72-5070

DANTO, Joseph, 1943-
INTERAURAL ATTENUATION FOR BONE-CONDUCTED STIMULI.

The City University of New York, Ph.D., 1971
Health Sciences, hearing

University Microfilms, A XEROX Company, Ann Arbor, Michigan

INTERAURAL ATTENUATION FOR
BONE-CONDUCTED STIMULI

by

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A dissertation submitted to the Graduate Faculty in Speech in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

1971

This manuscript has been read and accepted for the Graduate Faculty in Speech in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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ACKNOWLEDGEMENTS

The writer wishes to gratefully acknowledge the assistance of the members of the advisory committee, Professors Lang, Duffy and Gerstman, for their aid in the preparation of this document. Special thanks go to the chairman of the committee, Professor Lang, who spent many hours giving advice and consolation.

Thanks are extended to Dr. Martha Rubin of the Lexington School for the Deaf who permitted the use of the facilities wherein the research was conducted.

In addition, the writer wishes to thank his family who have spent many months without husband and father.

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CHAPTER I

INTRODUCTION

When an acoustic stimulus is presented to one ear, there is some fraction of the acoustic energy which will reach the opposite ear; i.e., there is a reduction of signal strength as the stimulus crosses the skull. This phenomenon of crossover or interaural attenuation has been described as the "reduction in the physical intensity of an acoustic signal in passing from a transducer on one side of the head to the opposite cochlea." (Studebaker, 1967: 361)

The amount of this attenuation, for a signal generated by a headphone, has been established, for pure tones, to be from 40 dB in the low frequencies to 70 dB in the high frequencies. Zwislocki (1953) made these measurements by using threshold determinations.

For a signal arising from a bone vibrator, Studebaker (1967) hints that the measurements of interaural attenuation are not as well established. There are differing opinions expressed as to the presence or absence of interaural attenuation for a bone-conducted signal.

> If the right ear is deaf or has a much worse bone conduction than the left, the bone-conducted tone from that worse (right) ear will be heard in the left whenever the intensities 10-20 dB greater than the bone-conducted threshold of the better (left) ear are used. (Langenbeck, 1965:91)

Langenbeck apparently accepts the presence of at least a 10 dB interaural attenuation for a bone-conducted signal.

Feldman rejects this concept. He claims:

> ... one of the major problems in testing bone conduction thresholds is the fact that any stimulation of the skull, regardless of site, effectively activates each end organ. (1961:42)

Conflicting opinions can even be found within the writings of the same author. Hirsh (1952:182) states: "... it is almost inconceivable that we can stimulate one cochlea and not the other when a vibration is applied to the skull ..."; while later in the same text (253) he appears to contradict this: "... bone conduction cross hearing is only 10 dB as opposed to 50 dB for air ..."

Barany (1938) and Kirikae (1959) have investigated the bone conduction phenomenon and in the process have discussed factors relating to interaural attenuation for a bone-conducted signal. Barany's research, however, was carried out with empty skulls and human cadavers as the models and only at 435 Hz. Using two transducers, he measured the relative intensity and phase to achieve a cancellation of signal. Barany has suggested the following as a result of his experiments.

> To the greatest possible extent experiments should be performed on the intact healthy living ear. The main interest should be directed to bone conduction at low frequencies, because here the masking effect is greatest and consequently ... most significant. (Barany, 1938:28)

Kirikae expanded Barany's investigation to include 500 and 1,000 Hz using a similar cancellation technique. In addition, threshold data were obtained on a unilaterally deaf subject. These data indicated an interaural attenuation for bone-conducted stimuli on the order of 5 - 30 dB depending on variables of stimulus frequency and placement of sound source on the skull.

Personal discussion with Juergen Tonndorf, about the problem of measuring the attenuation of bone-conducted signals, resulted in the realization that much of the research concerned with interaural attenuation has involved the use of threshold data as the dependent variable and this information is necessarily confounded by sense organ function. The question then was raised: Does a signal arising from a bone vibrator stimulate both ears with equal intensity?

THE PROBLEM

The problem for the present research was: Does acoustic energy supplied, direct to one point on the skull by a bone vibrator, arrive as equal energy at the two ears - or is there some interaural attenuation as a function of frequency? In studying this question, the plan was to use direct measurements (not threshold data) on live skulls and to make these measurements within the frequency range of 100 to 1,000 Hz. These measurements were the sound pressure levels in the external meatuses.

IMPORTANCE OF THE STUDY

The clinical importance of the study lies in the measurement of the existence of some degree of interaural attenuation for a bone-conducted signal. This is of value in the determination of the possibility of contralateral participation in bone-conduction testing. If the possibility exists, masking procedures would need to be implemented.

The importance of the study in audiologic research is that it serves to clarify some of the conflicting reports on the presence or absence of interaural attenuation for bone-conducted signals. The technique presented also serves as a guide for future studies which should attempt to repeat these data for normative purposes.

SUMMARY

Much conflicting data have been presented concerning the existence of interaural attenuation for bone-conducted signals. Most of those studies which used live skulls have depended on threshold data. Studies utilizing more direct measurements have made those measurements on cadaver skulls. Most measurements made on live skulls have been obtained at only one or two test frequencies.

This researcher sought to make direct measurements of interaural attenuation on live skulls and to do this across a wide range of frequencies. Subjective data (threshold measurements) were not used, but rather sound pressure measurements in the external meatuses.

The belief was that data of this research would be important because they would clarify confusing present literature and definitely demonstrate the presence of some amount of interaural attenuation. In addition, it would be clinically important in setting guidelines for clinical masking in bone-conduction testing.

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CHAPTER II

REVIEW OF THE LITERATURE

Measurement of interaural attenuation has been made for air-conducted stimuli as well as for bone-conducted stimuli. Although this investigation was primarily concerned with the attenuation of a bone-conducted signal, a discussion of the research for air-conducted interaural attenuation would be indispensible methodological background for this study. In addition, the research concerning interaural attenuation for bone-conducted stimuli has not been as uniform throughout the various researchers as the investigations of air conduction interaural attenuation.

INTERAURAL ATTENUATION FOR AIR-CONDUCTED STIMULI

Perhaps the most detailed measurements of interaural attenuation for an air-conducted stimulus have been made by Zwislocki (1953). He used three methods to measure interaural attenuation. One method, the masking method, involved measuring the subject's threshold with equal intensity levels of masking first in the same ear as the stimulus and then in the ear contralateral to the tone. The difference in the thresholds, in decibels, was accepted as "the magnitude of the acoustic attenuation between the ears." (Zwislocki, 1953:753)

A second measure used by Zwislocki was referred to as the method of best beats. When two tones of slightly different frequencies are presented, one to each ear,beats will be perceived by some listeners. Zwislocki presented a high intensity tone to one ear and gradually introduced, from a subliminal level, a second tone of slightly different frequency to the other ear. As the second tone was increased in intensity, beats were perceived. Zwislocki claimed that the beats will be perceived when the two tones have approximately the same intensity in the one ear. The difference, then, between the intensity of the two signals, is the interaural attenuation for an air-conducted signal.

The third technique involved the cancellation of one tone by another tone of equal frequency and intensity but 180^{o} out of phase. One signal was presented to one ear at a low intensity and the other was presented at a high intensity to the opposite ear. When the perceived intensity of the two tones was equal in one ear and the two signals were out of phase with each other, silence should result in that ear. Zwislocki encountered difficulty with this technique because of the Stenger Effect.[1] He overcame this by having the subject watch an oscilloscope to see when the "weak" tone was being presented. The subject adjusted phase and intensity controls until the cancellation was achieved.

Zwislocki reported:

> When the overheard tone and the compensation tone are in opposite phase the compensating tone must be at least 6 dB stronger in order to produce the same intensity when it is sounded and when it is interrupted. (1953:753)

Therefore, to calculate the interaural attenuation, all that was necessary was a subtraction of 6dB from the level of the compensation tone.

Zwislocki then compared the three methods and found the data to be in agreement with each other. He continued to measure interaural attenuation with different headphone systems and found that interaural attenuation was frequency dependent and varied from approximately 40 dB in the low frequencies to 70 dB in the high frequencies.

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[1] The Stenger Effect described the phenomen that given two tones of the same frequency, you will only perceive the tone in the ear in which it is loudest.

INTERAURAL ATTENUATION FOR BONE-CONDUCTED STIMULI

The problem with the measurements of interaural attenuation for a bone-conducted signal is that they seem not to be as widely accepted as those for air conduction. There appears to be much conflicting data as to the existence and amount of interaural attenuation for bone-conducted stimuli.

Feldman (1961:41) states that "any stimulation of the skull, regardless of site, effectively activates each end organ." Langenbeck (1965), Studebaker (1964), and Hirsh (1952), apparently contradict this by discussing the presence of 10 to 20 dB of interaural attenuation for bone-conducted signals.

These statements, as well as those of other writers, offer no data of their own but rely on the data of previous studies which did not directly measure interaural attenuation. To this writer's knowledge, there have been no studies designed specifically for the purpose of measuring interaural attenuation for a bone-conducted signal. Researches designed to measure other variables have been interpreted as they relate to bone-conducted acoustic stimuli. These researches will be reviewed in the paragraphs which follow.

Many measurements have been interpreted with respect to the phenomenon of bone conduction: for example, the following variables have been evaluated with respect to measurement of threshold: vibrator placement, type of vibrator, application pressure of the vibrator, and frequency of the test stimulus.

