstone (1827) studied the effect of plugging the external ear during presentation of sound via bone conduction and found that the sound was heard in the plugged ear. Weber (1834) independently discovered the same phenomenon and found that lateralization also occurred in unilateral hearing loss.

Based on his investigations of the lateralization phenomenon, Weber devised a procedure for determining the type of hearing loss for cases with unilateral loss or unequal bilateral loss. In the Weber test, a tuning fork is set into vibration and placed on the midline of the forehead. If the tone lateralizes to the poorer ear, the loss is said to be conductive in that ear. If the tone is heard in the better ear, the loss in the poorer ear is said to be sensorineural.

Rinne (1855) studied the length of time a subject heard an air-conducted signal with the length of time the same subject heard a bone-conducted signal. He observed that the tonal perception time by these two routes was different for patients with conductive and sensorineural losses. As a result of this observation, Rinne devised a procedure for differentiating nerve impairments from conductive impairments. In the Rinne test, a tuning fork is set into vibration and held approximately half an inch from the tragus of the test ear for presentation of the air conduction stimulus. When the patient no longer hears the sound by air conduction, the fork is placed on the mastoid process near the test ear for presentation of the bone conduction stimulus. If the stimulus is heard for a longer period of time by bone conduction than by air conduction, a conductive impairment is indicated.

Schwabach (1884) investigated the relationship between the hearing of normal subjects and subjects with impairments in order to devise a quantitative measurement of hearing impairment. He reasoned that the normal ear would detect the air or bone conducted signal for a longer period of time than the impaired ear and that the difference in time between the detection by the impaired ear and the normal ear would indicate the magnitude of the hearing loss. The index for reference for this measurement is the normal hearing of the examiner. Schwabach presented stimuli via air conduction and bone conduction to his subjects and compared the period of time the sound was detected by each subject with the period of time the examiner detected the same stimulus.

The three tuning fork tests described above represent the primary investigations of sound transmission via bone conduction before 1900. Weber, Rinne and Schwabach first observed the phenomenon of hearing by bone conduction in relation to lateralization and the occlusion effect. Weber and Rinne formulated the first qualitative tests of hearing impairment. By comparing normal hearing with impaired hearing, Schwabach formulated the first quantitative test of hearing impairment. Further investigation of these phenomena has been carried out with the use of electroacoustic devices with which more exact quantitative measurements could be made.

Transmission of the Bone Conducted Signal

Primary Modes of Conduction

Because the head is not a solid homogeneous mass, sound conducted through the structures of the head cause different patterns of vibration. The specific pattern of vibration formed is dependent upon the frequency of the signal that is being transmitted. In one pattern of vibration, the skull vibrates as a whole parallel to the movement of the source of the vibration. Because of their inertia, the cartilaginous and bony structures of the head suspended by ligaments tend to lag behind the movement of the skull. The amplitude and frequency of displacement of these structures is equal to but out of phase with the skull. Of these structures, the greatest influence upon sound transmission is attributed to the ossicular chain. The ossicular chain moves as a unit causing a disturbance of the cochlear fluid directly through contact of the stapes with the oval window. This is the primary pattern of vibration for frequencies below 800 Hz. Because transmission of the signal is dependent upon the inertia of the cartilaginous and bony structures, this mode of transmission is termed inertial bone conduction.

In the second pattern of vibration, the movements of the skull are not parallel to the movements of the mechanical vibrator, but rather segments of vibration are set up with each segment separated by nodes or points of minimal movement. The number of segments of vibration, or antinodes, is determined by the frequency of the stimulating tone. The compressional and flexural forces generated by the stimulating tone compress the contents of the skull, and this vibrational energy reaches the basilar membrane through compression of the walls and contents of the cochlea. These compressional factors are present primarily in the transmission of sound above 800 Hz. For transmission of sound between 800 Hz and 1000 Hz the segments of vibration of the skull are divided into two sections along the first nodal line of compression which lies in a sagittal plane that runs from ear to ear. For frequencies above 1000 Hz, there are at least four antinodes divided by the first and second nodal lines of compression. The second nodal line of compression is in the frontal plane perpendicular to the first nodal line. The sections of the skull vibrate away from and toward the center of the skull with the same amplitude and phase of the vibrator. This mode of transmission of sound is termed compressional bone conduction.

The investigators primarily responsible for description of the inertial and compressional modes of transmission of sound via bone conduction were Bekesy (1932a), Barany (1938) and Kirikae (1959). These investigators observed and measured the vibrations of the skull when a vibrating object was placed on the frontal bone of the forehead.

The Influence of the Middle Ear

Holcomb (1958), Huizing (1960) and Tonndorf (1963) have speculated that the action of the middle ear in bone conduction transmission is more complex than the unit vibration of the ossicular chain previously described in inertial bone conduction. Holcomb (1958) studied bone conduction sensitivity in patients with conductive hearing losses using tuning forks and a plug in the external auditory canal. He termed this method 'inverse bone conduction.' Holcomb concluded that 'inverse bone conduction' did not accurately assess middle ear function. Further, he states that the conduction of the test signal is the result of the interaction of three pathways and the response is dependent upon the predominate pathway in the middle ear. Holcomb (1958, p.

1034) further defines these pathways in terms of three types of 'middle ear action':

1. an inertial effect of the ossicles.
2. distortion and consequent change in volume of the tympanic cavity.
3. distortion of the otic capsule reflected through the ossicular chain to the eardrum.

Tonndorf (1963, p. 29) studied the vibrational patterns of the structures within the middle ear space in experimental animals and human subjects and concluded that the middle ear contribution to bone conduction transmission was made up of two components: " a) ossicular inertia and b) the compliance of the air enclosed in the middle ear spaces." Holcomb (1958) and Tonndorf (1963) agreed that the changes in the pressure of the air within the middle ear affect the vibration of the oval window in bone conduction transmission of the signal.

Huizing (1960) reasoned that the ligaments and the annulus tympanicus of the middle ear were also directly involved in the middle ear effect on bone conduction transmission by virtue of the fact of their direct connections with the ossicular chain. Additionally, Huizing (1960, p. 81) states:

> In bone conduction, all parts of the head are set into vibration, together with the bony skull, so that we can speak of a complex of coupled vibratory systems. The bone conduction phenomenon, as found clinically and experimentally, should be regarded as a result of a change in the properties of these systems (i.e. middle ear, external ear, lower jaw, etc.). The changes cause alterations in the mutual relationships of the impedence and couplings, which has a repercussion on the vibration of the cochlea.

In summary, Tonndorf (1963) and Holcomb (1958) determined that the effect of the middle ear in inertial bone conduction was due to the movement of the air enclosed in the otic capsule in addition to the movements of the ossicular chain. Huizing further stated that the tendons and ligaments of the middle ear contributed to an overall middle ear effect resulting from the coupling of the two vibratory systems and their interaction.

Additional Variables in Bone Conduction Sensitivity Measurement

Bone conduction sensitivity is influenced by additional variables resulting from the method used to obtain bone conduction thresholds. Among these variables are the type of vibrator used, the static pressure exerted by the vibrator, vibrotactile sensitivity of the placement site of the vibrator, the condition of the middle and external ear, and the occlusion effect. The specific effects of each of these variables will be discussed in the following sections.

Types of Vibrators

There are two types of vibrators used for producing test signals--mechanical vibrators and electroacoustic vibrators. Historically the first vibrator used for this purpose was of the mechanical type and consisted of an iron bar against a zither (Capivacci, 1589). The zither was used to set the vibrator into motion. The iron bar was later modified so that the frequency of its vibration could be controlled.

These developments yielded the currently used tuning forks each of which is designed to produce a certain frequency of vibration; however, the amplitude or intensity of the tone produced is dependent upon the force with which the fork is struck.

In order to control more quantitatively the intensity output of such signal sources, electro-mechanically-driven bone vibrators were devised. Currently, two types of electroacoustic transducers are available for clinical use. The first electrically driven vibrator to be developed was the grenade type (a bulky, cylindrical device with a piston-like cone extending approximately a half inch from one end which would be brought into contact with the object to be stimulated), and the hearing aid type (a small rectangular device designed to be worn on the head). The hearing aid type vibrator replaced the grenade type because of its greater ease in handling with no loss in efficiency. Dirks (1964b) demonstrated that no significant difference existed between the output of the grenade type vibrator and the output of the hearing aid type vibrator. Because of the greater control of frequency and intensity output that can be exercised by the use of an electrically driven bone vibrator and because of the greater ease in manipulating the aid type vibrator, the hearing aid type electroacoustic transducer is currently favored for clinical use.

Static Pressure Exerted by the Vibrator

The force exerted by the vibrator against the head has proven to be influential on bone conduction threshold measurements. Konig (1957) investigated threshold values obtained at the forehead under controlled conditions of static vibrator pressure. He reported that the magnitude of the threshold value is inversely related to the force exerted by the vibrator until the force reaches 1000 grams. Konig (1957) recommended, therefore, that the vibrator exert a static pressure of from 750 to 1000 grams since this range yields the least amount of variability in threshold measurement. Support for Konig's original findings was provided by Jerger and Jerger (1965) who also demonstrated an inverse relationship between static vibrator pressure and threshold values. Further, Jerger and Jerger (1965) showed that for static vibrator pressures below 750 grams there is a greater threshold variability for frequencies below 2000 Hz than for higher test tone frequencies.

In contrast to the above, studies by Harris and Haines (1953) and Dirks (1964b) indicated that little variation in threshold occurs for static pressures above 400 grams. Naunton (1957) calculated that the average force of 448.4 grams exerted by a standard spring type headband was sufficient for reliable threshold measurement. In a study of the occlusion effect, Goldstein (1963, p. 39) stated that "A pressure of 800 grams was arbitrarily chosen as being strong enough to achieve maximum signal sensitivity without undue discomfort to the subjects."

All of the studies of static vibrator pressure indicate that the threshold values increase as pressure decreases. The threshold value increase is more directly related to reduction of static pressure below 750 grams and is most marked for the lower frequencies (Jerger and Jerger, 1965).

The Influence of Vibrotactile Sensitivity

Bone conduction threshold measurement can also be influenced by the tactile sensitivity of the vibrator placement site. Favors and Lilly (1969) stated in a review of the pertinent literature that those bone conduction thresholds measured at 250 and 500 Hz in subjects with severe sensorineural impairments are often significantly better than corresponding air conduction thresholds. Favors and Lilly (1969) also reported the clinical occurrence of cases of air-bone gaps that were inconsistent with patients' histories and medical examinations. The authors concluded that the questionable bone conduction threshold values were not true auditory thresholds but rather were tactile responses to vibration. Favors and Lilly (1969) investigated vibrotactile threshold values for these frequencies. Following this investigation, the authors calculated the normal threshold for vibrotactile sensitivity to be 46.8 dB (HL) at 250 Hz and 61.7 dB (HL) at 500 Hz. The authors stated that these thresholds are above the normally used output levels of a clinical bone vibrator, therefore, vibrotactile sensitivity would not interfere with assessment of auditory thresholds at the forehead.

