1989

Speech reception via bone conduction

Sherry G. Morris
Portland State University

AN ABSTRACT OF THE THESIS OF Sherry G. Morris for the Master of Science in Speech Communication presented May 5, 1989.

Title: Speech Reception via Bone Conduction.

APPROVED BY THE MEMBERS OF THE THESIS COMMITTEE:

[redacted]

Thomas Dolan, Chair

[redacted]

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The purpose of this investigation was to determine if the performance-intensity function for spondees delivered via bone conduction (using the Radioear B-72 and Pracitronic KH-70) differed from the performance-intensity function for air conduction (using TDH-39 earphones). A secondary consideration addressed in this study was the comparison of the discrimination scores using the three transducers. Performance-intensity functions for spondee thresholds were calculated on 12 normal hearing subjects using two bone conduction vibrators, the Radioear B-72 and Pracitronic KH-70, and TDH-39 earphones. Results indicated that there was no significant difference between the performance-intensity function of speech via bone conduction as compared to speech via air conduction. Also, there was no difference between the Radioear B-72 and Pracitronic KH-70 bone conduction vibrators. Discrimination scores also gave similar results between transducers. In conclusion, the results of this study suggest that the use of speech tests, such as the speech reception threshold and discrimination tests, which were originally designed for use via air conduction can safely be used for bone conduction.

SPEECH RECEPTION VIA BONE CONDUCTION

by

SHERRY G. MORRIS

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
SPEECH COMMUNICATION:
SPEECH AND HEARING SCIENCES

Portland State University
1989

TO THE OFFICE OF GRADUATE STUDIES;

The members of the Committee approve the thesis of Sherry G. Morris presented May 5, 1989.

[redacted]

Thomas Dolan, Chair

[redacted]

James Maurer

[redacted]

Chadwick Karr

APPROVED:

[redacted]

Theodore Grove, Department of Speech Communication

[redacted]

Bernard Ross, Vice Provost for Graduate Studies

ACKNOWLEDGEMENTS

I would like to thank Dr. Thomas Dolan for all his time and guidance.

I would also like to give a very special thanks to my mother, father, Michelle, & Christopher for all their patience, support, and help.

Sherry Grace Morris

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CHAPTER I

INTRODUCTION

Speech delivered via bone conduction (BC) has become a useful tool in supplementing diagnostic measures in audiometry. Wolfe & Merrill (1969) demonstrated that the speech reception threshold (SRT) obtained via bone conduction was useful in the diagnosis of conductive losses in young children. The use of the speech signal rather than that of a pure tone stimulus is thought to be more meaningful for children and other hard-to-test populations and thus better to use clinically (Velente & Stark, 1977).

Goetzinger and Proud (1955) found that speech reception thresholds obtained via bone conduction had a high correlation with average pure tone thresholds by bone conduction, at frequencies .5, 1 and 2 kHz. Speech delivered via bone conduction thus can also be a useful check on the reliability of pure tone test results (Stockdell, 1974; Edgerton, Danhauer and Beattie 1977; Valente & Stark, 1977).

The most commonly used material for determining the speech reception threshold are the CID W-1 spondaic word lists. However, this test was designed for delivery via air conduction (by earphones or loudspeaker). A potential problem in the delivery of word lists via bone conduction is that the frequency response on the bone conduction vibrators is narrower and more irregular than the earphones or loudspeakers used in the clinic. For example, the Radioear B-72 has large resonate peaks near 200, 1200, and 3800 Hz and little output above 5000 Hz (see Figure 1). This pattern of frequency response could affect speech intelligibility. We therefore must ask if the use of the CID W-1 test is appropriate for bone conduction.

A particularly important aspect of tests of speech intelligibility (such as the CID W-1 test) is the articulation or performance-intensity (PI) function. This function is a plot of the percent of words correctly identified as a function of the intensity level. The slope of the performance-intensity function is important in determining if the tool being used is a sensitive hearing instrument (Egan, 1949). The steeper the function or slope, the more precise the determination of the speech reception threshold. With a steeper performance-intensity function, there is a smaller intensity range over which speech is intelligible versus unintelligible. Hirsh, Davis, Silverman, Reynolds, Eldert, and Benson (1952) determined that the slope of the performance-intensity function for W-1 spondees was very steep, rising at a rate of 8% per dB over the range of 20-80%. It is because of the steep slope that the test is so reliable. Also,