Relationship Between Interaural Attenuation and Vibratory Patterns of the Skull

Bekesy (1960) devised an instrument for measuring the vibratory characteristics of solid objects.He developed a vibrating probe that was brought into contact with a vibrating object. If the object vibrated at the same phase and intensity of the probe, the probe would maintain its unimpeded vibratory pattern. If, however, the object was not vibrating at the same phase and intensity as the probe, the probe's vibrations would be altered because of a transmission of energy to the object. Using this apparatus, Bekesy determined that the skull vibrates as a whole at 800 Hz. In other words, it vibrates as a single unit with all parts moving simultaneously and in phase. The vibratory patterns become more complex when the vibrating frequency approaches 1,600 Hz.

Barany (1938) modified the method of Bekesy in order to increase accuracy and for other, less important, reasons stated in his article. The experiment of Barany was carried out only at 435 Hz. A probe similar to the one described by Bekesy was applied to the skull both adjacent to and opposite to the bone vibrator. By balancing the vibratory characteristics of the probe, he determined that the amplitude of vibrations was equal on both sides of the skull. He therefore concluded that the skull vibrates as a simple sphere at 435 Hz. This supports the conclusions of Bekesy.

Feldman (1961) used these data for his statements about interaural attenuation. He deduced that there is no interaural attenuation for a bone-conducted signal since the amplitude was reported to be equal on both sides of the skull. It would seem that he was ignoring the fact that these data indicate the transmission characteristics of the skull as a solid vibrating object and do not, nor were they designed to consider the contribution of other modes of bone conduction.

Kirikae (1959) reported a series of experiments designed to measure some of the mechanisms of bone conduction. One series measured the vibratory patterns of empty skulls, filled skulls, and a cadaver.

In order to measure the vibratory patterns, a rochelle salt crystal served as a transducer. A sine wave generator was connected to a vibrator and to one channel of an oscilloscope. The crystal was connected to the other channel of the oscilloscope. This permitted a display of the phase differences between the two signals - the input signal and the output signal.

Thirty-one spines were cemented to various parts of the skull so that, at each point on the skull, three planes of movement could be measured. The skulls were then driven from either the forehead or the mastoid at 250, 500, or at 1,000 Hz. Measurements of the voltage and phase were taken from the output of the crystal for three planes (horizontal, saggital, and transverse) of each of the thirty-one locations on the skull. The resultant voltages and phase relationships for each of the experimental conditions were presented in tabular form. The patterns produced were usually complex and the reader is referred to the original article for the actual data.

The conclusions drawn by Kirikae support those of Barany and Bekesy to the extent that the skull is observed to vibrate as a single sphere at low frequencies and in a more complex pattern at high frequencies. This conclusion seems to indicate that energy reaches both sides of the skull equally. It will become apparent in later discussions that this conclusion may not be fully acceptable.

Relationship Between Interaural Attenuation and Cancellation By an Air-Conducted Signal

Bekesy (1960) designed an experiment which demonstrated that an air-conducted tone and a bone-conducted tone cancel each other at the cochlea. He presented a bone-conducted tone to the skull and had the listener manipulate the phase and intensity of an air-conducted signal presented at the ear until silence was obtained. This, Bekesy claimed, demonstrated that both signals were received in the cochlea. The actual measurements obtained were not reported by Bekesy.

Using a procedure similar to that of Bekesy, Barany (1938) attempted to measure this pehnomenon. He introduced a bone-conducted signal to the skull. One ear was masked with noise introduced through metal tubing in the auditory meatus. In front of the other ear, a loudspeaker was used as the source of an air conducted signal. The subjects adjusted the intensity and phase of the air conducted signal until silence was obtained. The bone vibrator was then moved to various parts of the skull and the experiment repeated. The frequency tested was 435 Hz. The results of the experiments, for three subjects, were reported in the form of vector diagrams of the skull. The data give relative amplitude and phase of the air-conducted cancellation signal. Barany claims these data are equal to the bone-conducted signal with a phase shift of 180°. He noted that bone conduction is greatest when the bone vibrator is placed at the sides of the head and weakest when the vibrator is placed at the forehead and occiput.

These data seem not to support the contention that energy is equal at all points on the skull.In fact it seems to indicate rather clearly that the energy levels differ at different points on the skull. These differing energy levels are evidence of some degree of interaural attenuation.

Relationship Between Interaural Attenuation and Threshold as a Metric of Bone Conduction

Kirikae (1959) developed a series of experiments to measure the shift in threshold observed on a unilaterally deaf subject as a bone vibrator was moved to various points on the skull. The results indicated patterns of thresholds from 0 dB re: best mastoid threshold to 30 dB poorer than best mastoid threshold, depending on the frequency of the stimulus and the site of application of the bone vibrator.

One of the comments made by Kirikae is that the thresholds on the deaf side were "lower by 5 to 10 decibels to that of the normal side." (1959:39) This reveals the data support the presence of some degree of difference in the thresholds of the two ears under bone-conduction stimulation.

In a sub-part of this experiment, Kirikae measured the phase shift of the acoustic energy as it traverses the skull. If the phase at two opposite points of the skull was reversed, it may be assumed that the skull is moving as a simple sphere with both poles moving in the same direction at the same time. He accomplished this by measuring the phase adjustment necessary to cancel a signal arising from a bone vibrator applied to various points on the skull. Thermal noise introduced into one ear effectively isolated that ear from participating in the experiment. The results of the study revealed phase to be reversed for the 500 Hz signal at opposite mastoids, and in phase at opposite mastoids for the 1,000 Hz signal. These data support the conclusions of Bekesy (1960) and Barany (1938) that the skull moves simply as a sphere at low frequencies and in a more complex pattern at higher frequencies. The difference between these data and those of the previous experiment is that these are only measures of the phase of the signal and the vibratory patterns of the skull. It is evident by the disagreement of data within the same experiment that this phenomenon (vibratory pattern of the skull) is not necessarily related to the difference in energy levels reaching the ears and therefore may not necessarily be a true index of interaural attenuation.

Relationship Between Interaural Attenuation and the Measurement of Air-Conducted Signals in the External Auditory Meatus

Goldstein and Hayes (1965) in their investigation of the occlusion effect, utilized yet another measure of the bone-conduction phenomenon. They used the sound pressure level in the external auditory meatus as a measure. Specifically, they measured, using probe tube microphones, the sound pressure level in the external meatus when the ear canal was open and when it was obturated. The measurements were taken with a bone vibrator located at two positions on the skull. Twenty-eight normal hearing listeners heard five frequencies under the experimental conditions.

Goldstein and Hayes (1965) found an increase in sound pressure in the external auditory meatus when the ear was occluded. The increase in sound pressure level was somewhat greater than the threshold shift that accompanied the occlusion. This lead one to postulate other factors as being contributory to the perceived bone conduction phenomenon: i.e., phase.

Huizing (1960:46) also measured the sound pressure levels in the meatus. His investigations were designed to test the assumption that "... it (the sound pressure) is thought significant for bringing about the sound perception in bone conduction." He thought that the radiated acoustic energy in the meatus was the source of stimulus for hearing. This is one of the modes of bone conduction as discussed by Tonndorf. (1966:9)

Huizing used subjects with normal hearing and measured the sound pressure level with an audio-frequency spectrometer and a probe microphone fitted with a polyethylene tube. The source of signal was a clinical audiometer with a fixed gain setting. There is no reference to the type of transducer used.

In the first of these experiments, Huizing (1960:48) measured the sound pressure level in the external auditory meatus as a function of frequency. The data indicate a sound pressure of 30 - 40 dB SPL for frequencies up to 1,200 Hz. For higher frequencies, the sound pressure levels varied too rapidly to be measured accurately. The magnitude of the stimulus was fixed at a gain of 80 dB from an audiometer. He did not specify the reference level for either the stimulus or the sound pressure. (The references are assumed to be re: 0.0002 microbar.)

He measured the sound pressure in the external meatus while the skull was being stimulated with a 60 dB SL air-conducted stimulus. The data showed the sound pressure generated by the bone-conducted signal to be greater than that of the air-conducted stimulus in the low frequencies, but the converse to be true for the high frequencies.

Huizing's research uses a technique - direct measurement of the air conducted signal in the external meatus - which the present writer has selected as the metric for this research.

A second experiment performed by Huizing (1960: 49) measured the effects of site of application of the vibrator on the sound pressure generated in the meatus. This experiment was conducted only at 500 Hz. The sound pressure was found greatest when the vibrator was at the two mastoids and contralateral parietal bone and found least along the saggital plane. Huizing (1960:50) simply explains that these data demonstrate that the skull vibrates as a simple sphere at 500 Hz. This explanation does not account for the different intensities obtained when the vibrator was moved across the skull. A possible reason for this discrepancy is the technique of moving the bone vibrator. Bekesy (1960:133) and Naunton (1957:281) describe the difficulty involved in moving a bone vibrator since the placement of the vibrator can result in changes in the intensity and frequency of the signal. This variable was unaccounted for in Huizing's studies and may account for the different intensities obtained at different points of vibrator placement.

The conclusions presented seem to support the premise that the use of threshold as a metric can be somewhat misleading,particularly when small intensities are involved.

These data tend to explain on the basis of different metrics and techniques, how the conflicting arguments are presented for the amount of interaural attenuation.

SUMMARY

Interaural attenuation for air-conducted signals has been measured and reported by Zwislocki (1953). The amount of attenuation for bone conducted signals does not seem to be as widely accepted as those for air conducted stimuli. There appears to be much conflicting data as to the existence and amount of interaural attenuation for bone-conducted signals.

