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COMPARISON OF SPEECH PERCEPTION UTILIZING
MONOTIC AND DICHOTIC MODES OF LISTENING

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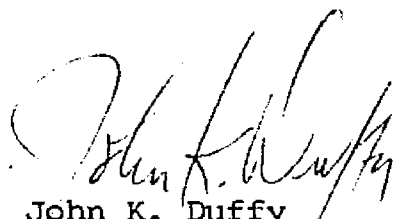
ERNEST ZELNICK

A dissertation submitted to the
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fulfillment of the requirements for
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The City University of New York.

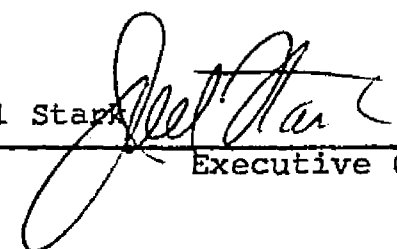
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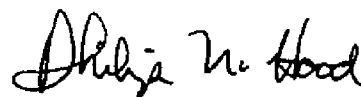
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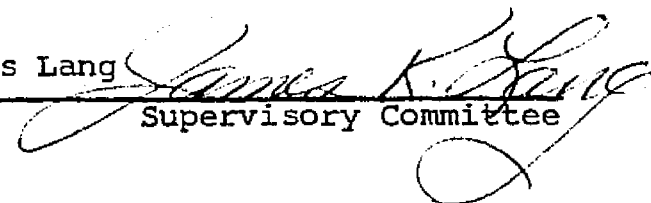
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CHAPTER I
INTRODUCTION

— A. Binaural Interaction.

The role of binaural interaction is an important question in psychoacoustics and auditory theory. It has been postulated by writers in the field that the possession of two ears gives us greatly enhanced powers of aural discrimination (Cherry).¹

If a person's ability to understand speech in noise can be improved by a mechanism which enables him to localize the sources of speech and noise separately, such a device would be of benefit to the listener. Localization seems to be dependent on at least two factors, namely, head movements and two more or less independent ears that are separated in space by approximately eight inches.

The problem of demonstrating the superiority of binaural over monaural hearing has turned out to be rather difficult of solution. The result is that it has rarely been demonstrated in the laboratory that two ears are of any advantage compared to one. One difficulty with comparisons of the advantages of binaural versus monaural hearing is that an appropriate test has been difficult to devise (Harris).²

¹C. Cherry, "Two Ears--But One World," In W.A. Rosenblith (Ed.), Sensory Communication. (Cambridge, Mass.: The M.I.T. Press, 1959), p. 99.

²J.D. Harris, "Research Frontiers in Audiology," In J. Jerger (Ed.), Modern Developments in Audiology. (New York: Academic Press, 1963), p. 427.

Although there has been general agreement as to the advantages of binaural hearing for localization of sounds, by both clinicians and research workers, there has been a difference of opinion as to the degree of increase of speech intelligibility. In fact, Jerger and Dirks,³ speaking of the supposed superiority of binaural hearing aids referred to it as an "enigma."

An examination of the studies which have concluded that there is little or no benefit from the binaural mode of listening, revealed that many of these studies were not designed in a manner which would elicit the increase of speech intelligibility for binaural over monaural hearing, if it were present.

B. Problems of This Research.

1. Reasons for the Study.

The purpose of this study was to design an experimental situation, utilizing high fidelity amplifiers and earphones in such a manner that speech intelligibility could be measured under various monotic and dichotic listening conditions, and thereby obtain data as to speech perception with the use of such modes with a group of subjects suffering from bilateral sensory hearing losses.

³J. Jerger and D. Dirks, "Binaural Hearing Aids: An Enigma," Journal of Acoustical Society of America, 33 (1961), p. 538.

It is felt that the present study is a logical outgrowth of the work of Harris,⁴ which reported statistically significant increases in speech intelligibility of the dichotic modes over the monotic modes of listening, utilizing high fidelity amplifiers and earphones on a normal hearing group and a group of defective hearing listeners. The purpose of this study was to ascertain if similar results would be obtained using high fidelity amplifiers and earphones in one experiment and utilizing hearing aids in the second experiment with subjects having bilateral sensory hearing involvements.

The study was structured so that head movements were avoided through the use of a dummy head. The investigation dealt only with conditions where signal-to-noise ratios were the same at the two ears. Nothing akin to the head-shadow effect was introduced in the experiment. Obviously, one should not expect binaural interactions in everyday life identical to those found in this study; however, by controlling head movement and the head-shadow effect, the results of binaural facilitation in noise and binaural summation on speech perception could be evaluated.