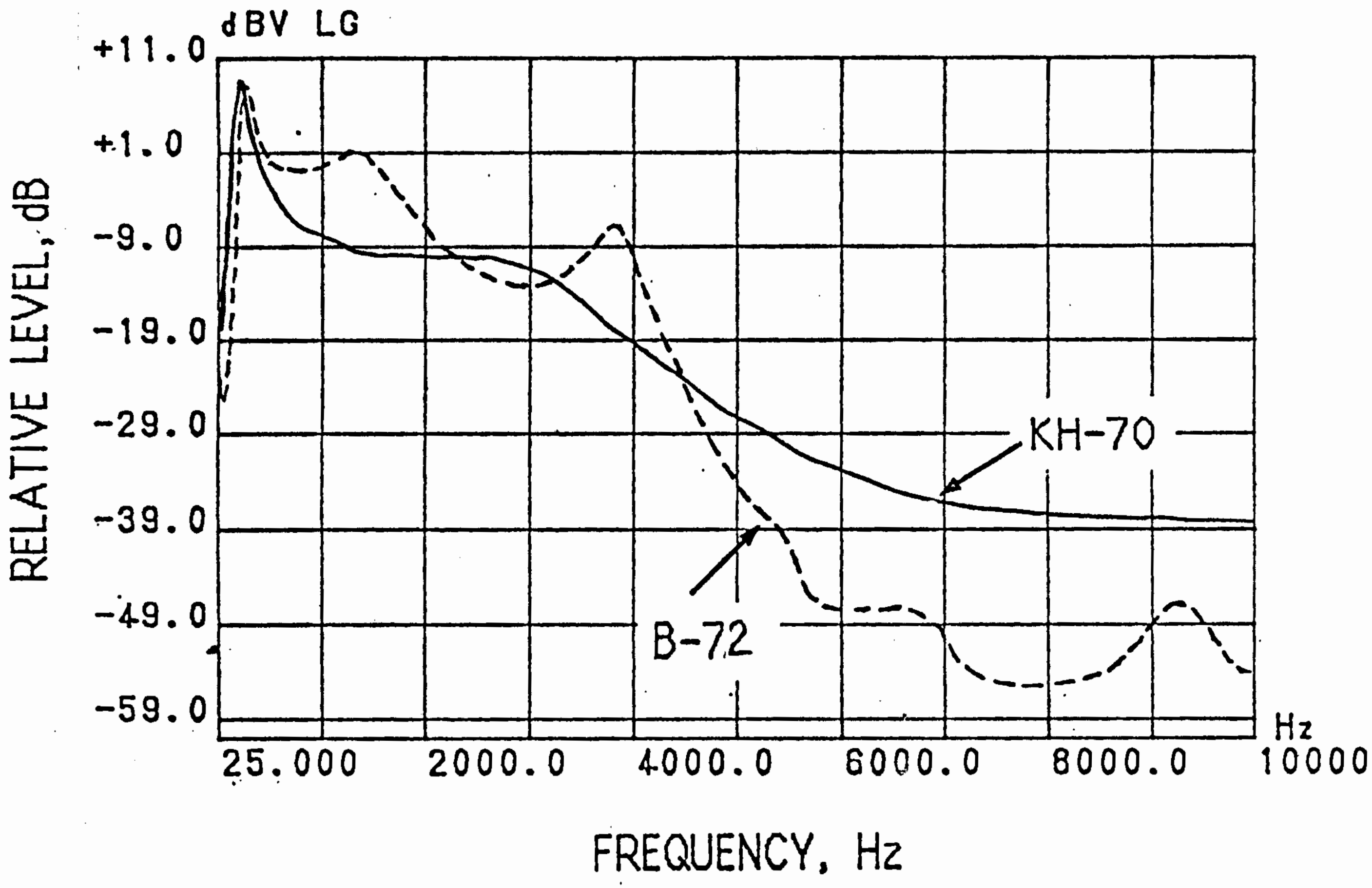


Figure 1. Plot of Intensity as a Function of Frequency. Frequency Response of B-72 and KH-70 Bone Vibrators

because the performance-intensity function is steepest for the mid range of scores, a score of 50% correct has generally been adopted as a criterion for speech reception threshold in the clinic.

In order to determine whether this criterion is also appropriate for speech reception threshold via bone conduction, it would be necessary to examine performance-intensity functions obtained with the various bone conduction transducers. I therefore obtained performance-intensity functions for the CID W-1 word lists, in normal hearing listeners for: 1) a Radioear B-72 bone vibrator (a typical bone conduction vibrator used in many audiology clinics), 2) a Pracitronic KH-70 bone vibrator (one which has a relatively flat frequency response that extends to higher frequencies) and 3) TDH-39 earphone. In addition to comparing the subject's performance on the CID W-1 word lists, I also compared the subject's performance using the three transducers by determining speech discrimination scores for NU-6 word lists delivered at suprathreshold levels.

The purpose of this study was to compare the intelligibility of speech delivered via two bone conduction vibrators with the intelligibility of speech delivered via air conduction.

CHAPTER II

REVIEW OF THE LITERATURE

Bone conduction (BC) testing involves the delivery of the stimulus through a vibration of the skull. The most common point of placement of the bone conduction vibrator is on the prominent area of the mastoid, or at the center of the forehead. The bone conduction vibrator or oscillator causes the skull to vibrate, which in turn causes displacement of the fluid within the cochlea, stimulating the hair cells of the Organ of Corti.

By stimulation delivered via bone conduction, the outer and middle ear systems are by-passed and the integrity of the inner ear system/neural pathway may be assessed. The most common stimulus used for bone conduction testing is the pure tone. Pure tone bone conduction testing is used in clinical audiology to determine the existence of a conductive component. By comparing the pure tone thresholds via air conduction to pure tone thresholds via bone conduction, a determination of the air-bone gap, or the difference between air conduction versus bone conduction thresholds can be made. This gap indicates the extent of the conductive component. Information obtained from the bone conduction tests may be used to determine candidacy for surgery and to determine through pre- and post-operative testing the extent to which surgery was beneficial.

SPEECH RECEPTION THRESHOLD

There are some limitations in the use of pure tones as stimuli in bone conduction testing. Some clients do not respond accurately or reliably to pure tone stimuli, such as children and other hard-to-test populations. Use of speech stimuli is thought to be more meaningful to children and other hard-to-test populations and thus a better stimulus. Also, the use of pure tones rather than speech stimuli does not give a true measure of the subject's ability to hear and process speech. It would seem that the use of a speech stimulus would give a more accurate measure of the subject's ability to hear and process speech.

The use of speech via bone conduction has become a useful clinical tool. Valente and Stark (1977) using 3 groups of subjects consisting of those with normal hearing (1), conductive losses (2), and sensori-neural losses (3), found a high degree of correlation between mean air conduction and bone conduction speech reception thresholds to respective pure tone averages in all subjects. They determined that the use of speech stimuli over a pure tone signal was especially valuable when testing children and other hard-to-test populations who are not able to give valid pure tone results.