Most statements concerning interaural attenuation for bone-conducted stimuli offer no data of their own by relying on the data of previous studies which did not directly measure interaural attenuation but rather were designed to investigate some of the variables involved in the measurement of bone-conducted signals.

This chapter reviewed those researches which discussed the variables of the bone-conduction response which related to, either directly or indirectly, interaural attenuation and the measurement of interaural attenuation. The specific variables discussed were: the vibratory patterns of the skull, the measurement of the air-conducted signal generated in the external meatus and its relationship with the bone-conduction response, and the use of threshold as a metric in bone conduction testing. A number of sources of errors in these techniques was discussed as well as the relationship of the data of these studies to interaural attenuation.

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CHAPTER III

PROCEDURE

The experiment involved the measurement of ipsilateral and contralateral frequency response graphs of the sound pressure level generated in the external auditory meatus by a bone-conducted signal.

EQUIPMENT

All testing was done in a two-room research suite with the subject in the anechoic chamber while the researcher and recording equipment were in the adjoining sound-treated control room. The inside dimensions of the anechoic chamber were 12 feet by 10 feet. The height from the suspended floor to the ceiling was 7 feet, 7 inches. The wedges were 2 feet, 3 inches long. The window from the control room was covered with a section of wedges during the actual test session. The control room was sound treated and was separated from the rest of the center by a long corridor and the audiology facilities.

It was necessary that an ambient noise level be at least 15 dB below the test levels. This level was selected on the basis of suggestions given in the Bruel and Kjaer manual for audiometer calibration. They state that at 15 dB above the noise floor, the presence of background noise will not summate appreciably with the test tone. If the background noise was within 15 dB of the test tone, Bruel and Kjaer advises the measurement of the intensity of the test tone will be contaminated by contribution of the noise to the tone intensity. The ambient noise levels in the anechoic chamber were measured with a Bruel and Kjaer model 2203 Sound Level Meter and found to be within acceptable limits for this experiment.

Stimuli for the experiment were provided by a Bruel and Kjaer Beat Frequency Oscillator type 1024. The output of the oscillator was applied directly to a Maico Model "C" bone vibrator held in place by a system of pulleys to be described later. The Model "C" bone vibrator was used at the suggestion of Juergen Tonndorf who advised that the mass of this unit would enhance the reliability of the results in the low frequencies over those that might be obtained with a hearing aid type vibrator.

A Bruel and Kjaer probe tube microphone, model 4134 was used to measure the sound levels in the auditory meatus. The signal from the microphone was amplified by a Bruel and Kjaer cathode follower, model 2615, and a Bruel and Kjaer microphone amplifier, model 2603, and then applied to a Bruel and Kjaer graphic level recorder model 2305. Use of the level recorder made possible a permanent record of the sound levels being measured.Figure 1 is a block diagram of the experimental apparatus.

The subject's head was held immobile in a supportive apparatus built specifically for this experiment. A sketch of the apparatus may be seen in figure 2.

The head holding apparatus was constructed as follows: A five foot length of 2" by 4" wood stock was used as a base. At midpoint, a shaft was driven through the stock leaving a half-inch projection above the base. To this projection, an optician's chin rest was attached. Six inches on either side of the chin rest, two 26-inch uprights were fastened to the base using two metal braces and two inside angle irons for each upright. This resulted in a strong, practically immobile arrangement. Four inches up from the base, a ¼-inch hole was drilled through each upright. Through these holes, six inch stove bolts were inserted, allowing an adjustment of the space between the heads of the bolts. The space could be adjusted from twelve inches to one inch. In order to maintain the position of these bolts, a second set of holes were drilled at right

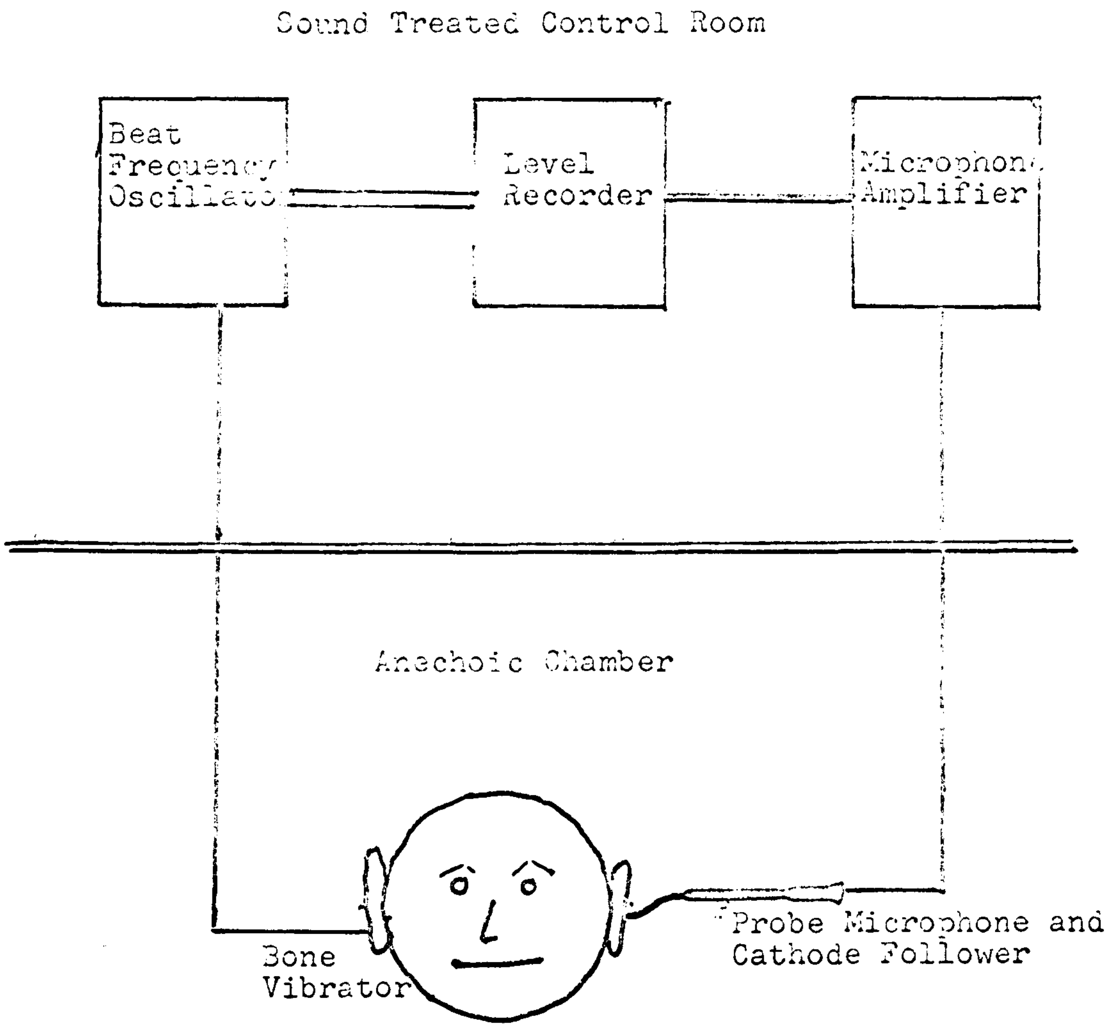

Figure 1

Block Diagram of Experimental Apparatus

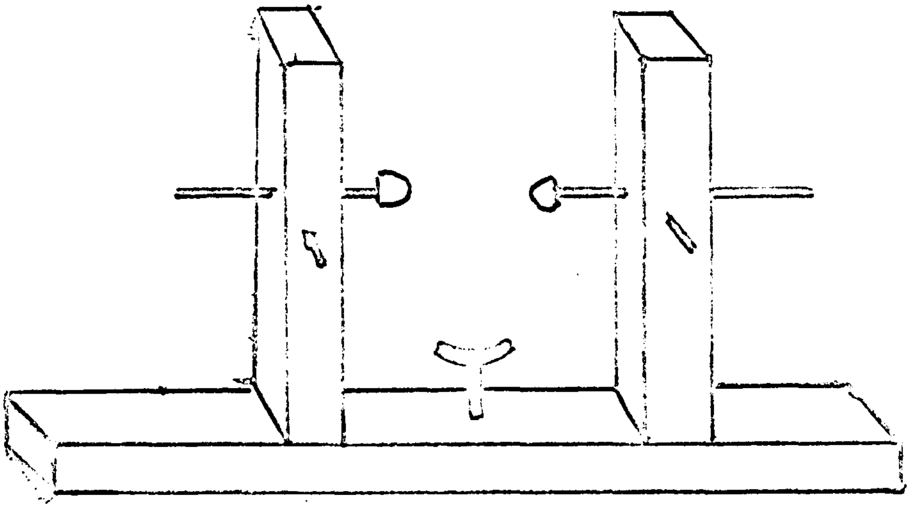

Figure 2

Head Holding Apparatus

angles to the first set. Using a hex-nut, fastened in place with perforated steel strips, a shorter bolt could be placed through the hex-nut to press firmly against and thereby hold fast the stove bolts. This approximated a set-screw arrangement. A one-inch piece of foam rubber was attached to the heads of the stove bolts. Thus, when the subject's chin was placed in the chin rest - the stove bolts, when properly adjusted and fastened, pressed firmly against the skull, just above the zygomatic arch. The effect was to immobilize the head. This apparatus was designed to be as firm as possible, although Barany (1938) comments that the structure used to hold the subject's head need not be absolutely rigid.