Martin and Wittich (1966), in a comparative study of tactile thresholds at the forehead and the mastoid found that the tactile thresholds at the mastoid were only slightly lower at 250, 500 and 1000 Hz than those at the forehead. Martin and Wittich concluded that the greatest effect of vibrotactile sensitivity would be at the mastoid and that the threshold was only 5 dB less than the vibrotactile threshold at the forehead.

In summary, Favors and Lilly (1969) and Martin and Wittich (1966) have reported that vibrotactile sensitivity is not a significant variable in bone conduction testing at the mastoid or the forehead site at vibrator output levels below-- 40 dB HL at 250 Hz and 60 dB HL at 500 Hz. These findings indicate that vibrotactile sensitivity does not increase or decrease bone conduction threshold values.

Vibrator Placement Site

The placement site for the vibrator on the skull affects the variability and reliability of threshold measurements made by bone conduction, and transmission of the signal via bone conduction. The following paragraphs present the advantages and disadvantages of two common placement sites.

The variability and reliability of bone conduction thresholds has been measured with the bone vibrator on the mastoid process and the frontal bone of the forehead. Hart and Naunton (1961) made a longitudinal study of bone conduction thresholds on normal hearing subjects, subjects with sensorineural impairments and subjects with conductive impairments and demonstrated that test-retest reliability of measurements made at the forehead were superior to the test-retest reliability measurements made at the mastoid. In another study of test-retest reliability, Dirks (1964a) concluded that bone conduction measurements made at the forehead demonstrated greater reliability than those made at the mastoid. Studebaker (1960) demonstrated no significant difference in intrasubject variability at the two sites, but found that the mastoid site demonstrated significantly greater intersubject variability in normal hearing subjects. In subjects with conductive impairments, the same relationship was noted, but the correlation did not reach the .01 level of significance. Therefore, Studebaker (1960) concluded that measurements of variability favor the forehead position because of the indication of smaller variability.

Many writers have attempted to explain the variability of the threshold measurements made at the mastoid on the basis of the transmissional characteristics of the site. The exterior contour of the mastoid process varies, thus altering the contact area of the vibrator and changing its efficiency. Further, because of the use of the standard spring-type headband, the static pressure exerted by the vibrator varies with head size. In addition to these factors, it has been speculated that an unusually porous mastoid process can act as a resonator and increase the intensity of the stimulus thereby resulting in an invalid measurement. One final source of potential error is the close approximation of the mastoid site to the pinna. If the vibrator contacts the pinna, the cartilages of this structure will vibrate sending energy through the walls of the external auditory meatus to the tympanic membrane with a resulting invalid threshold measurement. Possibly as a result of one or more of the above mentioned factors, Hart and Naunton (1961) demonstrated that movement of the vibrator at the mastoid of less than one centimeter can vary the threshold measurement by as much as ten dB in some patients.

In contrast to the mastoid, the forehead provides a flat dense surface for placement of the vibrator. The securing apparatus for forehead placement is an adjustable circumferential headband with which a constant pressure can be maintained among subjects. Hart and Naunton (1961) demonstrated that movement of the vibrator of three centimeters at the forehead did not significantly influence the threshold values obtained.

Although the forehead site yields more reliable thresholds, more energy is required to reach threshold at this site than is necessary at the mastoid. This 'loss of sensitivity' or attenuation of the signal has been quantified by many investigators (Dirks, 1964a; Kelly and Reger, 1937; Naunton, 1961; Studebaker, 1960; Goldstein, 1963; and Hoops, 1961). Mean differences between forehead and mastoid thresholds (F-M) reported by these investigators range from 6.71 dB to 15.90 dB at 250 Hz; 4.71 dB to 13.90 dB at 500 Hz; 2.43 dB to 13.70 dB at 1000 Hz; 2.21 dB to 8.7 dB at 2000 Hz and -1.0 dB to 8.10 dB at 4000 Hz. Table 1 summarizes the mean values found by these investigators.

Examination and comparison of these studies indicate three trends in the data. First, in all the studies the mastoid site is more sensitive. Secondly, the difference in sensitivity, or 'loss of sensitivity,' at the forehead is frequency dependent with its greatest effect in the lower frequencies. Thirdly, the variation of the magnitude of the difference is notable. Studebaker (1960) and Goldstein (1963) reasoned that the variations noted in the magnitude were due to one or more of the following factors: differences in vibrator type; differences in static vibrator pressure; or differences with regard to the use of contralateral masking. Because of the additional attenuation of a signal originating at the forehead compared to that offered at the mastoid, the output intensity of the vibrator must be increased for forehead placement in order to equate mastoid and forehead

TABLE 1

MEAN DIFFERENCES BETWEEN FOREHEAD AND MASTOID BONE CONDUCTION THRESHOLD MEASUREMENTS (F-M) REPORTED BY PREVIOUS INVESTIGATORS

Investigator	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Kelly and Reger (1937)	13.0	11.0	7.0	5.0	6.0
Studebaker (1960)	12.6	11.4	6.0	8.0	4.8
Hoops (1961)	15.90	13.90	13.70	8.3	8.1
Naunton (1961)	11.0	8.0	5.0	4.0	-1.0
Goldstein (1963)	6.71	4.71	2.43	2.21	5.86
Dirks (1964a)	9.7	9.4	7.1	8.7	5.0

thresholds. When the intensity is increased to compensate for the differences, however, the relationship between the energy input and the output of the vibrator may become non-linear. This can result in distortion of the pure tone signal. For example, working at input levels greater than the vibrator's intended range at 250 Hz, a strong second harmonic of 500 Hz may be produced at the same level as the 250 Hz tone. Therefore, isolation of the response to 250 Hz is impossible with patients with low frequency hearing loss or a rising pure tone threshold configuration.

Generally, the forehead site is preferable to the mastoid site because of the greater reliability and smaller variability of the threshold measurements made at the forehead. The threshold variability at the mastoid site has been attributed to variations in the surface contour and density of the process, whereas, the forehead site shows no such variation. Additionally, recent investigators (Goldstein, 1963; Huizing, 1960; Studebaker, 1960) have concluded that the influence of the middle ear is reduced in bone conduction transmission when the vibrator is placed at the forehead. However, the forehead presents one clear disadvantage--a reduction in sensitivity that results in an elevation of bone conduction thresholds in normal hearing subjects. In order to compensate for this reduction in sensitivity, sound levels must be increased which can cause the vibrator to be overdriven yielding distortion products.

The next section explores the phenomenon of the occlusion effect and the reasons why the incorporation of this effect into clinical measurements might be an alternative to increasing vibrator intensity output.

The Occlusion Effect

Huizing (1960, p. 3) defines the occlusion effect in this manner:

> If the external auditory canal is unilaterally or bilaterally occluded while a sound stimulus is being given by bone conduction, the tone becomes louder. This phenomenon. . . is the occlusion effect.

This phenomenon has been investigated in order to explain its origin. The following sections discuss the various theories that have been proposed as to how the occlusion of an ear causes what appears to be an improvement in threshold sensitivity.

Origin of the Occlusion Effect - Although the occlusion effect was independently discovered by Tortual in 1827, Wheatstone in 1827 and Weber in 1834, the first to propose a theory of the origin of the occlusion effect was Rinne in 1855. Rinne proposed that the increased loudness was a resonance effect in the external auditory meatus. Other early theories included the explanation proposed by Lucae (1862, 1864), reported by Huizing (1960, p. 5), which states that the occlusion effect is the result of a "rise of the pressure in the auditory canal and labyrinthe." Huizing (1960, p. 5) also reports Toynbee's reasoning that the phenomenon was a "reflection of sound which could not escape due to the occlusion." In 1863 Mach stated that the trapped energy was actually an over-flow of intensity from the cochlea causing a loudness increase. Consequently, Mach termed this explanation the Overflow Theory.

In contrast, the Ambient Noise Theory proposes that the occlusion effect is the result of the elimination--by occlusion--of the masking influence of the ambient noise in the test room. The Ambient Noise, or Masking, Theory is based on the original investigation by Hallpike in 1930. Hallpike (1930) observed that patients with conductive impairments detected the presence of a bone conducted stimulus for a longer period of time than the normal hearing listener. Hallpike concluded that the conductive mechanism blocked the transmission of the ambient noise in the test room to the cochlea. Therefore, any occlusion would interfere with the transmission of the noise in the room. Hallpike (1930) concluded that the occlusion effect was actually the result of the elimination of the interference or the masking effect of the ambient noise in the test room. Knudsen and Jones (1931) further investigated the occlusion effect and supported the original hypothesis proposed by Hallpike. The Ambient Noise, or Masking, Theory was refuted by many investigators who demonstrated the occlusion effect in quiet. (Goldstein, 1963; Naunton and Fernandez, 1961; Rytzner, 1954; Sullivan et al., 1947)

Bekesy (1932b) investigated the phenomenon of the occlusion effect in quiet and proposed that the apparent loudness increase was the direct result of mandibular inertia during bone conduction transmission. Because of its inertia, the condyloid process of the mandible vibrates out of phase with the skull thereby compressing the walls of the external auditory meatus. With the ear unoccluded, this additional vibration within the external auditory is dissipated into the ambient air outside the ear. When the ear is occluded, this additional vibration travels inward to the cochlea and causes a decrease in the measured threshold value. Bekesy based this theory on measurement of the sound pressure levels in the external auditory meatus. By moving an occluding plug from the cartilaginous portion of the canal to the bony portion, he was able to demonstrate that there was no increase in the sound pressure level in the canal, or decrease in the measured threshold. Bekesy reasoned that the effect of the mandibular action was negated in the bony portion of the canal since this section was more medial than the point of contact of the condyloid process, and, therefore, no vibrations would be generated.

Frank _et al_. (1952) supported Bekesy's original hypothesis. After measuring amplitude and phase of vibration of the jaw in relation to the skull vibration during bone conduction, Frank _et al_. (1952, p. 44) reported:

> . . . that the lower jaw vibrations have a frequency response of displacement and phase shift somewhat

> similar to a simple oscillator with a resonance frequency somewhere between 110 and 180 cps. That means that far below the resonance, jaw and skull vibrate with the same amplitude and phase, whereas, far above the resonance, the lower jaw stays nearly at rest and the skull vibrates independently.

Therefore, Frank *et al*. demonstrated that the Bekesy hypothesis was feasible regarding the amplitude and phase of vibration of the mandible and skull.