Goetzinger and Proud (1955) investigated the feasibility of using the speech reception threshold via bone conduction as a supplement to pure tones delivered via bone conduction. They found no significant difference between means obtained for pure tones and speech via bone conduction.

Hudgins, Hawkins, & Karlin (1947) investigated different types of words to be used for auditory speech material. They found that there are four basic criteria essential in selecting auditory speech material: a) Familiarity - the auditory test is a measure of the threshold of intelligibility for speech, rather than a measure of vocabulary or intelligence; b) Phonetic dissimilarity - the dissimilarity or differences between sounds. The presence of rhyming words or similar words is a type of discrimination and would be more difficult; c) Normal sampling of the speech sounds of English-when testing for the threshold of speech, all speech sounds should be represented in the stimulus; and d) Homogeneity (the rate of intellibibility per (dB) increase in loudness) with respect to audibility. Homogeneity is important due to the fact that the rate of intelligibility rises steeply within a small range of intensity.

Spondees were chosen by Hudgins et al. (1947) over other dissyllabic words and monosyllabic words. The spondees were found to be the most homogeneous with respect to audibility. The rate of intelligibility increased 10% for every 1 dB increase in intensity, and contributes to the stable and steep performance-intensity function.

According to Davis (1948) the performance-intensity function for air conduction rises at "a rate of 4% per decibel increase in loudness until at approximately 33 dB (above .0002 dynes/cm2) the average normal listener correctly repeats 50% of the words." Above the 50% correct level, Davis indicates the performance-intensity function continues to rise more slowly until at 70 dB SPL 100% of the words are correctly heard.

Hirsh et al. (1952) also found the intelligibility of spondaic words increases "more rapidly with an increase in intensity" than monosyllabic words and that the determination of the speech reception threshold was lower for spondaic words than for monosyllabic words.

Speech tests have been used to determine site of lesion, assess effectiveness of communication, "to determine candidacy for surgery, to determine candidacy for amplification, planning rehabilitation and assessing central auditory function" (Penrod, 1985).

Audiology clinics almost universally now use spondaic words for determining the speech reception threshold. Operationally, the speech reception threshold with spondees is typically defined as that intensity level at which a listener can repeat fifty percent of the words correctly. When determining the speech reception threshold clinically, the speech signal is presented at a level above the listener's threshold. As the listener repeats the words correctly, the level is decreased, until the listener misses a word. A bracketing technique is then employed to determine the level at which the listener correctly responds approximately fifty percent of the time.

Stockdell (1974) investigated the stability of speech audiometry by bone conduction and attempted to establish a zero level for speech reception via bone conduction. In this study Stockdell noted that the correlation between speech via air conduction and the pure tone average via bone conduction was .87, suggesting that "bone conduction results were possibly a better determiner of the predicted speech reception threshold in speech testing" over air conduction, especially with listeners who have a sensorineural loss or those where no conductive component exists (Stockdell, 1974). Final results of Stockdell's study indicated that bone conduction speech measures showed good stability.

Past research has shown that for normal listeners the threshold of intelligibility for spondaic words is on an average of 13 dB SPL higher than the threshold for hearing at 1 kHz. Thus, in order for there to show good agreement between the average pure tone threshold for hearing for frequencies .5, 1 and 2 kHz, it is necessary to use 0 dB speech reception threshold at a sound pressure level of 29 dB (Newby, 1979).

SPEECH DISCRIMINATION

Speech discrimination via bone conduction has also been suggested as useful in the clinical environment. Speech discrimination, the ability to discriminate between words, such as rhyming words, is often used to gain more detailed information in diagnosis, particularly with cochlear function (Goetzinger & Proud, 1955). Robinson and Kasden (1970) found that bone conduction speech discrimination may be a "more accurate method of measuring cochlear reserve...." Mixed losses or conductive losses would not give an accurate measure of cochlear reserve using the standard method of speech discrimination which utilizes the air conduction route.

The monosyllabic words used in speech discrimination tests have been through numerous revisions to become standardized. Originally, 24 lists of 50 words were constructed. The words were assigned to a list according to the phonetic composition of the first part of the word. These lists were referred to as the PB (Phonetically Balanced) lists. Revisions were made t "insure that the lists were nearly phonetically balanced" (Egan, 1949). The following criteria were used to create the 20 lists of 50 monosyllabic words: 1) monosyllabic 2) equal average difficulty 3) equal range of difficulty 4) equal phonetic composition 5) composition representative of English speech 6) words in common usage" (Egan, 1949).

The development of speech material used for discrimination testing has had several sources. Hirsh et al. (1952) developed the CID (Central Institute for the Deaf) word lists to overcome such problems as unfamiliar vocabulary and recordings which were not standardized. The CID lists were developed from words which met certain standardized criteria. Specifically, they were of one syllable; did not appear on more than one list; were familiar and the phonetic composition was representative of the English language (Penrod, 1985). An added improvement resulted from using magnetic recording tape.

After the PB lists were created, speech discrimination test materials were again revised. From the list of PB words, came the CVC (Consonant-Vowel-Consonant) list. This list was created to overcome the effect of word discrimination being affected by the word which precedes and follows the stimulus word. From the CVC word list Tillman et al. (1963) created two lists of words referred to as the Northwestern University (NU-4) lists.

Carhart and Tillman (1966) created the Northwestern University Auditory Test #6, (or NU-6) discrimination list, creating four different lists of 50 monosyllabic, phonetically balanced words, from the original lists of CVC, NU-4, and other sources.