The bone vibrator was held in place using an apparatus patterned after that described by Bekesy (1960). The bone vibrator, Maico Model "C",was attached by means of the collar supplied with it, to a four foot section of aluminum pipe. Three-fourths of the distance was marked off and a bolt passed through the pipe in a vertical direction. This bolt became the pivot point for the horizontal pipe and was attached to a photographer's tripod. The tripod allowed for easy and quick adjustment of the height of the apparatus while not sacrificing stability. At the end of the pipe opposite to that of the vibrator, a cord was attached which led to a pulley which changed the direction of pull and then to a set of weights which exerted a constant pull on the short end of the pipe. By calculating the relative lengths of the two sections of the pipe, it was determined that a weight of 2.11 kilograms was necessary to exert a constant vibrator application force against the skull of 1 kilogram. A sketch of this apparatus may be seen in figure 3.

The force of one kilogram was selected based on the study of Koenig (1957:11):

> Above a certain pressure force, about 1,000 grams, an increase in the pressure causes only slight variation in the bone conduction curve: a ceiling is reached.

Although Harris et al. (1953:1005) conclude "... thrust immaterial between 250 to 400 grams", it was felt that the wider range of values covered by Koenig justified accepting his data.

SUBJECTS

Three subjects, who reported negative otologic histories and presented normal audiograms, were selected for the study. Normal ears were selected so that there would be relatively little confounding of data by any pathology.

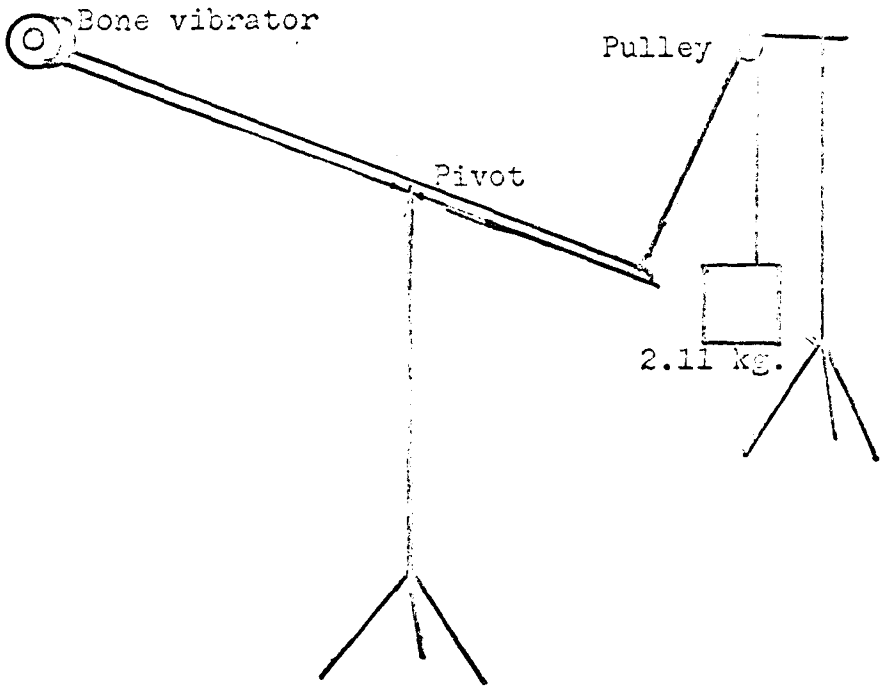

Figure 3

Apparatus for Applying the Bone Vibrator to the Skull
With a Constant Application Force

Barany (1938:28) suggests using healthy ears for this type of experiment. Bekesy (1960:36) discusses different types of research and the subject necessary for each type. If this research were designed to be normative in scope, more subjects would be indicated. However, this study is designed only to ascertain whether a physiologic phenomenon exists and if it can be measured. Therefore it was decided that the number of subjects used was sufficient.

PROCEDURE

Probe Microphone Calibration.

Bruel and Kjaer suggest trial and error as the best technique for determining the frequency response of the probe microphone arrangement. Since measurements were to be obtained in the ear canal, a two-inch section of flexible plastic tubing was added to the one-inch section of metal tubing supplied with the probe microphone kit. This permitted easy placement of the mouth of the tubing deep in the external meatus. In order to obtain a relatively flat response curve of the microphone arrangement (simply for ease of reading data) it was found that steel wool both at the opening of the plastic tubing and at the deep portion of the metal tubing was necessary. Using the techniques suggested by Bruel and Kjaer the frequency response curve of the microphone was generated. This curve is reproduced in figure 4.

Sine Generator Calibration.

As prescribed in the Bruel and Kjaer manual for the generator, the frequency of the oscillator was calibrated by adjusting the output of the oscillator to a zero beat with the line frequency. This was accomplished by adjusting the Frequency Scale Alignment until the slowest possible fluctuations were obtained on the meter. At no time was it necessary to make more than minor adjustments to obtain calibration.

Automatic recording is possible using the generator coupled with the graphic level recorder type 2305. The two instruments are connected by a flexible shaft which drives the paper drive simultaneously with the frequency sweep of the sine generator.

The level recorder was used with a paper speed of three mm/sec and a writing speed of 315 mm/sec. According to the appropriate Bruel and Kjaer manual, using this combination, with a lower limiting frequency of 20 Hz, the writing system would be stable and have no overshoot. The recorder was equipped with a 50 dB range potentiometer.

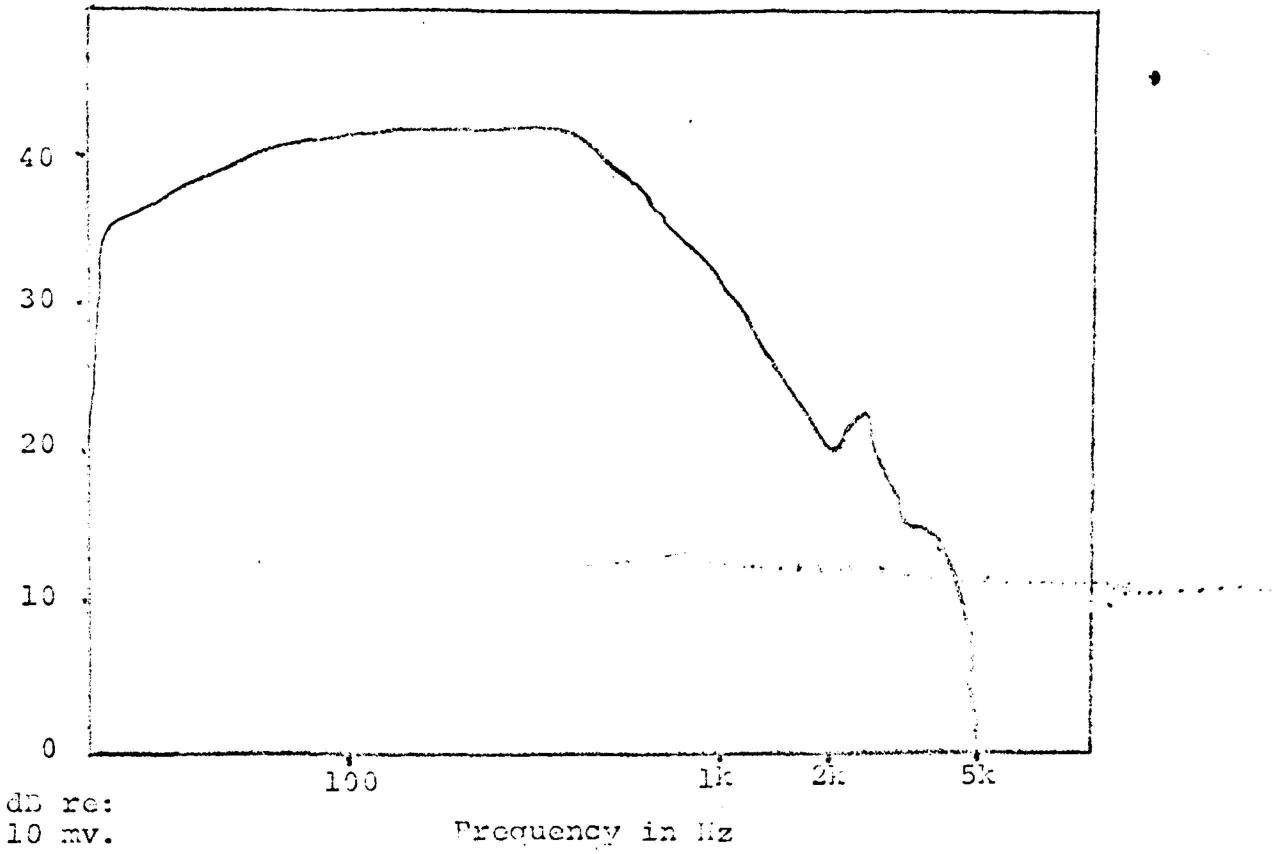

Figure 4

Frequency Response Characteristics of the Probe Microphone System as Measured in a 2 cc Coupler

After an appropriate warm-up period, the recorder was calibrated with the 100 mv reference signal so that the input voltages would be recorded in dB re: 10 mv. The reference signal is included in the calibration procedure.

Experimental Procedure.

After the equipment had been calibrated, the subjects were tested for normal hearing. The subject was considered to have normal hearing if the thresholds were 10 dB ISO or better throughout the audiometric frequency range. The subjects were then led to the anechoic chamber where they were seated at a desk to which had been fastened the supportive apparatus previously described. The subject's head was placed in this apparatus and appropriate adjustments were made to insure the relative immobility of the head. A commercial microphone stand with a goose-neck was used to hold the microphone during the experiment. A test-tube clamp was attached to the end of the goose-neck which permitted fine adjustment of the position of the microphone.