Allen and Fernandez (1960) further investigated the validity of the Bekesy hypothesis. These investigators studied the occlusion effect in two patients who had had the ramus of the mandible removed and demonstrated an occlusion effect of average magnitude. This study offered evidence which appears to negate the hypothesis that the occlusion effect arises from mandibular inertia, especially since it is evident, at least in the two subjects studied, that the mandible could not have been a factor in the occlusion effect demonstrated.

Similarly, Barany (1938) reasoned that the occlusion effect was an inertial phenomenon. As a result of his investigation of the physiology of bone conduction, Barany attributed the increase in sound pressure level in the external auditory meatus to the inertia of the occluding plug. Barany reasoned that the vibrating motion of the plug relative to the vibration of the skull caused the increase in pressure level that resulted in the better threshold.

In contrast to the above described theories, the Impedence Change Theory supposes that the presence of an occluding device in the external auditory meatus affects the impedence, or compliance, of the eardrum and the middle ear mechanism and, thereby, influences the vibration of the fluids of the cochlea through direct contact with the stapes at the oval window. Allen and Fernandez (1960) investigated the effect of loading the tympanic membrane with mercury. These investigators speculated that the impedence change caused by the mercury loading would be similar to the impedence change caused by the occlusion. The results of Allen and Fernandez's study supported their speculation that occluding the canal loads the tympanic membrane and, thereby, produces an impedence change in the conduction mechanism which is reflected in a lower threshold. Goldstein and Hayes (1965) also studied the effect of loading the tympanic membrane and agreed with the original conclusions drawn by Allen and Fernandez. In reference to the change of impedence of the eardrum when the external ear is occluded, Huizing (1960, pp. 12-13) stated:

> It is evident that on occlusion an air column of particular properties is suddenly coupled with the vibration of the middle ear and the cochlea, instead of the ambient air . . . the air column is adjusted to the state of antiresonance and maximal impedence is coupled to the ear.

As a manifestation of the impedence change theory of Allen and Fernandez and the research by Pohlman and Kranz (1926), Lanzkiewicz (1964) proposed that the occlusion effect was the result of the interaction of positive and negative air pressures in the external auditory meatus. The vibrating cartilages exert the initial pressure pockets that transmit energy to the tympanic membrane. Thus, the compliance of the membrane is changed. The sound pressure is sent through the ossicular chain resulting in an improved threshold.

Present theorists propose that the occlusion effect is the result of a combination of factors. For example, Tonndorf approaches the phenomenon on the basis of the function of all components in the occlusion effect operating as a unit. Tonndorf (1963, p. 39) explains the occlusion effect in this manner:

> The occlusion effect of the external canal is caused by a combination of a) elimination of the high-pass filter effect of the open ear canal and b) alteration of the resonant properties of the external ear canal. The first factor is responsible for the low frequency emphasis, the latter for the sharply defined changes in the middle to high frequencies.

<u>Stability of the Occlusion Effect</u> - Dirks and Swindeman (1967) demonstrated that the variability of occluded bone conduction measurements was no greater than the variability of unoccluded bone conduction measurements. Dirks and Swindeman (1967) also demonstrated that the standard deviation representing the spread of the occluded thresholds decreased as frequency increased. In contrast to these findings, Hodgson and Tillman (1966) and Elpern and Naunton (1963) demonstrated a relatively higher variability of occluded bone conduction thresholds than was found with unoccluded bone conduction thresholds, however, Elpern and Naunton (1963) showed that the test-retest reliability of occluded bone

conduction thresholds is equal to the test-retest reliability of unoccluded bone conduction thresholds in normal hearing subjects. Elpern and Naunton (1963) also investigated the magnitude of the occlusion effect in relation to the headphone enclosure and concluded that the magnitude of the occlusion effect varied inversely with the volume of the headphone enclosure. Nevertheless, these investigators found no significant difference among standard clinical earphones supplied for use with pure tone audiometers.

Hodgson and Tillman (1966) demonstrated that the magnitude of the occlusion effect was increased with an increase in the static pressure exerted by the earphone cushion against the head. Hodgson and Tillman (1966, p. 149) attributed this increase to the following:

> . . . because of the yielding properties of both flesh and rubber earphone cap, an increase of application force tends to reduce the volume enclosed under the earphone cap and at the same time probably tends to close off any acoustical leaks.

As was discussed earlier, the occlusion effect can be altered by the point of placement of the occluding plug within the external meatus. Bekesy (1932c) demonstrated that the maximum magnitude of the occlusion effect is attained either when an insert plug is placed half the distance to the tympanic membrane, or at the external lateral opening of the external meatus. Bekesy (1932c) observed that occlusion at one fourth and three fourths the distance of the canal from the tympanic membrane negates the occlusion effect.

Further, Huizing (1960, p. 13) explained this absence of the occlusion effect by stating that "at one half a wavelength and one wavelength the air column [in the meatus] is adjusted to the state of antiresonance and maximal impedence is coupled to the ear." He concluded that, because this condition of antiresonance was not achieved at one fourth and three fourths the length of the canal, maximal impedence was not produced.

Magnitude of the Occlusion Effect - Many investigators have measured the occlusion effect at the five common bone conduction frequencies in normal hearing subjects and subjects with sensorineural hearing impairments. (Goldstein, 1963; Kelly and Reger, 1937; Rytzner, 1954; Studebaker, 1960; Sullivan *et al*., 1947.) Mean values of the occlusion effect reported by these investigators range from 6.9 to 28.00 dB at 250 Hz, 3.8 to 23.00 dB at 500 Hz, 5.0 to 18.0 dB at 1000 Hz, -.75 to 9.0 dB at 2000 Hz and -4.62 to 6.0 dB at 4000 Hz. Table 2 summarizes the mean occlusion effect demonstrated by these investigators.

Examination and comparison of these studies indicates three trends. First, in all studies, the magnitude of the occlusion effect is greatest in the lower frequencies and decreases as frequency increases. Secondly, in the studies that compared the magnitude of the occlusion effect at the forehead and mastoid, there appears to be a difference in

TABLE 2

MEAN OCCLUSION EFFECT VALUES FOR NORMALS REPORTED
BY PREVIOUS INVESTIGATORS

Investigator		250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Kelly and Reger (1937)		13.0	11.0	7.00	5.00	6.00
Sullivan _et al_. (1947)		20.0	23.0	18.0	9.0	3.0
Rytzner (1954)		16.5	12.0	6.75	- .75	-2.50
Studebaker (1960)	(F)*	8.0	8.3	6.4	.5	.5
	(M)	6.9	3.8	5.8	.7	2.3
Keys and Milburn (1961)	(F)	15.0	10.0	5.0	3.0	2.0
	(M)	15.0	13.0	9.0	1.0	2.0
Naunton and Fernandez (1961)		14.0	13.0	7.0	--	--
Tillman (1963)		17.0	17.0	12.0	--	--
Goldstein (1963)	(F)	15.88	15.77	6.18	- .29	- .97
	(M)	21.76	13.60	7.17	.46	-4.62
Elpern and Naunton (1963)		28.00	20.00	9.0	0	0
Hodgson and Tillman (1966)		27.00	23.00	10.0	0	--
Dirks and Malmquist (1969)		19.3	19.0	7.0	--	--
Dirks and Swindeman (1967)		23.7	19.3	7.5	- .6	--

*F or M indicates the site of placement for the vibrator: forehead or mastoid.

magnitude of the effect at the sites. Thirdly, the variation in the measured magnitude of the occlusion effect is notable and could be the result of differences in the test method which affected the stability of the occlusion effect.

Universality of the Occlusion Effect - Huizing (1960, p. 14) states, in regard to the universality of the occlusion effect, that "It is important to emphasize that the occlusion effect is absent in all forms of conductive deafness." In 1969, Dirks and Malmquist demonstrated support for Huizing's statement by reporting greatly reduced magnitudes of the occlusion effect in subjects with conductive impairments. These authors further investigated this reduction in magnitude by comparing thresholds measured on two groups of subjects with conductive losses--those with stapes fixation and those without stapes fixation. The authors reported that the difference between the groups was marked in that the stapes fixation group demonstrated a smaller occlusion effect than did the non-fixation group. Dirks and Malmquist concluded that, because of the measured difference in the occlusion effect in subjects with stapes fixation and subjects with no stapes fixation, occlusion of the external meatus could be used as a diagnostic tool for differential diagnosis of the etiology of conductive hearing impairment. Sullivan et al. (1947), Tillman (1963), Rytzner (1954) and Onchi (1954) have also demonstrated reduction or absence of the occlusion effect in subjects with conductive hearing loss. For example, Sullivan et al. reported a mean occlusion effect of 1.0 dB at 250 Hz, 1.0 dB at 500 Hz and 1.0 dB at 1000 Hz for subjects with conductive loss.

Based on the comparison of air conduction with occluded and unoccluded bone conduction thresholds in subjects with normal hearing, subjects with conductive hearing loss and subjects with sensorineural loss, Naunton (1957) proposed that the clinical absence, or reduction in the magnitude, of the occlusion effect in subjects with conductive hearing loss was the result of a "built-in" occlusion effect. Naunton (1957) thought that the pathological condition of the middle ear acted acoustically to improve the bone conduction threshold by increasing the bone conduction sensitivity, and that because the pathological condition acted as a block it was not possible to measure an occlusion effect when the ear was artificially occluded within the external canal.

In summary, bone conduction thresholds can either be measured with the ear occluded or unoccluded. The change, or apparent increase, in bone conduction sensitivity noted when the test ear is occluded in normal hearing subjects and subjects with sensorineural losses has been termed the occlusion effect. Theories as to the origin of the occlusion effect include the Overflow Theory, proposed by Mach in 1863, the Inertial Theories proposed by Bekesy (1932b) and Barany

(1938), the Ambient Noise Theory proposed by Hallpike (1930), the Impedence Change Theory proposed by Huizing (1960) and the Air Column Pressure Change Theory proposed by Lanzkienicz (1964). In contrast, present thought concerning the origin of the occlusion effect indicates that the occlusion effect arises from a combination of elements as opposed to a single factor. Recent investigators have made conflicting reports as to the variability and test-retest reliability of occluded bone conduction thresholds. Investigations of the magnitude of the occlusion effect have demonstrated that the phenomenon is frequency dependent with its greatest effect in the lower frequencies. Dirks and Malmquist (1969), Onchi (1954), Tillman (1963), Rytzner (1954) and Sullivan et al. (1947) have demonstrated an absence, or reduction in the magnitude, of the occlusion effect in subjects with conductive losses.