To date, few audiologists use speech discrimination tests via bone conduction, primarily because tests of discrimination via bone conduction have not been standardized (Barry & Gaddis, 1978). Most studies which have dealt with speech discrimination tests via bone conduction have been directed toward use in preoperative testing and hearing aid candidacy. Speech discrimination scores are obtained prior to surgery. Following surgery the client's speech discrimination scores are again obtained. Comparison of pre- and post-operative scores are then made to determine the success of the surgery (Robinson & Kasden, 1970).

SPEECH VIA BONE CONDUCTION

Many of the studies using speech via bone conduction are investigations of instrumentation and calibration variables. Frank & Crandell (1986) investigated the acoustic radiation, or sound leakage, from the Radioear B-71 and B-72 bone vigrators and the Pracitronic KH-70 bone vibrator. Results from frank & Crandell's investigation indicated that the KH-70 bone vibrator had the least amount of acoustic radiation. Frank & Crandell recommended that precautions should be taken when testing with bone conduction to eliminate acoustic radiation and avoid a possibly invalid air-bone gap.

Richter & Brinkmann (1981) investigated measures of standardization for threshold force levels (the amount of force the bone vibrator is coupled to the mastoid or forehead). They found that equivalent threshold force level curves for mastoid and forehead placement were nearly parallel. Bone conduction transducers were most sensitive near 2 kHz.

An important factor associated with the use of speech delivered via bone conduction is the frequency response of the transducer. Typically, the frequency response of a common bone conduction vibrator, such as the Radioear B-72 is limited in the higher frequencies to 5 kHz. The B-72 also has three resonant peaks at 200, 1200, and 3800 Hz. Such a frequency response can affect the speech signal by concentrating more energy in the lower frequencies rather than in the mid to high frequencies and thus perhaps affecting intelligibility. A new bone conduction vibrator, the Pracitronic KH-70, is a high frequency transducer. It is housed in rubber to help avoid acoustic radiation and has a frequency response of up to 16 kHz. The KH-70 has a peak output at 200 Hz, with the output gradually decreasing as the frequency is raised to 14 kHz (Figure 1). The maximum output for the KH-70 is 55 dB HL at 8 kHz decreasing to 33 dB HL at 16 kHz (Frank & Ragland, 1987). Due to the KH-70's extended frequency response it is possible that more concentration of high frequency energy in the speech signal could improve the speech intelligibility.

Pertinent studies investigating the performance-intensity function for speech via bone conduction are almost nonexistent. Edgerton, Danhauer, and Beattie (1977), using 25 normal hearing subjects, included as one variable in their investigation, characteristics of the performance-intensity function for spondees via bone conduction with the Radioear B-70A bone vibrator. Their results revealed that the performance-intensity functions for air conduction and bone conduction indicated no significant difference between the two stimulus modes.

As noted earlier, there are few studies which incorporate performance-intensity functions of speech via bone conduction and few norms have been established. It would seem appropriate then to further study performance-intensity functions of speech via bone conduction.

CHAPTER III

METHODS

SUBJECTS

Two males and ten females ranging in age from 13-46 years participated in this study. Pure tone thresholds were below 20 dB (re: ANSI, 1969) at octave test frequencies from 250 to 8000 Hz for all subjects.

INSTRUMENTATION

Figure 2 shows a schematic diagram of the apparatus. The W-1 word lists were presented by means of a Sony TC-377 tape recorder. The tape recorder was connected to a LeaderLAT-45 attenuator, which connected to a NAD 224OPE amplifier. The amplifier output was then led to one of the three transducers used to present the stimuli. A Hewlett-Packard 400L volt meter was used to monitor the voltage applied to each transducer.

The three transducers used to present the speech stimuli were a TDH-39 earphone, a Radioear B-72 and a Pracitronic KH-70 bone conduction vibrator. The frequency response of each of the bone vibrators is shown in Figure 1. The KH-70 has a relatively smooth frequency response with a peak output at 200 Hz, graduatlly decreasing as frequency is raised to 14 kHz. The Radioear B-72 bone conduction vibrator has a more limited

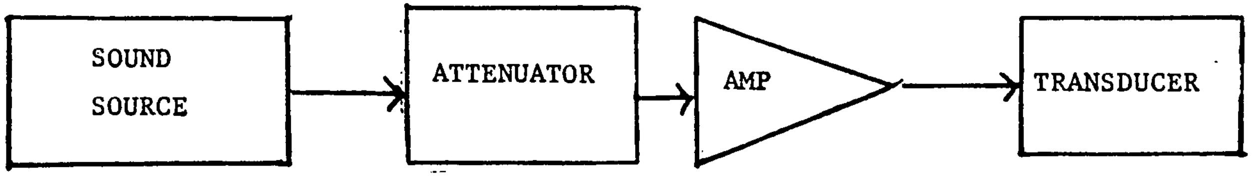


Figure 2. Schematic Diagram of Instrumentation

frequency range with three resonant peaks at 200, 1200, and 3800 Hz.

The subject's responses were monitored by means of a microphone connected to a Bogen MTA-30 amplifier. the output of the amplifier was led to a Realistic loudspeaker.

STIMULI

An Auditec recording of CID-W1 word lists A-F were dubbed onto a 1/4 inch reel-to-reel tape. Each list consisted of the same 36 spondees in a different order. The six lists were recorded in order of A-F and F-A. An Auditec recording of the Northwestern University NU-6 discrimination word lists (4) were also dubbed onto a 1/4 inch reel-to-reel tape. Each of these lists consisted of 50 monosyllabic words.