2. Specific Questions This Research Attempted to Answer.

a. Would a dichotic amplifying system as compared with a monotic system, alter speech perception,

⁴J.D. Harris, "Monaural and Binaural Speech Intelligibility and the Stereophonic Effect Based Upon Temporal Cues," Laryngoscope, 75 (1965), p. 438.

as measured by the Revised Peterson-Lehiste CNC word lists, for individuals with approximately symmetrical bilateral sensory hearing losses?

b. Would a two-channel (monotic V-cord arrangement), system of amplification to one ear as compared with a one channel (monaural) system to the same ear, alter speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for individuals with approximately symmetrical bilateral sensory hearing losses?

c. Would a two-channel (double V-cord arrangement), amplifying system to each ear as compared with a binaural system, alter speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for individuals with approximately symmetrical bilateral sensory hearing losses?

d. Would a two-channel (monotic V-cord arrangement), system of amplification to one ear as compared with a binaural system, alter speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for individuals with approximately symmetrical bilateral sensory hearing losses?

e. Would a two-channel (double V-cord arrangement), amplifying system to each ear as compared with a two-channel (monotic V-cord arrangement), system of amplification to one ear, alter speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for individuals with approximately symmetrical bilateral sensory hearing losses?

f. Would a system of amplification using high fidelity amplifiers and earphones as compared to an amplifying system using commercial hearing aids, alter speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for individuals with approximately symmetrical bilateral sensory hearing losses?

g. Would a system of scoring one point per phoneme correctly reported as compared with a system of scoring one point per word correctly identified, provide a more refined method of measurement of speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for individuals with approximately symmetrical bilateral sensory hearing losses?

C. Importance of the Study.

Davis and Silverman⁵ made the following statement:

Theoretically, binaurally hearing aids should make it much easier to discriminate the voice of a particular talker from background noises, from other sources. It is too early to judge how well and for which hard-of-hearing individuals the possibilities are fulfilled.

They thereby indicated their feeling of the need for further study in the area of binaural fitting of hearing aids.

Harris,⁶ writing on the need for further research and the applications of binaural systems of amplification for

⁵H. Davis and S.R. Silverman, Hearing and Deafness. (New York: Holt, Rinehart and Winston, 1960), p. 335.

⁶Harris, op. cit., p. 428.

the hard-of-hearing wrote:

It remains for careful and clever research to apply these ideas to populations partially defective, both bilaterally and unilaterally, and to relate them to actual performance with hearing aids. It may prove that studies with a blind sub-population would be of greatest usefulness in thus assessing the improvement in daily living afforded by the binaural hearing aid, since these individuals must routinely orient predominantly with aural cues.

Newby⁷ claimed that clinical audiologists are being more cautious in recommending binaural instruments, because of lack of research evidence that binaural hearing aids are superior to monaural ones.

Recently, O'Neill and Oyer⁸ expressed the need for further investigation of the effects of binaural hearing aids upon speech discrimination.

Another important feature of this study is that discrimination scores were determined by a new system of scoring one point per phoneme, in addition to the traditional method of scoring one point per word. If a change in scoring resulted in a difference in the comparison of speech discrimination scores, between the various modes of listening, then the method of scoring would appear to measure discrimination of

⁷H.A. Newby, Audiology. (New York: Appleton-Century-Crofts, 1964), pp. 298-299.

⁸J.J. O'Neill, and H.J. Oyer, Applied Audiometry. (New York: Dodd, Mead & Company, Inc., 1966), p. 252.

speech differently, and the clinician and the research worker would have an additional tool available to them in their evaluation of an individual for a hearing aid.

D. Summary.

The plan for this study was to compare speech perception as measured by the Revised Peterson-Lehiste CNC word lists, for individuals with approximately symmetrical bilateral sensory hearing losses, utilizing monotic and dichotic modes of listening.

This study was further designed to compare discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, of an amplifying system using high fidelity amplifiers and earphones, to a system of amplification using commercial hearing aids, for individuals with approximately symmetrical bilateral sensory hearing losses.

Discrimination scores were determined by a system of scoring whereby one point was awarded for each phoneme correctly reported, as measured with the Revised Peterson-Lehiste CNC word lists.

Furthermore, if differences in speech discrimination scores do exist, by utilizing different modes of listening, then audiologists would be encouraged to make further tests of discrimination with binaural and two-channel (V-cord arrangements) systems of amplification, in the selection of hearing aids for individuals with approximately bilateral symmetrical sensory hearing losses.

CHAPTER II

REVIEW OF THE LITERATURE

Although speech intelligibility can be conveyed through a single neurological channel, there are circumstances when understanding of speech is improved to an appreciable degree when it is heard through two ears, rather than one. However, such advantages are not the inevitable concomitants of simply activating the second channel, nor are they merely by-products of the localization experience. Instead, they accrue when conditions evoke appropriate phenomena of summation, facilitation, integration and squelching.

In recent years, there has been considerable discussion and research as to the advantages of binaural hearing and as to the benefits of binaural hearing aids in helping individuals suffering from peripheral hearing disorders. A review of this literature follows:

A. Literature on Binaural Advantages with Normal Hearing Subjects.

1. Binaural Summation at Absolute Threshold.

Keys¹ concluded that the optimal conditions for binaural hearing are present when both ears are stimulated at equal sensation levels. His study found that there was a 2.73 dB increment of the binaural threshold for pure tones over the monaural threshold. He further reported a 2.70 dB increment for the binaural speech threshold compared to the monaural threshold for speech.