The Clinical Use of Occluded Forehead Bone Conduction Measurement

Hirsh (1952) and Naunton (1957) suggested that bone conduction measurements be made with the test ear occluded in order to reduce the interference from ambient noise. Dirks and Malmquist (1969) and Elpern and Naunton (1963) have suggested that occluded bone conduction measurement be used as a tool for differential diagnosis of the etiology of conductive impairments. As was described previously, the occlusion effect is used to assess type of hearing loss in tuning fork tests. In 1969, Martin proposed that the occlusion effect be used in conjunction with forehead placement of the vibrator. Martin (1969) reasoned that the magnitude and frequency dependent nature of the occlusion effect could be used to compensate for the frequency dependent loss of sensitivity noted when bone conduction thresholds were measured from the forehead. Conley and Elpern (1969) investigated Martin's original proposal and demonstrated that occluded forehead bone conduction thresholds were equivalent to unoccluded mastoid bone conduction thresholds in normal hearing subjects.

In contrast, Feldman (1961, p. 41) stated that occlusion of the test ear introduced "new, and not easily controlled, variables" into bone conduction measurement. Naunton and Fernandez (1961, p. 318) reasoned that we should "not discard information of differential diagnosis value by covering the ears and making bone conduction tests even more confusing." Studebaker (1970, p. 98) states:

> Unoccluded test methodology is the preferred procedure for several reasons:
>
> 1. If measurements are made occluded relative to an occluded reference standard value and if our patients' thresholds are as good as normal, then we cannot know whether the normal occlusion effect, the so-called 'built-in' occlusion effect, or some combination of these contributed to the good thresholds.
>
> 2. If our patient's bone conduction thresholds are elevated we cannot tell whether this occurred because he doesn't have a 'built-in' occlusion effect, because he has some sensorineural hearing loss, or finally because he has a normal occlusion effect and even more sensorineural loss. This dilemma pertains even if only an

occasional patient with a conductive loss does not have the 'built-in' occlusion effect and, of course, these patients are far more than just occasional.

3. If, on the other hand, our patients with a conductive loss are tested unoccluded using unoccluded normal thresholds as the reference, we do not need to wonder whether the occlusion effect influenced the result.

There are certain advantages to testing bone conduction with forehead placement of the vibrator because of the inconsistency of the density and contour of the site. One disadvantage is the possibility of overdriving the vibrator in order to compensate for the reduced intensity reaching the cochlea when forehead placement is used. If the occlusion effect, which causes an increase in the intensity of the signal reaching the cochlea, could be used to compensate for the reduction noted the major objection to forehead placement would be eliminated. The questions that remain are whether such compensation can be achieved, whether the effect holds over a variety of clinical patients, and whether the same information is obtained as with unoccluded mastoid placement.

CHAPTER III

INSTRUMENTATION AND PROCEDURE

A review of the literature on bone conduction measurement indicates that the forehead is a more advantageous site for placement of the vibrator than is the mastoid site because of the greater reliability and smaller variability of the threshold measurements made at the forehead. Feldman (1961) summarizes the conclusions of various researchers who attribute the greater variability and smaller reliability of the mastoid measurements to the transmissional characteristics of the site. He states that the contour of the surface of the mastoid varies which may cause a reduction of the area in contact with the vibrator; that the density of the mastoid process is more variable and causes a reduction in the efficiency of the energy transfer; and that the site includes cartilaginous structures which may also vibrate and affect the threshold measurement. However, measurements made at the mastoid site generally result in lower thresholds than comparable measurements made at the forehead. The mastoid site, therefore, is sometimes considered more useful clinically because of the greater range of intensity afforded by the lower thresholds measured there. In order to take advantage of the greater reliability and smaller variability at the forehead, the greater range of intensity at the mastoid must be sacrificed. Evidence appearing in the literature suggests that an additional variable, such as the occlusion effect, when used in conjunction with forehead placement might equate forehead and mastoid measurements making the forehead more acceptable as a placement site for a standard clinical bone vibrator.

Martin (1969) has suggested that the magnitude of the occlusion effect may be equivalent to the differences by which thresholds measured at the forehead are greater than thresholds measured at the mastoid. If this equivalency exists, the occlusion effect used purposely with forehead placement might mitigate several of the problems associated with bone conduction tests.

Conley and Elpern (1969) have presented evidence that occluded forehead bone conduction and air conduction thresholds are approximately equal in normal-hearing subjects. Based on the assumption that air conduction and unoccluded mastoid bone conduction thresholds are equal in such subjects, they concluded 1) the method proposed by Martin is clinically feasible and 2) the relationship demonstrated between air conduction and occluded forehead bone thresholds in normal-hearing subjects may also exist in the patients with conductive and sensorineural impairments. The present study was designed to explore this possibility.

Subjects

The subjects for the present study were drawn from the

Veterans Administration Hospital in Durham, North Carolina. Twenty-three adults ranging in age from 23 to 79 served as subjects. This group of 19 males and 4 females was further subdivided into six normal-hearing subjects, ten subjects with conductive losses and seven with sensorineural losses. Only one ear of some of the subjects met the qualifications of the definition of the category; therefore, data for these subjects includes only test results of one ear. Normal hearing was defined as thresholds better than 15 dB HL (re: Hearing Levels (HL) of the American National Standard Institute, 1969 audiometric standard); by air conduction with bone conduction thresholds (re: Hearing Levels of the Hearing Aid Industry Conference Interim Bone Conduction Standard); within ± 5 dB of the air conduction thresholds. A conductive loss was defined as air conduction thresholds greater than 30 dB HL with at least a 15 dB difference between the air conduction and bone conduction thresholds. Sensorineural loss was defined as bone conduction thresholds greater than 20 dB HL with air conduction thresholds within ± 5 dB. Subjects received an examination in the hospital's Ear, Nose and Throat Clinic. On the basis of preliminary audiometric and medical studies, each subject was assigned to one of the categories.

Instrumentation

A Grason Stadler E 800 audiomatic audiometer was used to generate and control the test signal and the contralateral noise. This automatic unit permits the patient to administer his own hearing test. For this experiment fixed frequency tracings were obtained for a sample of the patient's threshold at the test frequency over a one minute period.

For this experiment, the E 800 automatic audiometer was fitted with a special cam permitting bone conduction measurement. A correction factor was applied to the threshold measurements obtained on CF-2 audiogram forms for bone conduction thresholds to correct for the cam. The test signal was routed to the right member of a matched pair of Telephonic TDH-39 earphones mounted in MX-41/AR cushions for air conduction. This earphone served as the experimental earphone and was always used to deliver the air-conducted stimulus. The bone conducted test stimulus was provided by a Radioear B-70A vibrator. The noise stimulus produced by the noise generator in the E 800 audiometer was routed to the left member of a pair of Telephonic TDH-39 earphones in MX-41/AR cushions. This earphone served as the masking earphone and was always used to deliver the masking noise to the ear contralateral to the test ear.

An interrupted tone with an "on" time of 200 milliseconds at peak amplitude and a 25 millisecond symmetrical rise and decay time was used for all measurements. This signal had a 50 per cent duty cycle. A one minute fixed frequency tracing was made at each of the test frequencies. The motor-driven attenuator of the audiometer was operated at an attenuation rate of 2.5 dB per second for both air conduction and bone conduction tests. The test stimulus consisted of a pulsed or interrupted tone at each of five frequencies at octave intervals from 250 to 4000 Hz. The tone stimulus for each threshold measurement was presented in conjunction with contralateral masking. The masking noise consisted of a broad band white noise and was presented to the contralateral ear at a predetermined level immediately prior to the presentation of the test tone in each condition and was removed immediately following the termination of the test tone.

Testing was completed in an Industrial Acoustics Company (Model GDC-2R) two room sound-treated audiometric test suite in the Audiology Clinic of the Veterans Administration Hospital. A two-way vision mirror permitted visual communication between the test and control rooms. The subjects could be monitored auditorily by means of a talk-back system.

Description of Experimental Procedures

Threshold measurements were obtained for each subject under four different experimental conditions. For each condition, thresholds were obtained at octave intervals between 250 and 4000 Hz. Contralateral masking noise was used to isolate the test ear under all experimental conditions. Responses were recorded by the patient as he responded to the test stimuli. The threshold measurements were extracted from the original threshold tracings and recorded on an individual subject data sheet. Experimental controls included calibration checks, standard instructions, constant vibrator pressure and a counterbalanced schedule of treatment conditions.

Test Conditions

Condition I consisted of measurement of air conduction thresholds for each of five test frequencies. The experimental earphone was secured to the head over the test ear and the masking earphone over the non-test ear.

Condition II consisted of measurements of bone conduction thresholds at the mastoid with the test ear unoccluded. The vibrator was secured to the site by use of a reinforced spring type headband. The static vibrator pressure was measured and the headband adjusted to maintain a minimum force of 800 grams. The masking earphone was secured over the non-test ear.

Condition III consisted of measurement of bone conduction thresholds at the forehead site with the test ear unoccluded. The bone vibrator was placed at the midline of the frontal bone approximately one inch above the eyebrow line and secured by an adjustable circumferential headband. The static vibrator pressure was measured and adjusted to approximately 800 grams. The masker earphone was secured over the non-test ear.

Condition IV differed from Condition III in that the test ear was occluded with a dummy standard clinical earphone TDH-39 and an MX-41/AR earphone cushion.

In summary the four conditions were as follows:

Condition	I	Air Conduction Threshold Measurement (AC)
Condition	II	Unoccluded Mastoid Bone Conduction Threshold Measurement (UM)
Condition	III	Unoccluded Forehead Bone Conduction Threshold Measurement (UF)
Condition	IV	Occluded Forehead Bone Conduction Threshold Measurement (OF)

Masking

A 50 dB level of effective masking was introduced to the contralateral ear prior to the presentation of the test signal to the test ear. This effective masking level was calculated for each frequency on the basis of a modification of the formula presented by Studebaker (1964):

$$50 \text{ dB effective level} = Min_n + T_m + 50 \text{ dB}$$

where Min_n equals the minimum noise level required to just mask the test tone for normal-hearing subjects, and T_m equals the threshold of the contralateral ear for the frequency to be tested. This sum represents the amount of masking noise needed to reach the desired 50 dB effective level. The minimum noise level for each frequency was determined by calculating the band-width in decibels of the critical band-widths presented by Zwicker, Flottorp and Stevens (1957) and adding these to the ANSI, 1969 threshold sound pressure levels for each test frequency.

Response Recording

In response to the test signal, each subject traced a threshold on individual audiogram forms (E-800 CF-2). A tracing consisted of a series of recorded excursions over a one minute period. Threshold values were obtained from the tracings by averaging the values indicated by the limits of the last five excursions of the tracing. A correction factor obtained from weekly calibration data was then applied to the measurement.

Experimental Controls

Four controls were used to reduce the effects of experimental error: instructions were standard for each subject; a quasi-counterbalanced schedule of treatment conditions was used to reduce the effect of systematic biases on the data and frequent calibration checks were made.