PROCEDURES

Each subject participated in two 2-hour sessions. The subjects were seated in a sound-shielded room and instructions were read to the subject. The subject's task was to repeat the stinulus word presented. Subjects were given the opportunity to ask questions at this time.

For bone conduction testing, the transducer was placed on the most prominent area of the mastoid process of the test ear with the force level equivalent of 550 grams, as measured with a Bruel and Kjaer strain gauge. A foam earplug (E.A.R., Cabot Corp.) was placed in the test ear to reduce the effects of acoustic radiation of the bone conduction vibrators. Broad band masking noise was used on the non-test ear via a TDH-39 earphone at a level of 70 dB SPL.

The order of the three transducers was counter-balanced across subjects. A bracketing technique was employed to determine the initial speech reception threshold for each subject. The bracketing technique consisted of starting 30-40 dB above an estimated speech reception threshold and presenting a spondee. If the subject's response was correct then another word was presented. If the second word was correct, the tester descended in 1 dB steps until one of the two consecutive spondees was missed. When this spondee was missed, two more spondees were presented and the tester determined the lowest level at which two out of four spondees were correctly repeated. This level was taken as the estimated speech reception threshold.

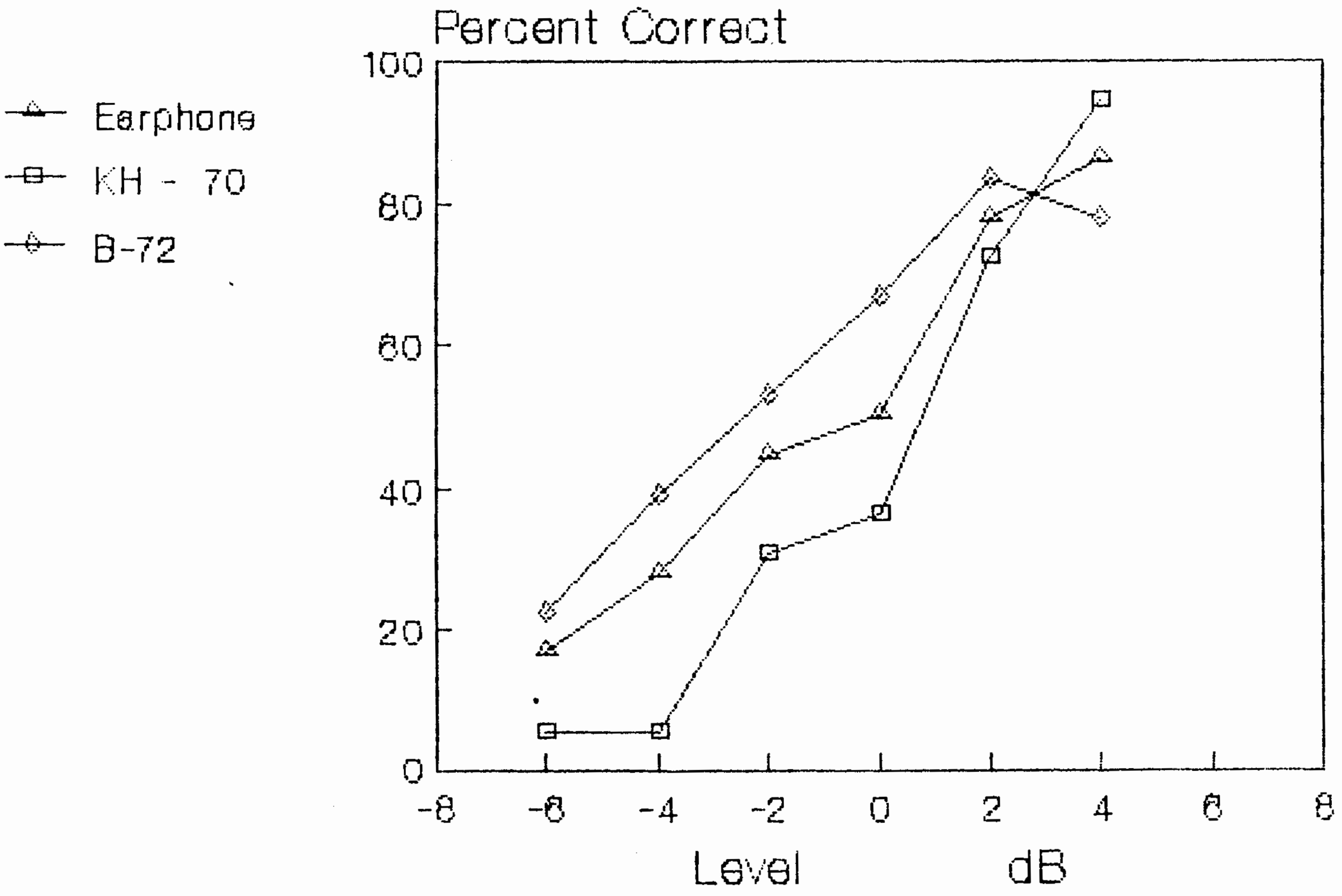
Rest periods of 5-10 minutes were given whenever the subject indicated one was needed. Each W-1 list (A-F) was presented at a different level. The presentation level was calculated from a subject's previously established speech reception threshold. The levels for each subject were -6, -4, -2, 0, 2, and 4 dB relative to the pre-determined speech reception threshold. The number of correct spondees was computed for each subject. The NU-6 discrimination lists were presented at a 40 dB sensation level above the pre-determined speech reception threshold and the percentage of words correctly identified was calculated. A different list was used for each transducer.

CHAPTER IV

RESULTS

Figure 3 shows one subject's performance-intensity (PI) function for each of the three transducers. The ordinate is the percentage of correctly identified spondees, and the abscissa is the intensity level relative to the pre-determined SRT. For each transducer the percentage of correctly identified spondees increased as the intensity level was increased. This was true for all 12 subjects.