The plastic end of the probe tube was inserted into the external auditory meatus. Care was taken, through visual inspection, that the opening of the tube was not directly against the canal wall. Barany (1938:154) and Huizing (1960:48) report that, for frequencies below 1 kHz, no changes in the sound pressure level exist throughout the external meatus. Therefore, it was not critical how deep the tubing went into the canal. It was, however, visually placed beyond the first bend in the canal.

The bone vibrator was placed against the subject's mastoid in such a manner as to assure relative reliability of results. This was accomplished by visually inspecting the contact between the piston of the vibrator and the mastoid and adjusting to obtain a perpendicular relationship between them. Care was taken not to contact the cartilage of the external auricle. Both these cautions were suggested by Barany. (1938:148)

Since Bekesy (1960:133) and Naunton (1957:287) caution that the responses to a bone-conducted signal are extremely sensitive to change in position of the bone vibrator, it was decided that once the vibrator was positioned not to change the arrangement. Therefore, in order to get ipsilateral and contralateral response curves, the microphone was moved during the experiment and not the bone vibrator.

Two response curves were obtained for each subject: ipsilateral and contralateral conditions. Under the ipsilateral condition, the microphone was placed in the same ear to which the vibrator was applied. Under the contralateral condition, the microphone was moved to the opposite ear. During these maneuvers, care was taken not to move the subject's head nor disturb the bone vibrator.

The combination of beat frequency oscillator and graphic level recorder permitted the recording of the response curves of the transmission system of the live human skull. The oscillator swept from 20 Hz through 20 kHz at the maximum output of the attenuator position. The bone vibrator was connected to the attenuator output of the beat frequency oscillator which also drove the level recorder. It was, therefore, possible to record the sound pressure levels in the ipsilateral and contralateral external auditory meatuses.

Analysis of Data

The frequency response tracings for each subject - ipsilateral and contralateral graphs - were submitted to a statistical analysis. The Wilcoxon Matched Pairs Rank Test (Downie and Heath, 1959:238) was applied to test the hypotheses: for each subject, there is no significant difference between the ipsilateral and contralateral frequency response curves.

SUMMARY

A Bruel and Kjaer beat frequency oscillator was connected to a Maico Model "C" bone vibrator. The vibrator was applied to the skull of three subjects with normal hearing. The sound levels originating in the external auditory meatus of each ear were measured using a Bruel and Kjaer probe microphone and graphic level recorder. Thus, ipsilateral and contralateral frequency response curves were obtained for a bone-conducted stimulus.

An apparatus was constructed to hold the subject's head immobile. An apparatus was built to hold the bone vibrator, with a constant application force, agasint the skull.

The data, in the form of ipsilateral and contralateral frequency response tracings for each subject, were submitted to a statistical analysis to test the hypothesis: There is no significant difference between the ipsilateral and contralateral frequency response curves for each subject.

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CHAPTER IV

RESULTS AND DISCUSSION

This experiment was designed to measure the differences in sound pressure at the two external auditory meatuses while the skull was being stimulated by a bone vibrator. The bone vibrator was located at one mastoid.

The data were displayed in the form of frequency response graphs produced by the Bruel and Kjaer graphic level recorder. The graphs represent the relative magnitude of the sound pressure level in the external ear canals.

Figures 5 through 8 are the frequency response graphs for the three subjects and one control subject. The control was achieved by having subject no. 1 serve for two tracings in order to check the reliability of the experimental instrumentation. As can be seen from a comparison of figures 5 and 6, there are essentially no differences between the two sets of data. It was therefore accepted that the variability due to technique was at a minimum.

Figure 9 is a display of the sound pressure level differences for each subject. These data were obtained by

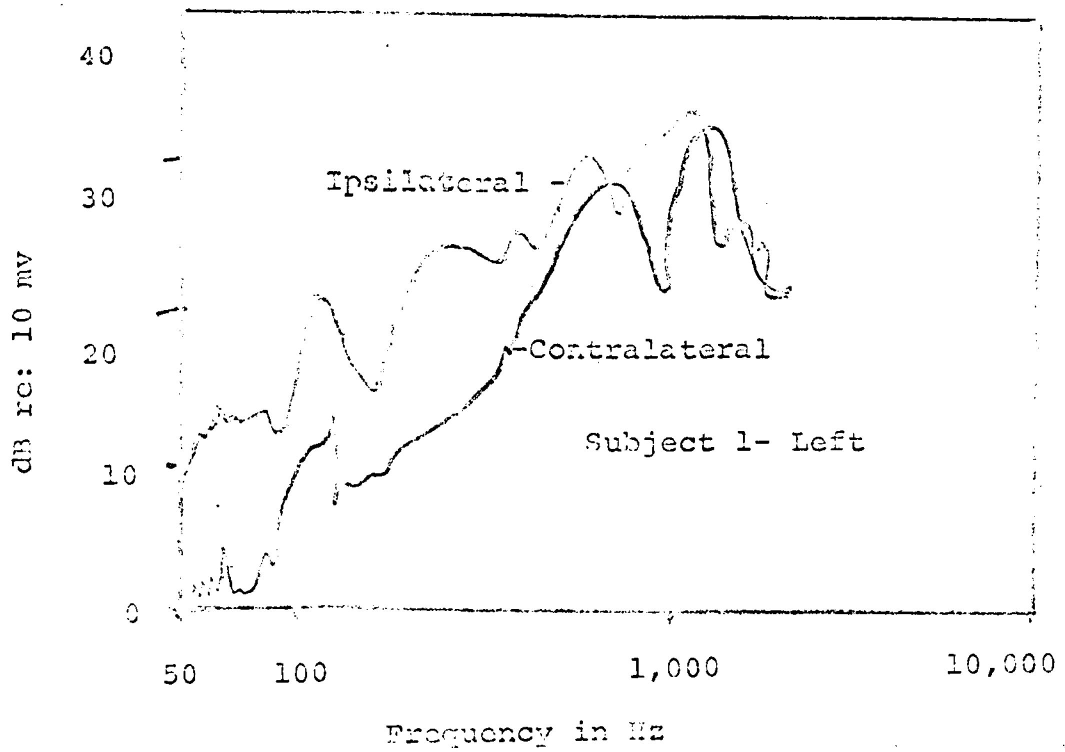

Figure 5

Ipsilateral and Contralateral Frequency Response Graphs For Subject 1. The trace labeled Ipsilateral represents the sound pressure obtained with the microphone probe in the same ear as the mastoid to which the vibrator is applied. The trace labeled Contralateral represents the response obtained with the microphone probe in the ear opposite to that under stimulation by the vibrator. The code Left or Right refers to the ear to which the vibrator was applied.

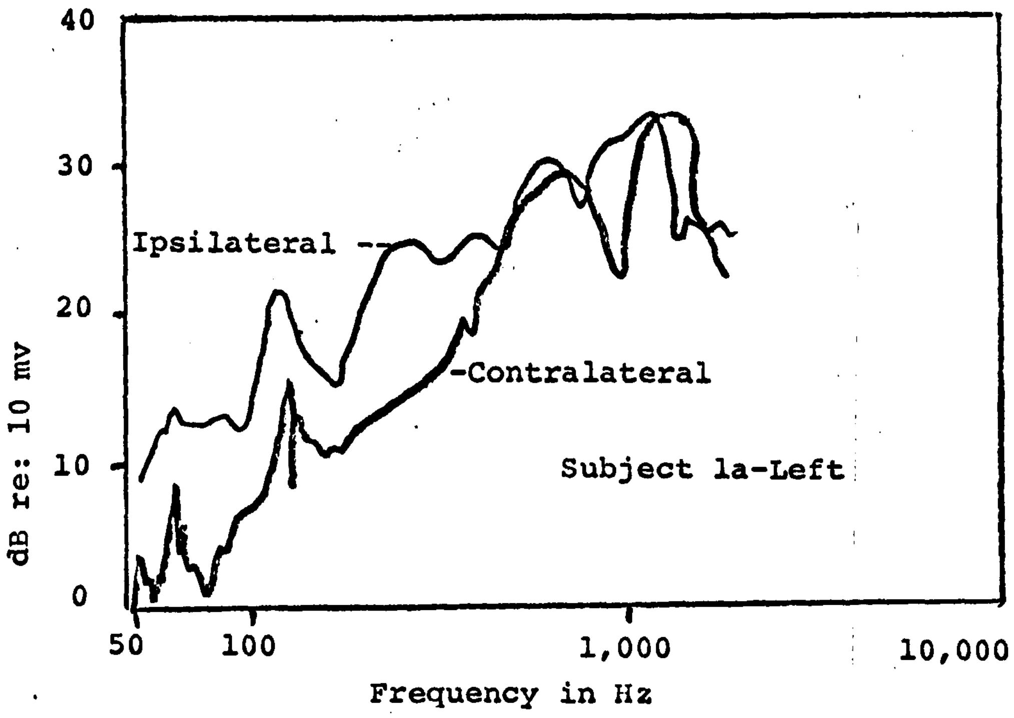

Figure 6

Ipsilateral and Contralateral Frequency Response Graphs for Subject 1a. The trace labeled Ipsilateral (traced from figure 5) represents the sound pressure obtained with the microphone probe in the same ear as the mastoid to which the vibrator was applied. The trace labeled Contralateral represents the response obtained on Subject 1 after removal and replacement of the microphone probe in the ear opposite to that under stimulation by the vibrator. The code Left or Right refers to the ear to which the vibrator was applied.