Each subject was given the following instructions:

> During all of the testing, you will hear two kinds of sounds--a tone and a noise. The tone will be interrupted or pulsed, whereas, the noise will be presented continuously. I want you to ignore the noise and listen to the tone. Whenever you hear the tone--or the pulsed sound--I want you to push the button down and hold it down for as long as you hear the tone. When you can no longer hear the tone, release the button.

The quasi-counterbalanced schedule of conditions presented in Table 3 dictated the order of presentation of the four treatment conditions and five test frequencies to each of the subjects. The first ear tested was also determined by the condition schedule. The schedule was used for each category of subjects separately.

TABLE 3

COUNTERBALANCED SCHEDULE OF TREATMENT CONDITIONS

No.	Treatment	Frequency	Ear
1	1234	12345	R
2	2341	23451	L
3	3412	34512	R
4	4123	45123	L
5	1234	51234	R
6	2341	12345	L
7	3412	23451	R
8	4123	34512	L
9	1234	45123	R
10	2341	51234	L

In order to monitor the output of the test equipment the following system of calibration was used each week prior to the day of testing. A Bruel and Kjaer artificial ear Model 2203 was used to measure output of the noise channel and the air conduction output of the pure tone channel. The maximum output of the noise channel was routinely monitored. For pure tone air conduction measurement, the experimental earphone was coupled to the microphone of the artificial ear. A reading of the sound pressure level (SPL) of the noise channel and each frequency of the pure tone channel was made and compared with the expected levels of ANSI S3 6-1969 Standards. The differences in the expected levels and the measured levels were recorded as correction factors and corrections made for individual threshold measurements. The output of the bone vibrator was monitored with the use of a Bruel and Kjaer artificial mastoid. Readings were made on the output of the vibrator and compared with the expected values supplied by the manufacturer. Correction factors were formulated on the basis of these measurements.

The static pressure exerted by the vibrator was maintained at a minimum of 800 grams. This pressure was measured with the spring weight scale supplied with the Bruel and Kjaer artificial mastoid.

Statistical Analysis

Threshold values were obtained from the tracings by averaging the limits of excursions and calibration corrections were made. Standard error of the mean difference and significance measurements were applied to derived difference scores. Means and standard deviations were also calculated for these measurements. The presentation of the statistical analysis and interpretation of the results is presented in the following chapter.

CHAPTER IV

RESULTS AND INTERPRETATION

The purpose of the present study was to investigate the use of occluded forehead bone conduction in a clinical setting. First, the relationship between the loss of sensitivity noted with forehead placement and the occlusion effect was investigated. Second, the occluded forehead thresholds were compared with the unoccluded mastoid thresholds for agreement. Thirdly, the pattern demonstrated by comparison of the air conduction thresholds with the unoccluded mastoid thresholds was matched with the pattern demonstrated by comparison of the air conduction thresholds with the occluded forehead thresholds. The following discussion presents the results of this investigation.

Calibration Data

The calibration data for the present study is shown in Table 4 with the presentation of the means of the air conduction (AC) and unoccluded mastoid bone conduction (UM) thresholds for normal hearing subjects. The thresholds obtained via air conduction are expressed in Hearing Levels referenced to the American National Standard Institute, 1969 audiometric standard. Thresholds obtained via bone conduction are expressed in Hearing Levels referenced to the

Hearing Aid Industry Conference Interim Bone Conduction Standard.

TABLE 4

MEANS OF AIR CONDUCTION (AC) AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN NORMAL EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
AC	17.06	11.63	6.78	6.15	7.03
UM	17.66	14.06	7.60	.18	12.52

Difference scores were obtained by subtracting the unoccluded mastoid bone conduction threshold from the air conduction threshold for each test ear (AC-UM). Table 5 presents the means and standard deviations derived from these difference scores. Examination of these data illustrate the relative agreement of these measurements and show that generally the variability of these thresholds is within the range normally expected.

TABLE 5

MEANS AND STANDARD DEVIATIONS OF AIR CONDUCTION MINUS UNOCCLUDED MASTOID BONE CONDUCTION (AC-UM) IN NORMAL EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Mean	- .60	-2.43	- .82	5.97	-5.49
SD	5.17	6.03	10.32	6.41	5.74

The following sections present the statistical analysis and discussion of the results of the present study. For purposes of this study, differences of 5 dB or less constitute equivalence.

Normal Hearing Subjects

The mean thresholds for normal ears at each frequency for the AC, OF, UF and UM conditions are presented in Table 6 and illustrated in Figure 1. Examination of these data reveals that in the present study the UF measurements across

TABLE 6

MEANS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION THRESHOLDS (UM) IN NORMAL EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
AC	17.06	11.63	6.78	6.15	7.03
OF	12.53	- 3.50	3.90	10.18	14.48
UF	24.23	12.30	11.45	13.55	11.72
UM	17.66	14.06	7.60	.18	12.52

frequencies are higher than or equal (within ± 5 dB) to the AC thresholds and the other bone conduction thresholds. A frequency dependence is exhibited in this relationship in that the difference between the UF measurements and the next highest value is greater at 250, 1000 and 2000 Hz than at the other test frequencies. The elevation of the bone conduction thresholds obtained under the UF condition reflects the magnitude of the loss of sensitivity noted with forehead placement. The largest mean values for the loss of sensitivity noted with forehead placement were found at 250, 1000

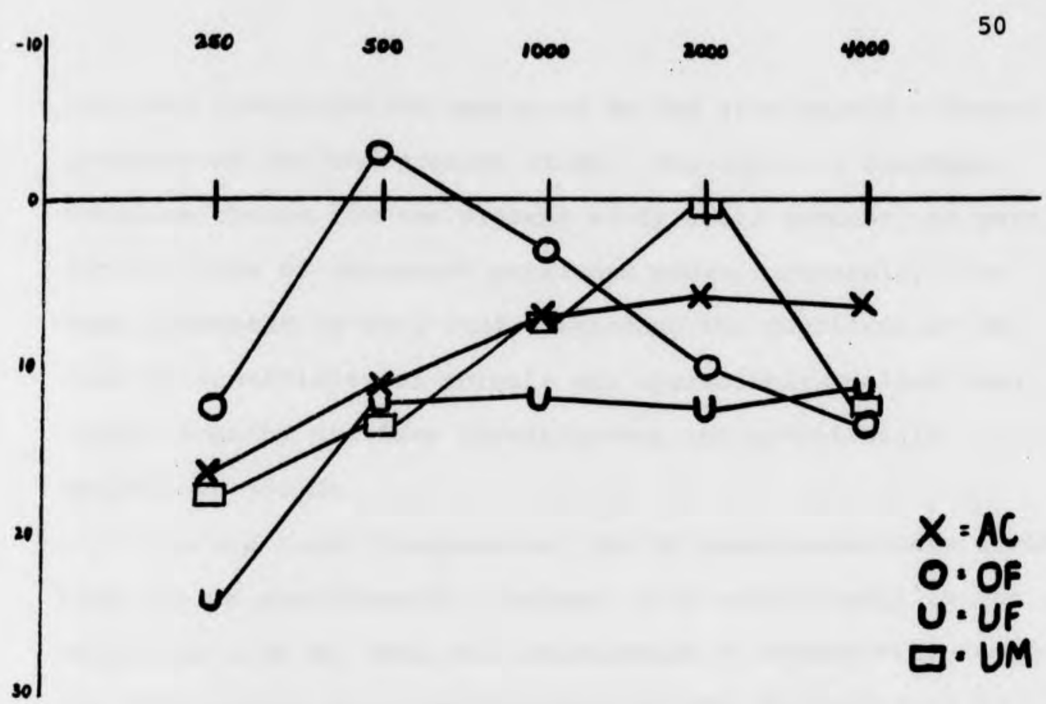

Figure 1. MEANS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN NORMAL EARS

and 2000 Hz (6.57, 3.85 and 13.37 dB respectively). A negative loss of sensitivity (threshold obtained with forehead placement lower than threshold obtained at mastoid) was demonstrated at 500 and 4000 Hz. In comparing the data obtained in the present study with results presented by previous investigators, a frequency by frequency comparison of the magnitude of the loss of sensitivity in normals shows agreement to be very limited. With the exception of 4000 Hz, the present data compare best with the data presented by Goldstein (1963) in which a smaller loss of sensitivity was reported at 500 Hz than at 250 Hz. The Goldstein study is the only investigation employing an 800 gram static vibrator pressure as did the present study. The level of constant pressure chosen for the present study could account, in part, for the lack of agreement mentioned above. Generally, the data presented by this study regarding the magnitude of the loss of sensitivity in normals are appreciably smaller than those given by previous investigators and specifically smaller at 500 Hz.

In the lower frequencies, the OF measurements are lower than the UM measurements, whereas, this relationship is reversed at 4000 Hz; thus the enhancement of sensitivity resulting from occlusion is most evident at 250, 500 and 1000 Hz (11.7, 15.80, and 7.55 dB respectively) and results in notable threshold improvement. The mean occlusion effect calculated for the normals in the present study agrees with all previously reported studies as to the frequency dependent nature of the magnitude of the occlusion effect. Unlike previous investigations, the greatest occlusion effect in this study was demonstrated at 500 Hz and not at 250 Hz.

As a result of the apparent "normal" magnitude of the occlusion effect and the reduced effect of forehead placement in the present study, the occlusion effect appears to overcompensate for the loss of sensitivity associated with forehead placement in the lower frequencies. For the occlusion effect to compensate for the loss of sensitivity, both phenomena must produce equivalent effects.

In the present study, differences greater than five dB between the mean loss of sensitivity and the mean occlusion effect were demonstrated at 250 Hz and differences greater than ten dB between these means were demonstrated at 500 and 2000 Hz. The large difference at 500 Hz can be attributed to the reduced loss of sensitivity and a greater than expected occlusion effect at this frequency. Similarly, the surprisingly large magnitude of the loss of sensitivity at 2000 Hz (13.37 dB) demonstrated a greater difference when compared with the magnitude of the occlusion effect at 2000 Hz (3.37 dB). In the present study, 1000 and 4000 Hz are the only frequencies at which the occlusion effect compensates for the loss of sensitivity. The occlusion effect and the loss of sensitivity produced small effects at these frequencies. t-ratios demonstrated significant differences between the magnitude of the loss of sensitivity and the occlusion effect at 500 and 2000 Hz.

Comparison of the OF and UM thresholds across frequencies indicates a lack of equivalence at 250, 500 and 2000 Hz where the difference between the mean measurements exceeded five dB. The differences at 250 and 500 Hz are accounted for, in part, by the large occlusion effect measured at these frequencies. The difference at 2000 Hz is probably the result of the large loss of sensitivity at that frequency. Significant differences based on t-ratios between the OF and UM measurements were found at 500 and 2000 Hz. This above information does not agree with the information presented by Conley and Elpern (1969) in which an equivalence was demonstrated between the AC and OF measurements, based on the assumption that AC and UM thresholds are equal in normals. The lack of agreement between the results of the present study and the results of the previous study may partially be due to the difference between the AC and UM thresholds and to the variability of the occlusion effect and the loss of sensitivity values in the present study.