In order to determine the slopes of each of the subjects' PI functions, the straight line of best fit was determined for each subject by means of linear regression. The individual data were normalized along the x axis by aligning the 50% point of the straight line of best fit with 0 cB on the x axis. Figures 4 through 6 show the scattergrams of the normalized group data for each transducer. The straight line of best fit to the group data is shown in each graph. Each subject's responses for each transducer was similar and closely clustered around the line of best fit. The mean slopes of the lines of best fit to the individual data are shown in Table I for the three transducers. A one-way analysis of variance indi-



<u>Figure 3</u>. Plot of percent correct as a function of intensity level equated to SRT (db). One subject's performance-intensity functions for three transducers.

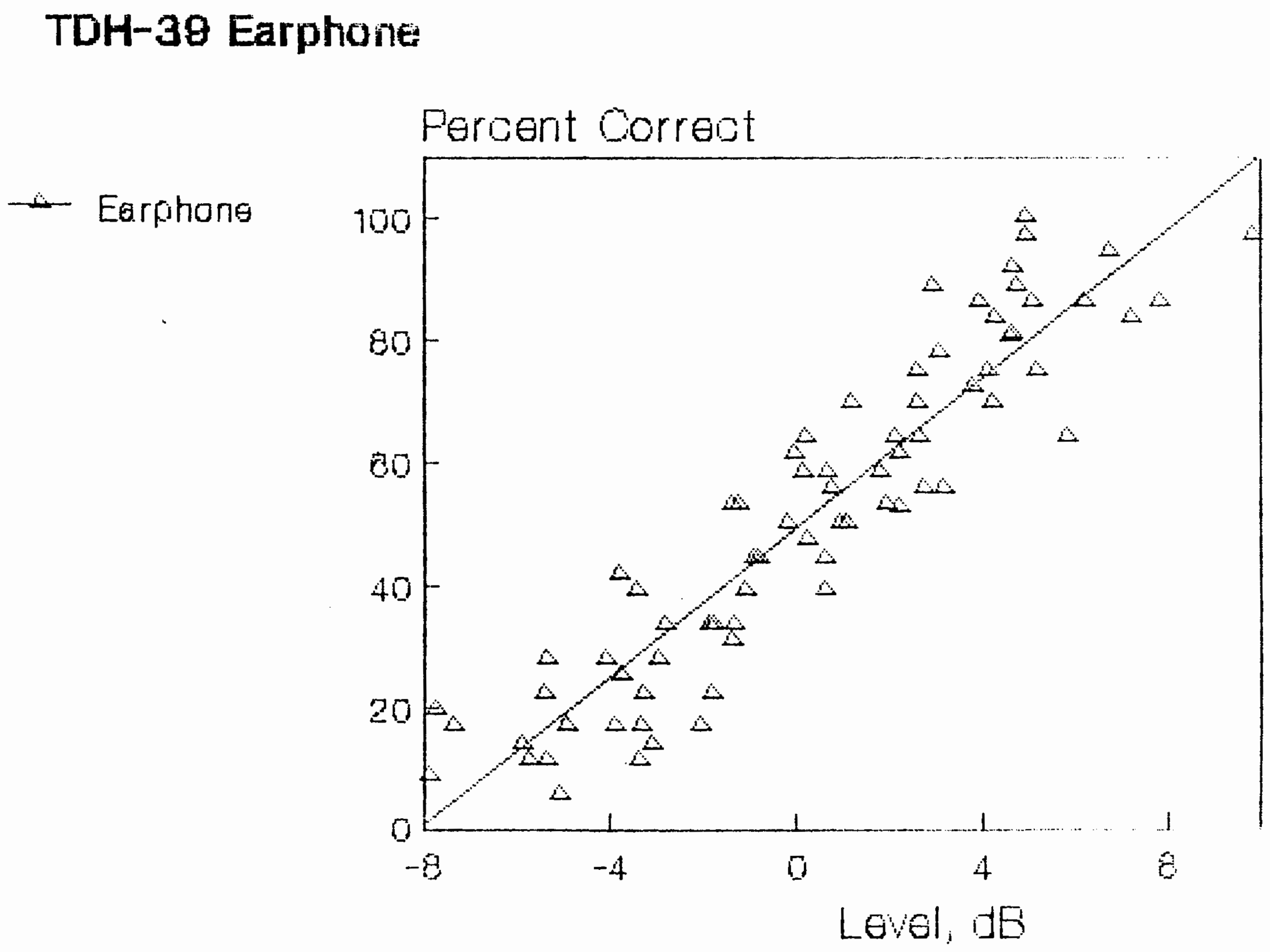


Figure 4. Plot of percent of spondees correctly identified as a function of equated intensity level. Scattergram of normalized group data for the TDH-39 earphone.