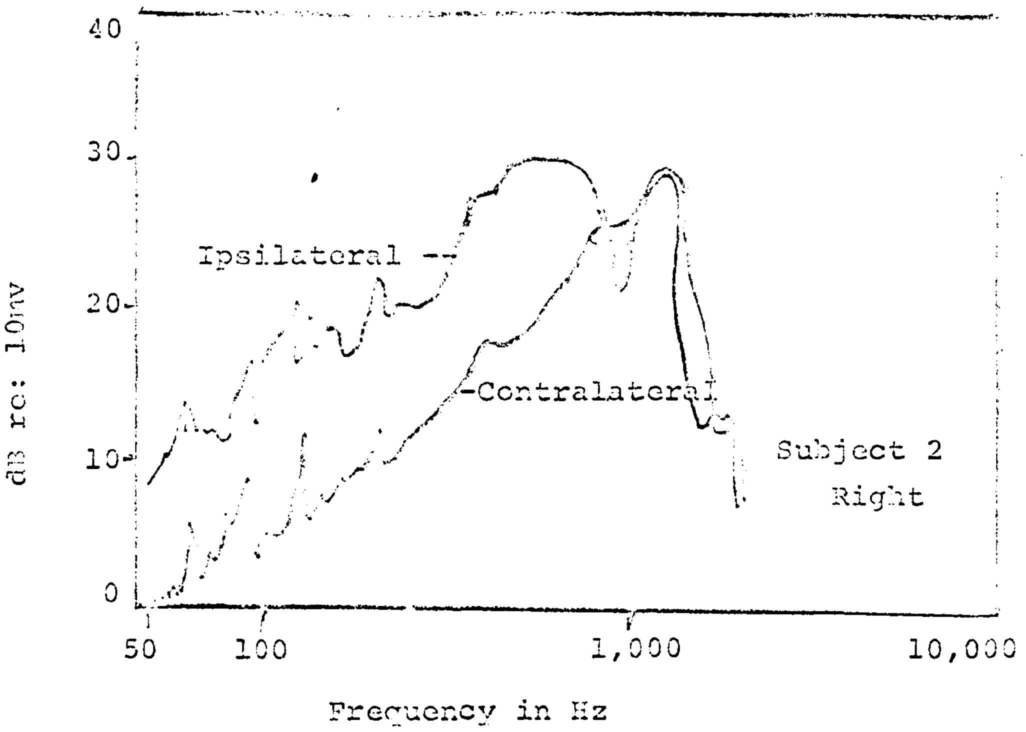

Figure 7

Ipsilateral and Contralateral Frequency Response Graphs For Subject 2. The trace labeled Ipsilateral represents the sound pressure obtained with the microphone probe in the same ear as the mastoid to which the vibrator was applied. The trace labeled Contralateral represents the response obtained with the microphone probe in the ear opposite to that under stimulation by the vibrator. The code Left or Right refers to the ear to which the vibrator was applied.

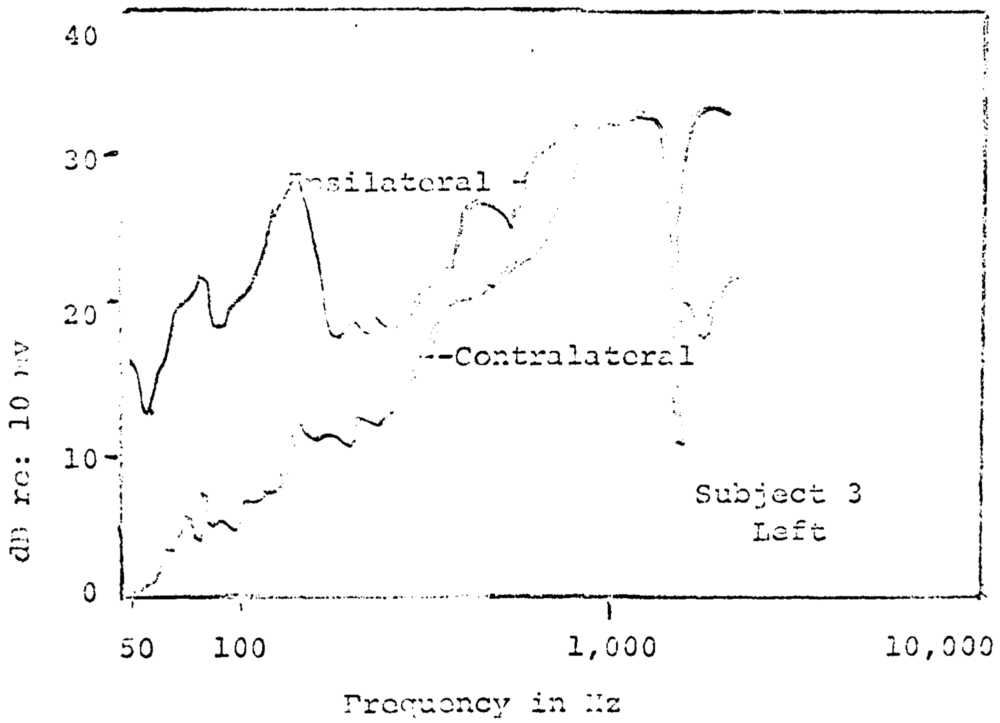

Figure 8

Ipsilateral and Contralateral Frequency Response Graphs for Subject 3. The trace labeled Ipsilateral represents the sound pressure obtained with the microphone probe in the same ear as the mastoid to which the vibrator was applied. The trace labeled Contralateral represents the response obtained with the microphone probe in the ear opposite to that under stimulation by the vibrator. The code Left or Right refers to the ear to which the vibrator was applied.

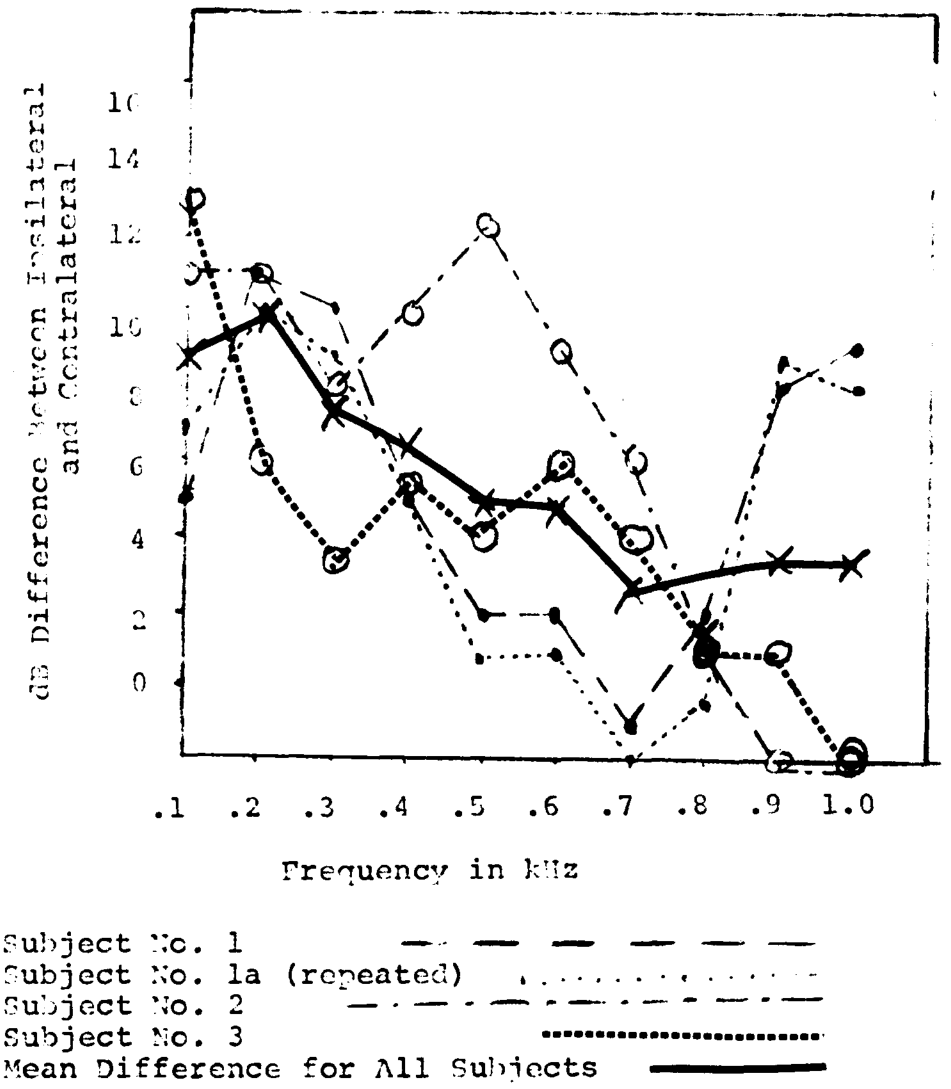

Figure 9

Sound Pressure Differences Between Ipsilateral and Contralateral Tracings for All Subjects taking the difference between the ipsilateral and contralateral tracings at 100 Hz intervals from 100 Hz to 1 kHz.

These data were statistically analyzed by applying the Wilcoxon Matched Pairs Rank Test (Downie and Heath, 1959: 238) to test the hypotheses: There is no significant difference in the ipsilateral and contralateral frequency response tracings for each subject. The results of this analysis permitted rejection, at the .05 level of confidence, of the null hypothesis for all subjects.