The differences above described affect the patterns demonstrated by (AC-OF) and (AC-UM). Differences exceeding five dB between the (AC-UM) and (AC-OF) values were demonstrated at 250, 500 and 2000 Hz. In the present study, therefore, the patterns were changed in normal ears at these frequencies and significant differences between the (AC-OF) and (AC-UM) means were demonstrated at 250, 500 and 2000 Hz.

Generally, for normal ears the large occlusion effect and the small loss of sensitivity at 500 Hz affected all three comparisons and resulted in significant differences in the paired comparisons at this frequency. Comparison of the loss of sensitivity and the occlusion effect in normals yielded significant differences additionally at 2000 Hz. A significant difference was also found at 2000 Hz when the OF and UM threshold were compared. Significant changes in pattern were demonstrated at 250 and 2000 Hz when the OF values were substituted for the UM values in an air conduction and bone conduction comparison. The above information indicates that the OF method is not directly interchangeable with the UM method. Nor does it appear to yield equivalent threshold configurations in normals.

Conductive Hearing Loss Subjects

Table 7 and Figure 2 summarize the mean threshold measurements obtained with AC, OF, UF and UM in conductive hearing loss group. The data presented clearly indicates that the UM thresholds are consistently lower than both the UF and OF thresholds. The elevation of the UF thresholds is

TABLE 7

MEANS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN CONDUCTIVE EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
AC	53.61	61.37	59.64	53.43	65.03
OF	16.02	22.52	23.03	32.27	34.46
UF	15.54	23.27	23.13	31.99	35.39
UM	4.66	15.64	14.01	24.40	36.71

due to the loss of sensitivity noted with forehead placement. These data reflect the inverse relationship between frequency and the magnitude of the loss of sensitivity in that the greatest value was obtained at 250 Hz and the least at 4000 Hz. Because of the apparent equivalence of the OF and UF measurements, these data additionally reflect the absence of

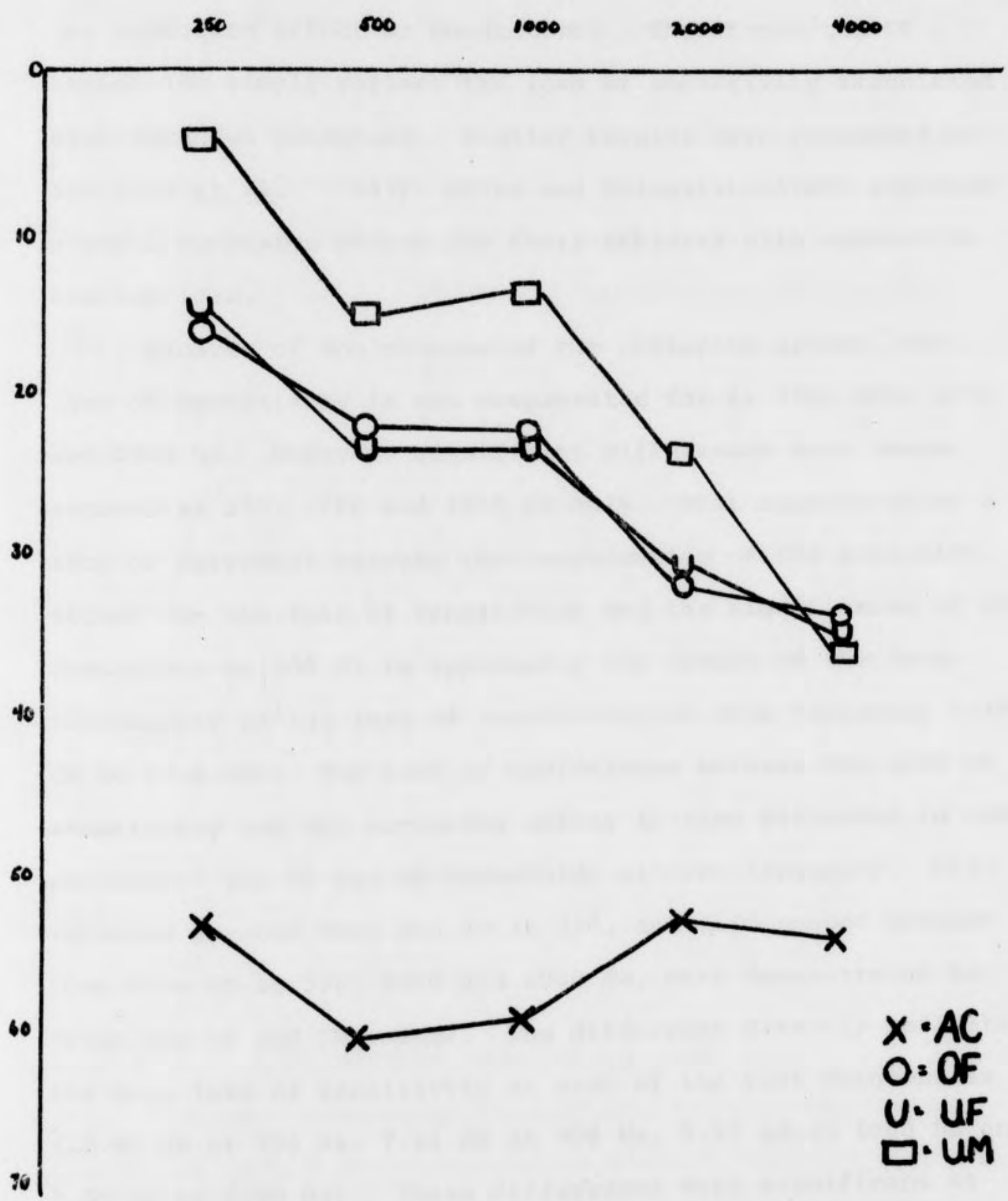

Figure 2. MEANS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN CONDUCTIVE EARS

the occlusion effect in conductives. Therefore, the OF thresholds simply reflect the loss of sensitivity associated with forehead placement. Similar results were presented by Sullivan et al. (1947); Dirks and Malmquist (1969) reported a small occlusion effect for their subjects with conductive hearing loss.

Because of the absence of the occlusion effect, the loss of sensitivity is not compensated for at 250, 500, 1000 and 2000 Hz. However, significant differences were demonstrated at 250, 1000 and 2000 Hz only. What appears to be a lack of agreement between the compensation of the occlusion effect for the loss of sensitivity and the significance of this comparison at 500 Hz is apparently the result of the large variability of the loss of sensitivity at this frequency (-18.4 dB to 27.8 dB). The lack of equivalence between the loss of sensitivity and the occlusion effect is also reflected in comparison of the OF and UM thresholds at each frequency. Differences greater than ten dB at 250, and differences greater than five dB at 500, 1000 and 2000 Hz, were demonstrated between the OF and UM values. The difference directly reflects the mean loss of sensitivity at each of the test frequencies (10.88 dB at 250 Hz, 7.63 dB at 500 Hz, 9.12 dB at 1000 Hz and 7.59 dB at 2000 Hz). These differences were significant at 250 and 1000 Hz. The noted lack of significance at 500 Hz again could be attributed to the variability of the loss of sensitivity at this frequency.

The air-bone gap demonstrated by comparison of the AC and UM thresholds was narrowed at all frequencies except 4000 Hz when the AC thresholds were compared to the OF thresholds. Specifically, the air-bone gap was decreased by 11.36 dB at 250 Hz, 6.88 dB at 500 Hz, 9.02 dB at 1000 Hz and 7.87 dB at 2000 Hz. Significant differences between the (AC-UM) and (AC-OF) were demonstrated at only 250 and 1000 Hz. While the difference at 500 Hz was not statistically significant, it was substantial.

Generally, most of the comparisons made by grouping of the data in the conductives reflect the absence of the occlusion effect. In the case of the conductives, each of the numerical comparisons based on the differences scores simply view the absence of the occlusion effect from a different perspective. The significance of the differences demonstrated the apparent narrowing of the air-bone gap in the present population militate against the use of OF for diagnostic purposes when used with present clinical definitions based on UM thresholds.

Sensorineural Hearing Loss Subjects

The mean thresholds obtained at each frequency under AC, OF, UF and UM are presented in Table 8 and illustrated in Figure 3. Examination of these data indicate that in the lower frequencies, the highest bone conduction thresholds were obtained with UF. The sensitivity loss resulting from forehead placement, without enhancement through occlusion, is

TABLE 8

MEANS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN SENSORINEURAL EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
AC	35.61	42.62	50.16	50.66	62.90
OF	26.45	26.38	41.54	54.04	56.50
UF	34.07	42.80	46.66	51.32	58.01
UM	24.75	40.60	44.44	47.94	60.94

responsible for these threshold elevations. The magnitude of the loss of sensitivity noted with forehead placement in the sensorineurals decreases as frequency increases (9.32 dB at 250 Hz to -2.93 dB at 4000 Hz).

In the lower frequencies, the lowest mean thresholds were recorded by UM and OF at 250 and 1000 Hz. At 500 Hz, the OF thresholds are lower than the UM thresholds. These comparisons reflect the magnitude of the occlusion effect demonstrated at these frequencies (7.62 dB at 250 Hz, 16.42 dB at 500 Hz and 5.12 dB at 1000 Hz). At 2000 and 4000 Hz, the bone conduction measurements are roughly equivalent and appear to be only slightly affected by either forehead placement or occlusion. The magnitude of the loss of sensitivity and the occlusion effect in sensorineural ears closely agree with the values presented for the normal ears in the present study.