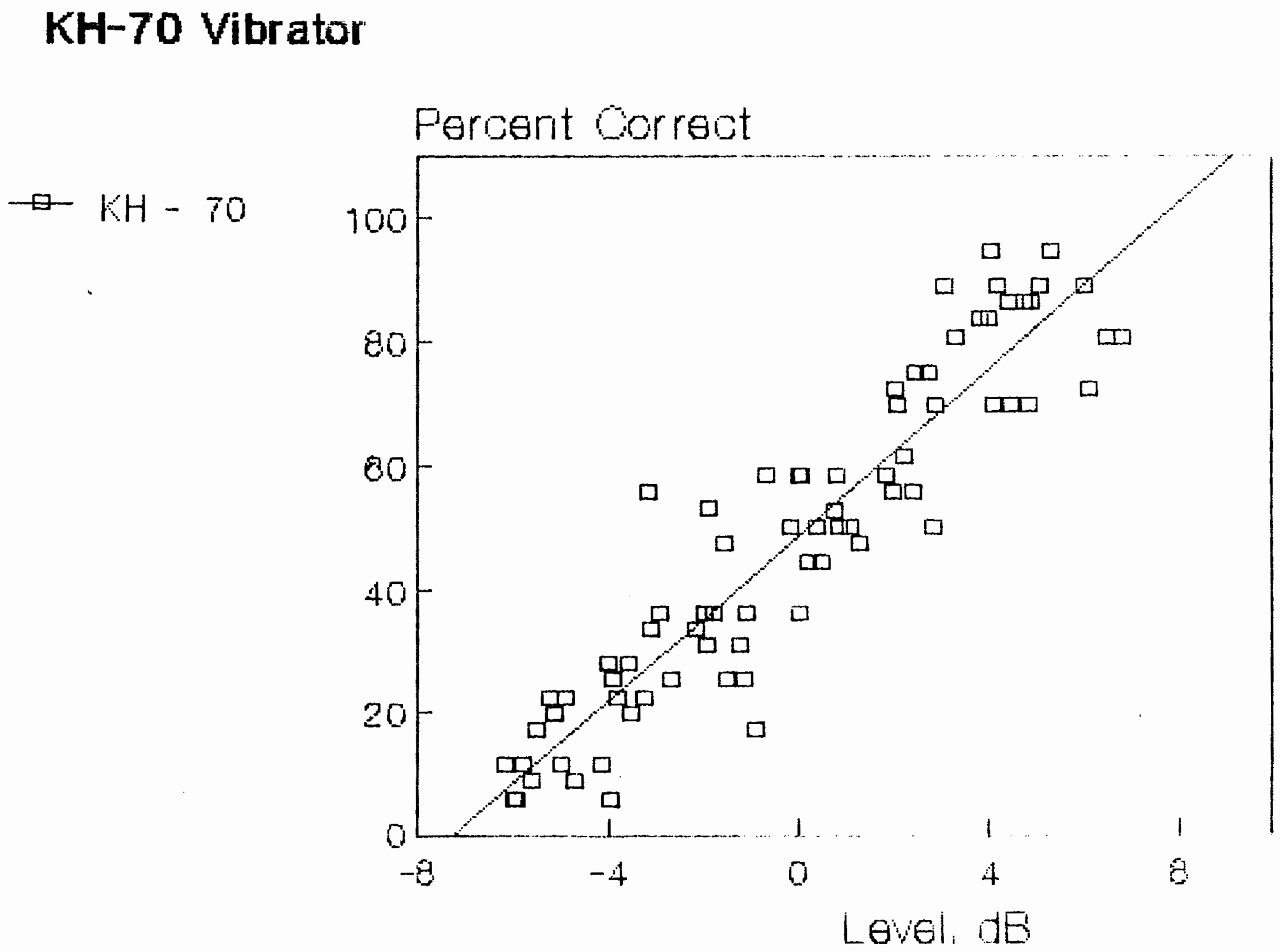


Figure 5. Plot of percent of spondees correctly identified as a function of equated intensity level. Scattergram of normalized group data for the KH-70 bone vibrator.