It can be noted from the data in figures 5 through 9 that there is a difference between the sound pressure levels obtained at the two ears; and, the amount of difference varies from one subject to another. The magnitude of these differences ranges from a maximum of +18 dB to a minimum of -4 dB. (The negative sign indicates the sound pressure was greater in the contralateral meatus than in the ipsilateral meatus.) These differences are frequency dependent. Except where the sign is negative, these findings coincide with Studebaker's definition of interaural attenuation.

> ... the reduction in the physical intensity of an acoustic signal in passing from a transducer on one side of the head to the opposite cochlea. (Studebaker, 1967, p. 361)

The variance between subjects has been previously reported by Huizing (1960:48) and attributed to the individual variations in the shape of the ear canal. He did, however, report the course of the curve to be , in general, the same for all his subjects.

The data of this study demonstrate the presence of up to an 18 dB difference between the sound pressure levels at the ipsilateral and contralateral meatuses. This difference was frequency dependent; approximately 15 dB at 100 Hz gradually reducing to less than 5 dB at 1 kHz. These data may be seen in figure 9.

Huizing (1960), Kirikae (1959) and Barany (1938) have used the signal arising in the external meatus as a measure of bone-conduction response. Therefore, the present data may be accepted as interaural attenuation for a bone-conducted signal.

DISCUSSION

Comparison with Other Data

The data of this research cannot be effectively compared with those studies which investigated the vibratory patterns of the skull because the techniques and metrics are not equivalent. Barany (1938) and Bekesy (1960) measured the vibratory patterns of the skull using the displacement patterns of the skull at various measuring points as the metric. Their data revealed that the skull vibrated as a simple sphere at low frequencies and equal intensities were noted at opposing poles of the skull. Barany and Bekesy did not relate this to interaural attenuation of a signal but other authors have (Feldman, 1961). If the skull vibrates as a simple sphere and no other factors were contributory, Feldman's conclusions that no interaural attenuation exists, would probably remain unquestioned. However, Barany (1938) discussed the contribution of the ossicular chain to the bone-conduction response; and Tonndorf (1966) reported that the total bone-conduction response is composed of multiple contributing modes, one of which is the contribution of the ossicular chain. It is felt that this research more effectively measures the total of these contributing modes than simply the acceleration of the cranium.

The detailed studies of cranial vibratory patterns executed by Barany (1938) were performed at 435 Hz. The present research investigated the phenomenon of interaural attenuation throughout the frequency range of 50 Hz through 1 kHz.

The data of this research might more reasonably be compared with those of Huizing (1960) since the techniques were similar. Huizing measured the sound pressure level in the meatus ipsilateral to the bone vibrator only. The raw data are not comparable beyond this point because he used, as a source of signal, an audiometer with a fixed gain setting and reported the data from his subjects without mentioning whether the data were mean scores or for a typical subject. Huizing (1960:48) reported his data in terms of the sound pressure in the meatus. The data of this researcher would have to be interpreted with the microphone frequency response corrected in order to determine actual sound pressure level. This, however, was not the intent of this study. This research was only concerned with the differences between the sound pressure levels at the ipsilateral and contralateral ear canals.

Huizing (1960:49) performed another study which yielded data comparable to the data of this study but performed the experiment only at 500 Hz. His experiment was designed to determine the variation in sound pressure as a function of placement of the bone vibrator. He kept the probe microphone fixed in place and moved the vibrator to various positions on the skull. The present researcher was concerned with the effects at different frequencies.

Huizing found the sound pressure to be approximately equal at both mastoid positions of the bone vibrator. The present research showed a difference of approximately 5 dB between the ears at this frequency. An explanation for this discrepancy might lie in the technique used. Previous researchers (Naunton, 1957) (Bekesy, 1960) have shown vibrator placement to be extremely variable and difficult to duplicate. The differences between Huizing's data and the data of this study are probably due to the fact that Huizing moved the bone vibrator during his experiment. In addition, Huizing did not state whether the absence of intensity difference at the two mastoids is for one subject or a mean of many subjects.

The data of this experiment substantiate the data of Kirikae (1959) in that he reported the presence of up to 30 dB of interaural attenuation, depending on placement of the bone vibrator. There are, however, two variables he did not control and which the present researcher sought to eliminate from this study. These are the movement of the bone vibrator to approach the condition of contralateral stimulation and the use of threshold as a metric.

Previous studies (Naunton, 1957) (Bekesy, 1960), discussed earlier in the paper, revealed an inherent variability of efficiency of the bone vibrator critically dependent upon placement on the skull. The difficulty of using threshold as a metric has been reported by Leguoix and Tarab (1959) and by Allen and Fernandez (1960). Both these research teams claim that other factors override interaural intensity differences in determining perception of lateralization. It is suggested by these remarks that a threshold may not be an accurate measure of intensity and that the latter may be confounded by other variables. By not controlling these variables of transducer placement and threshold as a metric, the data of Kirikae (1959) may be quantitatively at variance with those of this study. In addition, the attenuation reported by Kirikae (1959:30) was only expressed quantitatively as over 15 dB and the 30 dB figure previously quoted was only found in the text of the article. In fact, Kirikae (1959:29) reported he often encountered better bone conduction responses on the deaf side of the skull than on the normal side. He does not, however, discuss this phenomenon at length.

Again, the implications proposed by Legouix and Tarab (1959) lend support to the present writer's explanation for the differences between the physical intensities measured and the psychological thresholds reported. They state:

> ... at low frequencies, interaural phase differences are of greater importance than the interaural intersity differences in producing a sensation of lateralization... (1959:1453)

The present writer suggests, that if Kirikae's study were replicated controlling for those variables, the data would be more closely aligned with those reported in this study.

Experimental Variables

Precision of the study. It was felt that the avoidance of the variables discussed above resulted in an increase in the precision of the present research. This is substantiated by the results of the repeat tracing on subject no. 1 (figures 5 and 6). The average difference between the two tracings is less than one decibel. For a measure of threshold shift, Zwislocki (1952:753) claims the best accuracy he could obtain was ± 1.5 dB. The present research exceeded the precision of threshold testing because the method used avoided the variables such as phase which have been reported to confound threshold data. In addition, Ward (1960:242) claims that the threshold as a metric is not a stable phenomenon.

Source of energy in the meatus. Since the measurement of the energy in the external meatus was selected as the measure in interaural attenuation, it is important that the source of this energy be clearly described.

Bekesy (1960) attributed the sound pressure level to the relative movements of the mandibular condyle in the external auditory meatus as well as the vibration of the bony wall of the canal. These relative movements will generate pressure waves in the meatus. The sound pressure was also attributed to the vibration of the tympanic membrane and attached middle ear structures.

Tonndorf (1966) discussed the modes of bone conduction and includes among them the intensity level in the external meatus.

One might question the possibility of a contribution to the sound pressure in the meatus from air-conducted signals generated by the vibrator itself. Barany (1938) investigated the contribution of the air-conducted signals and found them to be minimal. He further questioned the possible radiation of acoustic energy from the equipment holding the vibrator. In comparison to the energy generated by the skull itself Barany (1938:145) claimed "there was little to be gained from insulating the bone conduction receiver and damping the stand."

Vibrator placement. One of the more important variables discussed was vibrator placement and the possible variance involved. The present research avoided difficulties in this area by moving the probe microphone to measure ipsilateral and contralateral sound levels. The same results might possibly be obtained by leaving the microphone in one ear canal and moving the bone vibrator from one mastoid to the other. In order to avoid the aforementioned difficulties with movement of a vibrator, an accelerometer might be connected to the bone vibrator to monitor its output and correct for possible variance. Barany (1938:42) claims there is a possibility of a change in frequency response characteristics of a bone vibrator when placed against the skull. This suggested procedure would allow for correction of these changes.

Barany (1938:48) disclosed that the receiver of the bone vibrator should be at right angles to the point of application on the skull. He found that changing the angle of incidence between the bone vibrator and the skull resulted in a change in the efficiency of energy transmission and a concomitant change in threshold values. This procedure was followed as closely as possible during the experiment by visually insuring the proper angle each time the vibrator was placed against the skull.

The pressure with which the vibrator is applied against the skull also creates a possible change in the frequency response of the bone vibrator. (Barany, 1938:40)

These variables (vibrator placement and application force) were controlled in this study by holding the vibrator placement and force constant and moving the microphone to achieve ipsilateral and contralateral measurements.

Equipment factors. Although the frequency response of the microphone was relatively flat when measured in the prescribed coupler, there were no measures made of the frequency response characteristics of the bone vibrator. The peaks noted at about 150 Hz and again at 750 Hz may be resonance peaks of the bone vibrator used in the experiment. The Bruel and Kjaer beat frequency oscillator model 1024 is equipped with a compressor amplifier circuit which permits a modulation of the output intensity of the generator to produce a flat frequency response at the transducer. The circuit, however, necessitated equipment not at this researcher's disposal. The addition of this feature to the present experiment would have resulted in a flat frequency response at the output of the bone vibrator and accelerometer. This might allow for more detailed investigation of the frequency response of the external meatus, and perhaps data which would be more comparable with those of other authors. This was, however, not the goal of this study. This research was concerned not with absolute values but only the difference between ear canal sound pressure. Therefore, this variable was not considered critical for this study.

Suggestions for Further Study

The data of this research lend support to the belief that the live human skull offers a measurable frequency dependent attenuation of a bone-conducted signal. This study did not establish, nor was its intent to establish, normative data. The study should be replicated with a larger population to establish norms for data of the type generated in this research.