Application of the t-ratios showed the difference

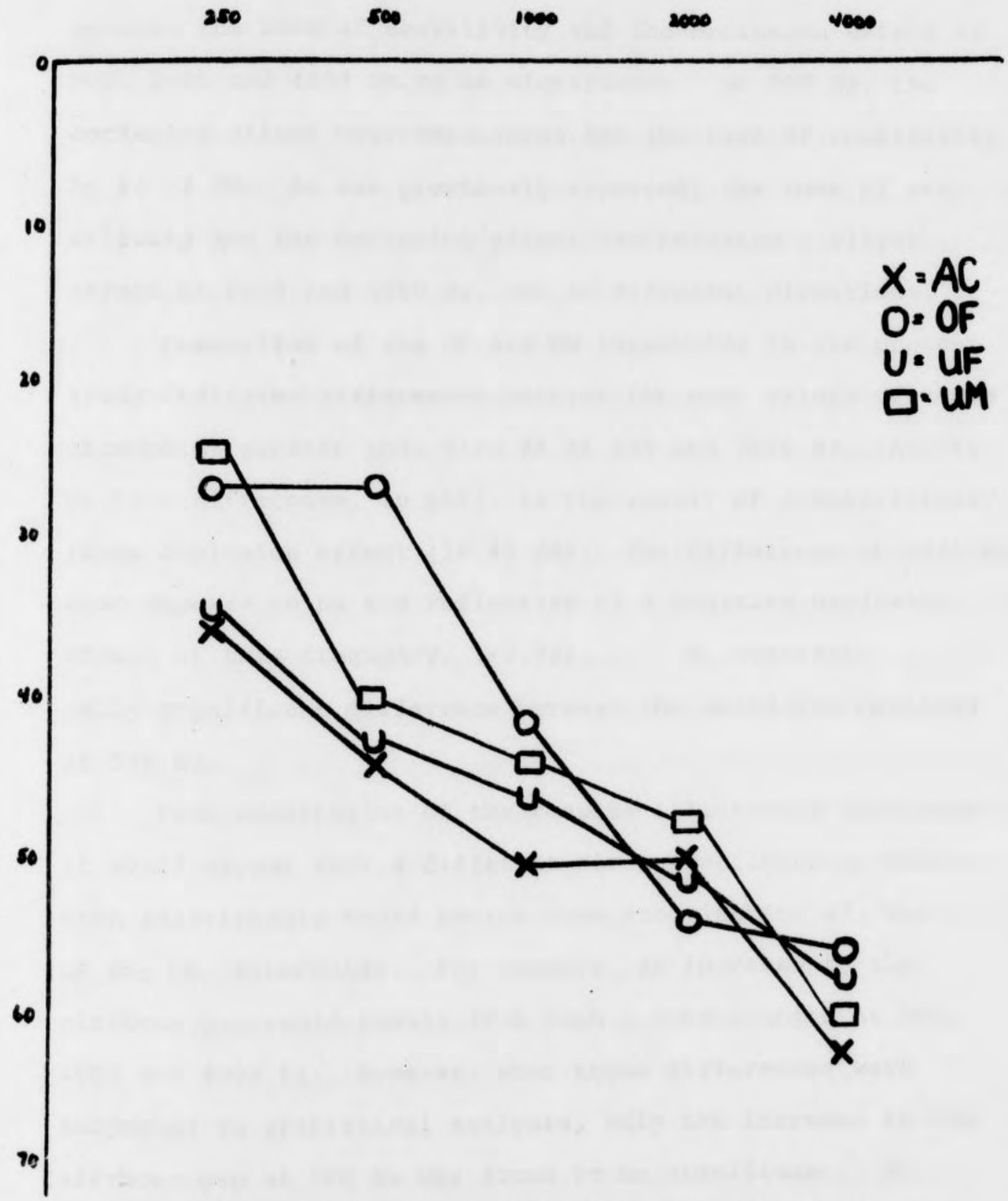

Figure 3. MEANS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN SENSORINEURAL EARS

between the loss of sensitivity and the occlusion effect at 500, 2000 and 4000 Hz to be significant. At 500 Hz, the occlusion effect overcompensates for the loss of sensitivity by 14.22 dB. As was previously reported, the loss of sensitivity and the occlusion effect demonstrated a slight effect at 2000 and 4000 Hz, but in different directions.

Comparison of the OF and UM thresholds in the present study indicates differences between the mean values of these thresholds greater than five dB at 500 and 2000 Hz. At 500 Hz this difference, in part, is the result of a surprisingly large occlusion effect (16.42 dB). The difference at 2000 Hz also appears to be the reflection of a negative occlusion effect at this frequency (-2.72). A statistically significant difference between the means was obtained at 500 Hz.

From examination of the results illustrated in Figure 3 it would appear that a different air conduction-bone conduction relationship would emerge from substitution of the OF for UM thresholds. For example, an increase in the air-bone gap would result from such a substitution at 500, 1000 and 4000 Hz. However, when these differences were subjected to statistical analysis, only the increase in the air-bone gap at 500 Hz was found to be significant. In addition, at 2000 Hz the (AC-UM) mean difference was found to be significantly different from the (AC-OF) mean difference. This results from the fact that the slight air-bone gap in the (AC-UM) comparison changes to a slight bone-air gap in the (AC-OF) comparison.

In general, for the sensorineural loss subjects the loss of sensitivity and the occlusion effect are approximately equal in magnitude, although opposite in effect on threshold, and consequently yield a non-significant mean difference at 250 and 1000 Hz. Since this relationship is intimately involved in the comparisons between the UM and OF thresholds and in the (AC-UM) and (AC-OF) differences, these were also found to be non-significant. In contrast, the occlusion effect was found to be significantly larger in magnitude than the loss of sensitivity at 500 Hz. This significantly larger occlusion effect obviously is the contributing factor in the significant differences between the UM versus OF thresholds and the comparison of the (AC-UM) and (AC-OF) differences at 500 Hz. At 2000 Hz, significant differences were demonstrated between the loss of sensitivity and the occlusion effect and the (AC-UM) and (AC-OF) values, while no significant difference was found in the OF and UM comparison. At 4000 Hz, a significant difference was found between the loss of sensitivity and the occlusion effect only. It is unclear why this significance appeared.

Statistical and comparative treatment of the data for sensorineurals indicates that at 500 Hz the occlusion effect and the loss of sensitivity are not equal in effect and, therefore, the OF and UM thresholds are not equivalent.

These differences are statistically significant. Therefore, OF measurements do not yield the same threshold level or configuration as obtained with UM placement. This being the case, use of OF placement could lead to either a misinterpretation or a confounding of the results in the clinical setting.

Variability

The type of statistical analysis of the variability of the OF, UF, UM and AC thresholds limited the conclusions based on these data to the present study. Table 9 and Figure 4 present the standard deviations of the AC, OF, UF and UM thresholds at each frequency for the normals.

TABLE 9

STANDARD DEVIATIONS FOR AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION THRESHOLDS (UM) IN NORMAL EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
AC	5.98	6.54	5.90	5.18	5.19
OF	5.17	9.22	4.67	4.53	7.85
UF	5.38	5.63	6.53	7.04	3.36
UM	8.52	9.69	6.74	3.84	7.73

The AC thresholds demonstrated variability across frequencies ranging from 5.18 dB at 2000 Hz to 6.54 dB at 500 Hz. The UF variability measurements ranged from the 3.36 dB at 4000 Hz to 7.04 at 2000 Hz and the UM threshold

Figure 4. STANDARD DEVIATIONS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN NORMAL EARS

variability ranged from 3.84 dB at 2000 Hz to 9.69 dB at 500 Hz. The variability under OF ranged from 4.53 dB at 2000 Hz to 9.22 dB at 500 Hz. Most notable of the variability differences at individual frequencies was present at 500 Hz where the OF and UM values exhibit greater variability than the UF values.

Table 10 and Figure 5 summarize the standard deviations of the air conduction and bone conduction thresholds for the conductive-loss group. Examination of Figures 4 and 5 clearly shows the greater variability demonstrated by all threshold measurements in the conductive ears as compared to the normal ears.

TABLE 10

STANDARD DEVIATIONS FOR AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN CONDUCTIVE EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
AC	14.79	9.62	10.06	14.15	17.16
OF	10.74	13.36	7.88	15.18	17.17
UF	11.56	13.26	8.12	15.04	17.54
UM	8.86	10.17	8.71	16.32	19.72

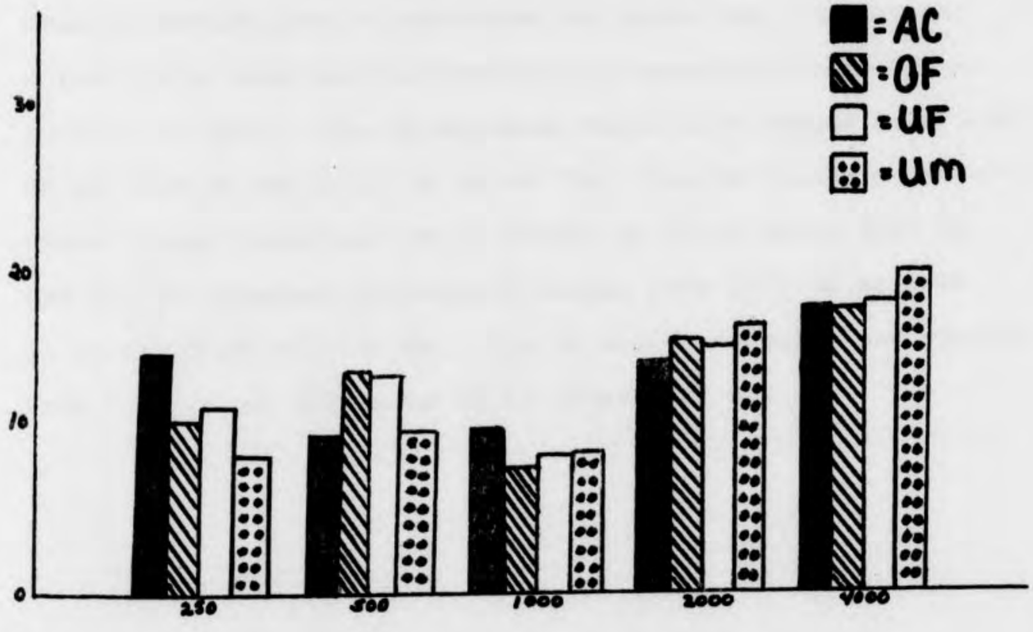

Figure 5. STANDARD DEVIATIONS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN CONDUCTIVE EARS.

The spread of the thresholds around the mean under UF ranged from 8.12 dB at 1000 Hz to 17.54 dB at 4000 Hz and under AC from 9.62 dB at 500 Hz to 17.16 dB at 4000 Hz. The OF standard deviations ranged from 7.88 dB at 1000 Hz to 17.17 dB at 4000 Hz. Across frequencies, the greatest range in variability was exhibited by the UM thresholds where the least was 8.71 dB at 1000 Hz and the greatest was 19.72 dB at 4000 Hz.

Table 11 and Figure 6 summarize the standard deviations obtained at each frequency for the sensorineural-loss group. Greater variability is exhibited by these data than by the normal data, but less variability by these data than by the conductive data. The AC standard deviations ranged from 5.99 dB at 2000 Hz to 11.22 dB at 250 Hz. The OF standard deviations ranged from 6.18 dB at 250 Hz to 10.45 dB at 4000 Hz and the UF standard deviations ranged from 5.35 dB at 2000 Hz to 11.65 dB at 4000 Hz. The UM standard deviations ranged from 6.46 dB at 500 Hz to 10.15 dB at 4000 Hz.