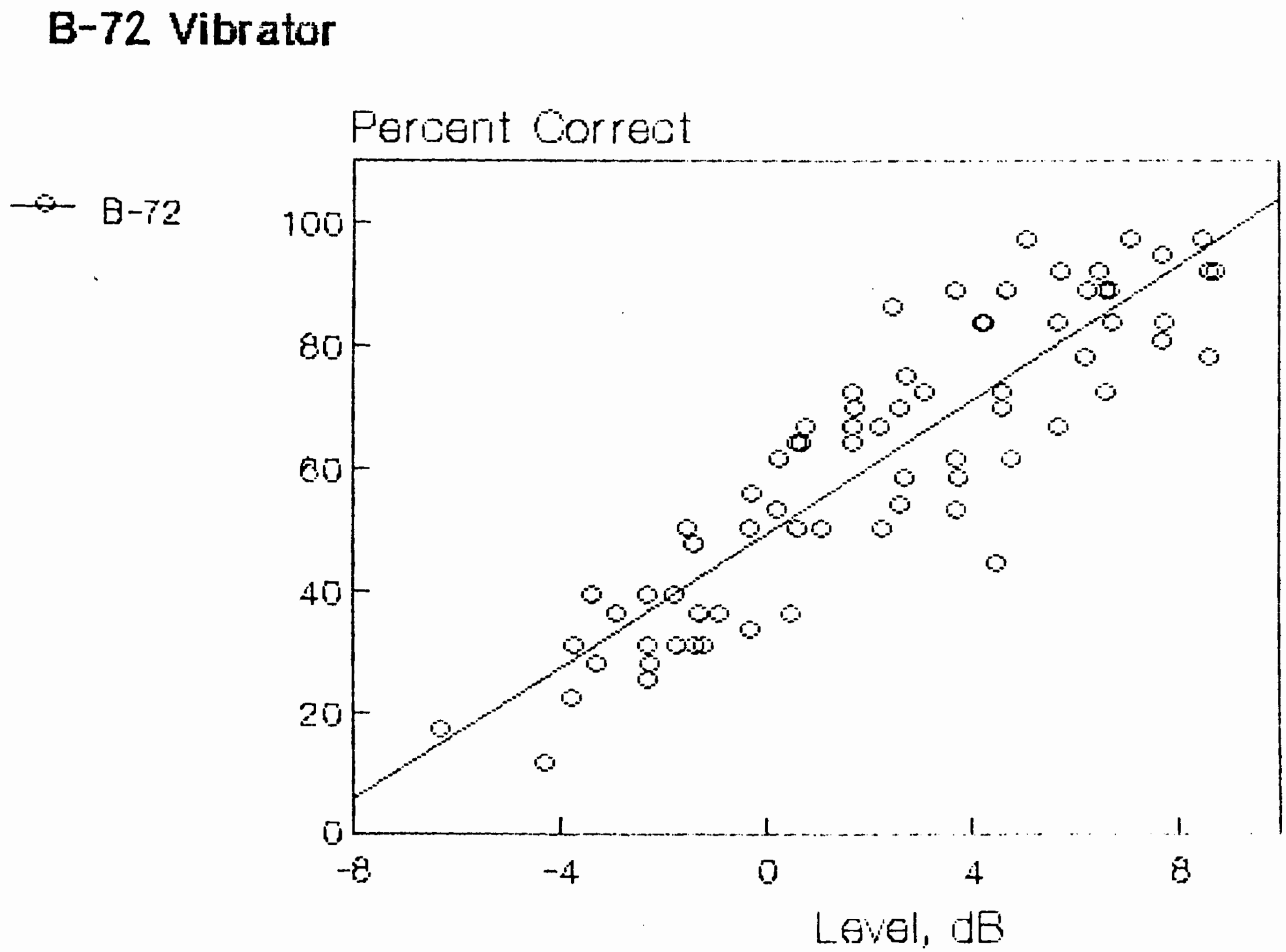


Figure 6. Plot of percent of spondees correctly identified as a function of equated intensity level. Scattergram for normalized group data for the B-72 bone vibrator.

TABLE I

MEANS SLOPES, STANDARD DEVIATIONS AND STANDARD ERRORS
GROUP DATA FOR THREE TRANSDUCERS

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
earphone	12	6.429	1.652	.477
KH-70	12	6.625	1.599	.462
B-72	12	5.604	1.304	.377

cated there was no significant difference in slopes for the three transducers, ($F = 2.342$, $P > .10$). Results of the analysis are given in Table II.

Table III displays the mean, standard deviation, and standard errors for the discrimination scores with each transducer. Each subject scored above 90% with all three transducers. A one-way analysis of variance indicated that there was no significant difference in the discrimination scores. Results of the analysis are given in Table IV.

TABLE II

RESULTS OF ANOVA FOR SLOPES OF SPONDEES USING THREE TRANSDUCERS

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	11	41.461	3.769	2.131	.0588
Within subjects	24	42.443	1.768		
treatments	2	7.044	3.522	2.189	.1358
residual	22	35.399	1.609		
Total	35	83.904			

Reliability Estimates for- All treatments: .531 Single Treatment: .274

TABLE III

MEAN, STANDARD DEVIATION, AND STANDARD ERRORS OF DISCRIMINATION SCORES

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Earphone	12	97.667	3.284	.948
KH-70	12	95.833	1.992	.575
B-71	12	97.167	3.01	.869

TABLE IV

RESULTS OF ANOVA FOR DISCRIMINATION SCORES IN PERCENTAGES

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	11	144.889	13.172	2.28	.0443
Within subjects	24	138.667	5.778		
treatments	2	21.556	10.778	2.025	.1559
residual	22	117.111	5.323		
Total	35	283.556			

Reliability Estimates for-...All treatments: .561 Single Treatment: .299

CHAPTER V

DISCUSSION

The purpose of this investigation was to compare the intelligibility of speech delivered via two bone conduction vibrators with the intelligibility of speech delivered via air conduction. Another variable also addressed in this investigation was the comparison of discrimination scores, using the same transducers.

The steeply rising slope of the performance-intensity function for the two bone conduction vibrators indicated that speech via bone conduction is consistent with the results of speech via air conduction. Thus, when testing children and other difficult to test populations who may not give reliable pure tone thresholds, speech via bone conduction appears to be clinically viable in determining if a conductive component exists.

Overall, the results indicated that the performance-intensity function for spondees delivered via bone conduction, utilizing the Radioear B-72 and Pracitronic KH-70, did not differ from the performance intensity of spondees delivered via air conduction, with normal hearing subjects. Specifically, the slopes of the functions were not significantly different. Our findings differ from those of Edgerton, Danhauer, and Beattie (1977), who found a lower slope for the PI function for bone conduction over air conduction. It is possible that the lower slope for bone conduction found in the Edgerton et al. study may be due to the transducer used (a Radioear B-70-A). The B70-A bone vibrator does not meet current standards (ANSI, 1981) for transmitting speech.

Discrimination scores of the present study were also similar between transducers, suggesting that speech intelligibility is comparable for bone conduction to air conduction.

The results of the present study suggests that we can safely use the CID-W1 spondee word lists when testing via bone conduction, even though the test was originally designed for use via air conduction. Also, my results suggest that the same criteria used for defining the speech reception threshold in air conduction, such as the 50% correct level, can be applied to bone conduction as well as to air conduction.

Finally, the results of this investigation suggests another area for further research. Using the particular type of equipment and procedures, further investigation into the performance-intensity function of speech via bone conduction as compared to speech via air conduction could be attempted using hearing-impaired subjects. Normal hearing listeners gave both SRT and discrimination scores at lower levels. With hearing-impaired listeners, higher levels of intensity would be required to obtain results. This could be useful in determining if the results from the present study are consistent with the hearing-impaired listener. Secondly the relationship of discrimination scores of speech via bone conduction versus air conduction has still not been clearly established with the hearing-impaired listener.

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