At the same time, a correlation should be sought among threshold, intensity in the external meatus, and phase of the signal on the same subject. The only behavioral data that were collected for this study was the establishment of normal hearing for each subject with a screening test. Beyond that point, it might prove informative to compare any variation in sound pressure data with phase or threshold shifts, since it has been reported (Tonndorf, 1966) that the phase of the various modes of bone conduction can cause variations in the total bone-conduction response.

The present study was carried out with the vibrator located at one mastoid position. The data demonstrated that there is a difference in SPL in the ipsilateral and contralateral meatus when a bone oscillator supplies energy to one mastoid process. But what if the stimulus is centrally located? The study should be replicated using the forehead as the point of application for the bone vibrator. If the difference in SPL is simply a factor of the distance traveled by the stimulus from the point of application of the bone vibrator to the point of measurement, then it might be assumed that a forehead placed bone vibrator would stimulate both ears equally, since the distance from the forehead to each ear is relatively equal. If the data of the replication reveal a more uniform similarity of frequency response tracings for the two ears, it might indicate that the distance from the source of energy is the main factor in interaural attenuation.

SUMMARY

Sound pressure level differences at the two external meatuses were measured while the skull was being stimulated by a bone vibrator. The data were in the form of graphs of SPL as a function of frequency as measured in the auditory meatus of the subjects tested. These graphs may be seen in figures 5 through 8.

A Wilcoxon Matched Pairs Rank Test (Downie and Heath, 1959:238) was applied to the data to test the hypothesis:

There is no significant difference in the ipsilateral and contralateral frequency response tracings for each subject.

The results of the study indicated a significant difference in the sound pressure levels obtained at the two ears and these differences ranged from + 18 dB to -4 dB. These differences were interpreted as measurements of interaural attenuation.

Comparisons were made between the present research and the researches of Huizing (1960) and Kirikae (1959). The techniques of those researchers yielded data which were not directly comparable with the present research. The results of a study using measurements of threshold were also compared with the data of this research; but, again, a number of sources of variance in the measurement of threshold prohibited a direct comparison with the data of this study. However, the threshold data reported do seem to lend support to the belief that there is some amount of interaural attenuation. The sound pressure data of Huizing (1960) were not easily aligned with the data of the present study. The differences were explained on the basis of variables of vibrator placement and application force. Those sources of variance were not controlled in the previous studies.

The data of Barany (1938) and of Bekesy (1960) were not directly comparable with the data of the present research. Their studies yielded data in the form of acceleration of the skull. They interpreted their findings by making statements about the vibratory patterns of the skull. These data were, however, used by other writers (Feldman, 1961) in their statements about the presence or absence of interaural attenuation for a bone-conducted signal.

The control of experimental variables in this study resulted in an increase in precision of this study over threshold techniques. The source of energy in the meatus was attributed to contributing modes of bone conduction and not to any possible confounding of data by air-conducted signals radiated from the bone vibrator or other apparatus. The variables of vibrator placement and application pressure were controlled and suggested improvements in technique were noted. It was suggested that a different circuit be used in future replications, which would allow for broader interpretation of results. It was also suggested that any replications be carried out with additional points of vibrator placement, particularly at the forehead.

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CHAPTER V

SUMMARY

Introduction

The reduction in the intensity of a signal in passing from a transducer on one side of the head to the opposite ear has been described as interaural attenuation. (Studebaker, 1967:36)

For air-conducted stimuli, the data of Zwislocki (1952) seem to be accepted. For bone-conducted stimuli, there are conflicting data as to the amount of interaural attenuation.

Most of the conflict can be traced to the use of different metrics and different research goals of the various authors. Some studies, using live skulls, have relied on threshold data whereas others have used other metrics. Many studies have investigated the characteristics of the skull as a vibrating object and have not been directly concerned with interaural attenuation.

The present research sought to study SPL in the auditory meatus as a measure of interaural attenuation.

These measurements were made on live skulls across a wide range of frequencies.

Background

The data for interaural attenuation for air-conducted signals have been supplied by Zwislocki (1952).The techniques he used, however, are not applicable to bone conduction.

Interaural attenuation for bone conduction. Many authors, (Feldman, 1961; Langenbeck, 1965; and Hirsh, 1952) present sometimes conflicting statements about interaural attenuation for bone-conducted signals, but do not present any data of their own to back up their claims. To the present writer's knowledge, there have been no studies designed to specifically measure interaural attenuation of bone-conducted stimuli.

Bone conduction dependent variables. The phenomenon of bone conduction and means of measuring it have been investigated. The skull has been found to vibrate as a simple sphere at low frequencies - all parts moving simultaneously and in phase. These data, although not designed for that purpose, were interpreted as indicating that no interaural attenuation exists for bone-conducted stimuli. Feldman (1961), in making this statement, may have been ignoring the fact that these data indicate the transmission characteristics of the skull as a solid object and do not consider the contribution of other modes of bone conduction.

Bekesy (1960) demonstrated that a bone-conducted signal could be cancelled by an air-conducted signal within the cochlea. Barany (1938) adapted the technique used by Bekesy and moved the vibrator to various points on the skull. Barany was thus able, at least at 435 Hz (the experimental frequency) to add behavioral measures to the research on bone conduction. His data do not seem to support the contention that energy is equal at all points on the skull. His data, in fact, demonstrated that energy levels differ at different points on the skull. These differing energy levels are evidence of measurable interaural attenuation.

The use of threshold data as a means of measuring the amount of interaural attenuation was reported by Kirikae (1959). He measured thresholds on a unilaterally deaf subject. By moving the bone vibrator to different points on the skull, he was able to generate data which indicated up to 30 dB of difference between the normal threshold and point of application. This would tend to support the presence of some degree of interaural attenuation.

In the same report, Kirikae (1959) performed a cancellation experiment and found that the skull moves simply as a sphere at low frequencies - in agreement with Bekesy (1960) and Barany (1938). It is evident that some factor other than the vibratory pattern of the skull must be involved in measurement of interaural attenuation.

Measurement of sound pressure in the external meatus has been shown to be an effective measure of the bone conduction response (Goldstein and Hayes, 1965; Huizing, 1960). In a series of experiments, Huizing (1960:49) measured the effects of vibrator placement on the sound pressure in the external meatus. At 500 Hz, the sound pressure was found to be greatest when the vibrator was at the two mastoids and found least along the saggital plane. The author explains this as evidence that the skull moves as a whole, but this explanation neglects to account for the different intensities noted as the vibrator moves across the skull. Barany (1938) has suggested it may be that sound generated (in the meatus) by vibration of eardrum and ossicular chain are reduced for saggital placement of the vibrator. Bekesy (1960)and Naunton (1965) caution that moving the bone vibrator can result in additional sources of error and modified frequency response. This might account for the different intensities obtained in Huizing's (1960) study. Both the researches of Huizing (1960) and Goldstein and Hayes (1965) tend to support the premise that the use of threshold as a metric can be somewhat misleading, particularly when small intensities are involved.

Method

An experimental procedure was designed to measure the sound pressure levels in the ipsilateral and contralateral external auditory canals while the skull was under stimulation of a bone vibrator.

A Bruel and Kjaer beat frequency oscillator was connected to a Maico Model "C" bone vibrator. The vibrator was applied to the skull of three subjects with normal hearing. The sound pressure in the external canals were measured using a Bruel and Kjaer probe microphone and sound level meter. The levels were recorded on a Bruel and Kjaer graphic level recorder. Ipsilateral and contralateral frequency response curves were obtained by moving the microphone from one ear to the other.

An apparatus was constructed to hold the subject's head relatively immobile. A pulley system was built to hold the bone vibrator against the skull with a constant application force.

The data were analyzed by subjecting the data for each subject to a Wilcoxon Matched Pairs Rank Test. This tested the hypothesis: There is no significant difference between the ipsilateral and contralateral frequency response curves for each subject.

Results

The data indicated a significant difference in the sound pressure levels obtained at the two ears for each subject. These differences were frequency dependent and ranged from + 18 dB to -4 dB.

Discussion

The data from this study did not directly compare with those of Barany (1938) or Bekesy (1960) since they measured the vibratory patterns of the skull. Their data were, however, used by other writers (Feldman, 1961) as a source for the statement that interaural attenuation does not exist for bone-conducted signals.

The work of Kirikae (1959) yielded threshold data which indicated the presence of up to 30 dB of interaural attenuation, depending upon the location of the bone vibrator. The variance of this measurement and the data of the present research were explained on the basis of the dependent variables used by Kirikae. These variables were the use of the threshold as a metric, and the technique of moving the bone vibrator during the experiment.

The techniques used by Huizing (1960) are comparable with the present experimental techniques. However, his study was carried out at 500 Hz only. In addition, the bone vibrator was moved during the study. The differences between the results of Huizing's study and the present research were explained as being due to this last variable.

Experimental variables

The discussion of the experimental technique of this study indicated that these data demonstrated a greater precision than threshold techniques. The variables of vibrator placement and application force were also controlled to increase precision and reduce variability of the results. The source of energy in the external meatus was attributed to the various modes of bone conduction and the experimental variable of position of the vibrator on the skull. It was not due to any contribution of unwanted radiations from either the bone vibrator or the holding apparatus.

Goldstein and Hayes (1965) and Huizing (1960) have used the sound pressure level in the meatus as a measure of intensity of the bone-conduction response. They have reported these data and interpreted them as interaural attenuation.

Suggestions were made for possible improvements in the technique. It was recommended that a compressor amplifier circuit be used in future replications so that a more detailed analysis of absolute values may be achieved. It was also suggested that additional points of vibrator application be used.

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