TABLE 11

STANDARD DEVIATIONS FOR AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN SENSORINEURAL EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
AC	11.22	6.51	7.19	5.99	7.81
OF	6.18	6.83	10.43	6.26	10.45
UF	7.47	10.18	7.96	5.35	11.65
UM	7.96	6.46	6.73	9.04	10.15

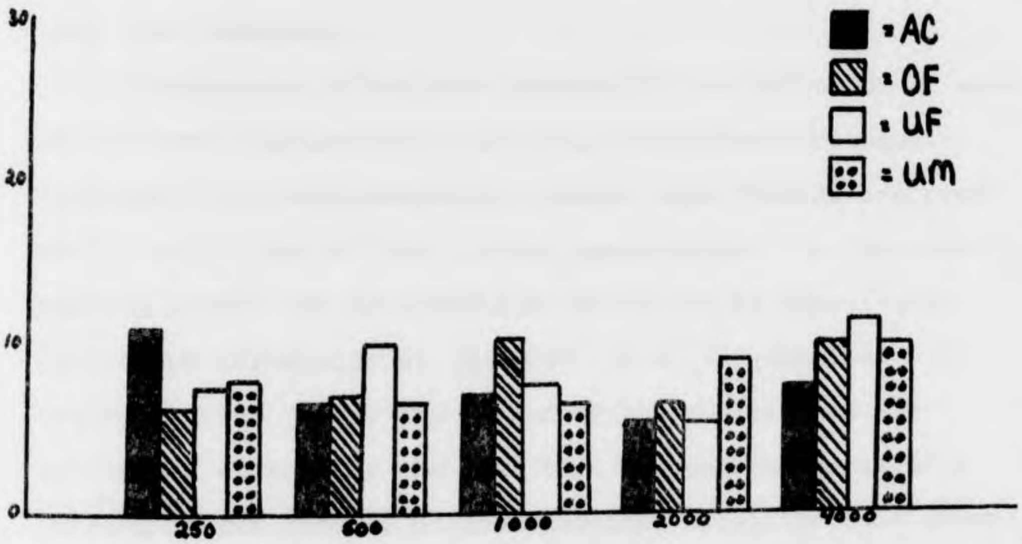

Figure 6. STANDARD DEVIATIONS OF AIR CONDUCTION (AC), OCCLUDED FOREHEAD BONE CONDUCTION (OF), UNOCCLUDED FOREHEAD BONE CONDUCTION (UF), AND UNOCCLUDED MASTOID BONE CONDUCTION (UM) IN SENSORINEURAL EARS

Summary

The present investigation was designed to explore the use of occluded forehead bone conduction in a clinical setting. Specifically, the present study explored the equivalence of OF thresholds and UM thresholds and the extent to which the occlusion effect compensates for the loss of sensitivity associated with forehead placement. Additionally, the study was designed to determine if the pattern demonstrated by comparison of air conduction thresholds and unoccluded mastoid bone conduction in various types of hearing loss is unchanged when air conduction thresholds are compared with occluded forehead bone conduction thresholds. Mean comparisons were made on each of the pairs of data at each test frequency.

Comparison of the mean thresholds for OF and UM at each of the test frequencies in all three diagnostic categories indicates that differences no greater than five dB are present in only six of the fifteen comparisons. In the normal hearing group, the OF thresholds could not be substituted for the UM thresholds at three of five frequencies. In the conductive group, the UM and OF thresholds were not equivalent at four of the five test frequencies apparently because of the absence of the occlusion effect in this group. In the sensorineural group, the OF and UM thresholds were not equivalent at two of the five frequencies. When the significance of the difference between the means of the OF and UM measurements was investigated, five of the fifteen comparisons demonstrated significant differences between the means. This information indicates that OF thresholds cannot be substituted for UM thresholds in a clinical setting without a loss of information.

Across category comparison of the mean occlusion effect and the mean loss of sensitivity indicates differences greater than five dB for nine of fifteen test frequency comparisons. The occlusion effect did not compensate for the loss of sensitivity in the present study at three of the five test frequencies in the normal group, at four of the five in the conductive group and at two of the five in the sensorineural group. Significant differences between the mean occlusion effect and the mean loss of sensitivity were demonstrated in eight of the fifteen comparisons indicating that the occlusion effect does not compensate for the loss of sensitivity associated with forehead placement in various types of hearing loss.

Comparison of the pattern demonstrated by AC and OF, and by AC and UM thresholds was based on (AC-UM) and (AC-OF) difference scores. Differences greater than five dB between the mean (AC-UM) and (AC-OF) scores were found in nine of the fifteen comparisons. In the normal group, these differences appeared at 250 and 2000 Hz. In the conductive group, differences greater than 5 dB were found at all frequencies except 4000 Hz. In the sensorineural group, these differences appeared at 500 and 2000 Hz. Similarly, significant differences between the mean (AC-UM) and (AC-OF) values was demonstrated in seven of the fifteen comparisons indicating that the pattern demonstrated by (AC-UM) is not the same as the pattern demonstrated by (AC-OF) in various types of hearing loss.

An overview of the data shows that the OF method does not yield the same threshold configuration or bear the same relationship to the air conduction thresholds as provided by the UM method. Additionally, the occlusion effect--an essential element in the OF method--produces different effects in various types of hearing loss and is, therefore, not universally applicable.

In addition to the data described above, the present study demonstrated the following findings consistent with previous investigations: 1) greater variability was demonstrated by the hearing-loss groups than by the normal group; 2) an absence of the occlusion effect was demonstrated in the conductive group in the present study; 3) an occlusion effect was demonstrated in the sensorineural group similar in magnitude to that demonstrated in the normal group.

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APPENDICES

Statistical Analyses

APPENDIX A

t-RATIOS -- SIGNIFICANCE OF THE MEAN DIFFERENCE BETWEEN UNOCCLUDED FOREHEAD MINUS UNOCCLUDED MASTOID THRESHOLDS (LOSS OF SENSITIVITY) AND UNOCCLUDED FOREHEAD MINUS OCCLUDED FOREHEAD THRESHOLDS (OCCLUSION EFFECT) FOR NORMAL, CONDUCTIVE LOSS, AND SENSORINEURAL LOSS EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Normal	2.02	6.13**	.92	4.52**	.62
Conductive	4.82**	1.71	2.31*	3.50**	.92
Sensorineural	.53	4.36**	1.04	2.58*	2.45*

* .05 level of confidence
** .01 level of confidence

t-RATIOS -- SIGNIFICANCE OF THE MEAN DIFFERENCE BETWEEN OCCLUDED FOREHEAD AND UNOCCLUDED MASTOID THRESHOLDS FOR NORMAL, CONDUCTIVE LOSS AND SENSORINEURAL LOSS EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Normal	1.79	4.55**	1.49	5.83**	.62
Conductive	2.83*	1.42	2.66*	1.22	.29
Sensorineural	.58	5.24**	.81	1.92	1.01

* .05 level of confidence
** .01 level of confidence

t-RATIOS -- SIGNIFICANCE OF THE MEAN DIFFERENCE BETWEEN AIR CONDUCTION MINUS UNOCCLUDED MASTOID BONE CONDUCTION (AC-UM) AND AIR CONDUCTION MINUS OCCLUDED FOREHEAD BONE CONDUCTION THRESHOLDS FOR NORMAL, CONDUCTIVE LOSS AND SENSORINEURAL LOSS EARS

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Normal	2.49*	6.57**	1.07	4.43**	.67
Conductive	2.48*	1.88	2.66*	1.79	.54
Sensorineural	.34	3.81**	.71	2.38*	1.23

* .05 level of confidence
** .01 level of confidence

Note: It should be stated that a spurious significance could occur when this number of mean comparisons is tested for significance.

APPENDIX B

MEANS AND STANDARD DEVIATIONS OBTAINED
FROM DIFFERENCE SCORES
FOR NORMAL EARS

	(UF-OF)	(UF-UM)	(OF-UM)	(AC-UM)	(AC-OF)
250 Hz					
Mean	11.7	6.57	- 5.13	- .6	4.53
Standard Deviation	3.48	8.09	6.59	5.17	4.89
500 Hz					
Mean	15.8	- 1.76	-17.56	- 2.43	15.13
Standard Deviation	6.03	7.88	10.59	6.03	7.03
1000 Hz					
Mean	7.55	3.85	- 3.7	- .82	2.88
Standard Deviation	7.85	9.15	9.15	10.32	5.98
2000 Hz					
Mean	3.37	13.37	10.0	5.97	- 4.03
Standard Deviation	3.62	6.75	5.45	6.41	4.49
4000 Hz					
Mean	- 2.76	- .8	1.96	- 5.49	- 7.45
Standard Deviation	7.68	7.96	10.92	5.74	8.41

APPENDIX C

MEANS AND STANDARD DEVIATIONS OBTAINED FROM DIFFERENCE SCORES FOR CONDUCTIVE EARS

	(UF-OF)	(UF-UM)	(OF-UM)	(AC-UM)	(AC-OF)
250 Hz					
Mean	- .48	10.88	11.36	48.95	37.59
Standard Deviation	3.39	7.44	8.02	10.56	11.90
500 Hz					
Mean	.75	7.63	6.88	45.73	38.85
Standard Deviation	3.67	13.42	12.09	5.37	11.49
1000 Hz					
Mean	.1	9.12	9.02	45.63	36.61
Standard Deviation	5.90	12.18	9.52	7.62	9.04
2000 Hz					
Mean	- .28	7.59	7.87	29.03	21.16
Standard Deviation	3.44	6.98	7.54	12.35	8.84
4000 Hz					
Mean	.93	- 1.32	- 2.25	28.32	30.57
Standard Deviation	2.24	8.19	7.77	10.09	10.37

APPENDIX D

MEANS AND STANDARD DEVIATIONS OBTAINED FROM DIFFERENCE SCORES FOR SENSORINEURAL EARS

	(UF-OF)	(UF-UM)	(OF-UM)	(AC-UM)	(AC-OF)
250 Hz					
Mean	7.62	9.32	1.7	10.86	9.16
Standard Deviation	4.51	10.05	10.57	11.19	13.64
500 Hz					
Mean	16.42	2.2	-14.22	2.02	16.24
Standard Deviation	7.43	8.49	5.59	10.19	7.93
1000 Hz					
Mean	5.12	2.22	- 2.9	5.72	8.62
Standard Deviation	7.69	5.83	8.72	8.92	10.98
2000 Hz					
Mean	- 2.72	3.38	6.1	2.72	- 3.38
Standard Deviation	4.51	6.82	9.62	6.79	5.72
4000 Hz					
Mean	1.51	- 2.93	- 4.44	1.96	6.4
Standard Deviation	2.32	5.53	4.19	8.74	8.21