¹J.W. Keys, "Binaural vs. Monaural Hearing," Journal of Acoustical Society of America, 19 (1947), pp. 630-631.

Shaw et al² demonstrated a difference of approximately 3 dB between the monaural and binaural pure tone thresholds when compensation was made for the difference in threshold sensitivity between the two ears.

Pollack³ found the difference between the monaural and binaural thresholds significantly greater for pure tones than the corresponding difference with noise (white noise), used as a stimulus. Furthermore, Pollack found the difference between the binaural threshold and the threshold of the better ear was not statistically significant when the two ears were stimulated at sensation levels more than 6 dB apart.

The above experiments demonstrated that the binaural threshold for pure tones expressed in terms of sound pressure developed at the eardrum is lower than the monaural threshold. If one ear is considerably better than the other, this summation effect is insignificant and the performance of the two ears is not noticeably different from that of the better ear (Wever and Lawrence).⁴

²A. Shaw, E.B. Newman, and I.J. Hirsh, "The Difference Between Monaural and Binaural Threshold," Journal of Experimental Psychology, 37 (1947), p. 229.

³I. Pollack, "Monaural and Binaural Threshold Sensitivity for Tones and for White Noise," Journal of Acoustical Society of America, 20 (1948), pp. 54-55.

⁴E.G. Wever and M. Lawrence, Physiological Acoustics. (Princeton: Princeton University Press, 1954), p. 56.

A study by DiCarlo and Brown⁵ indicated that for speech reception thresholds, binaural listening provided a slight lowering of the threshold as compared with the pseudo-binaural and better monaural thresholds. The binaural threshold for speech was lower than the better monaural threshold by 3.9 dB for the conductive loss group, 3.4 for those with mixed losses, and 2.4 for the subjects with sensori-neural hearing involvements. There was some variability in binaural summation, at least for those with sensori-neural hearing losses.

2. Binaural Summation at Supra-threshold Levels.

Binaural summation phenomenon with sounds at intensities greater than the threshold value was first noted by Seebeck.⁶ His observations have been corroborated by numerous authors who have also tried to determine quantitatively the amount of binaural summation, at supra-threshold levels.

According to Causse and Chavasse,⁷ binaural summation grows from threshold values of 3 dB with increasing intensity. They found that at a binaural sensation level of

⁵L.M. DiCarlo, and W.J. Brown, "The Effectiveness of Binaural Hearing for Adults with Hearing Impairments," The Journal of Auditory Research, 1 (1960), p. 47.

⁶A. Seebeck, "Beltrage zur Physiologie des Gehorund Gesichtsinnes," *Ann. Phys. Chem.*, (1846), pp. 449-458, (as cited by J.C.R. Licklider in Chapter 25), In S.S. Stevens (Ed.), Handbook of Experimental Psychology. (New York: John Wiley & Sons, 1951), p. 1031.

⁷R. Causse, and P. Chavasse, "Difference entre L'Ecoute Binaurculaire et Monoaurculaire pour La-Perception des Intensites Supraliminaire," *C.R. Soc. Biol., Paris* (1942), 136, (as cited by G. DeCroix and J. Dehausey), In Journal of Auditory Research, 4 (1964), p. 116.

35 dB, equal loudness was achieved with the monaural listening condition, with a 6 dB differential in the intensity of the sound.

Fletcher and Munson⁸ reported still higher values for binaural summation of loudness, at supra threshold levels. Their study indicated that the binaural intensity of a tone, at a sensation level of 60 dB could be 12 dB weaker than the monaural intensity of the same tone heard equally as loud.

Regardless of the intensity level of the acoustic stimulus, Fletcher and Munson, further reported that a tone heard binaurally was perceived by listeners twice as loud as the same tone heard monaurally.

Hirsh⁹ also found that tones sound louder to both ears than they do to one, and that binaural summation of loudness is more evident at supra threshold levels than binaural summation at the absolute threshold of hearing.

Studies by Bekesy¹⁰ found that for maximal binaural summation of loudness, the tones delivered to the two ears must be of the same frequency, whereas, tones of the same frequency delivered to the same ear, will not summate in loudness but will in fact have the threshold of the sound elevated, due to the masking effect.

⁸H. Fletcher, and W.A. Munson, "Loudness-Its Definition, Measurement and Calculation," Journal of Acoustical Society of America, 5 (1933), pp. 82-108.

⁹I.J. Hirsh, "Binaural Summation-A Century of Investigation," Psychological Bulletin, 45 (1948), pp. 193-206.

¹⁰G. Bekesy, "Experiments in Hearing." (ed. E.G. Wever. New York: McGraw-Hill Book Company, Inc. 1960), p. 349.

Azzi¹¹ wrote that monaural loudness grows as a function of the power of sound with an exponent of about 0.54 whereas binaural loudness grows with an exponent of 0.6. He therefore concluded that the relationship between the auditory stimulus and binaural sensation was not a logarithmic function but rather a power function, with a larger exponent for binaural hearing than for monaural audition ($y=ax^b$, $b= 0.6$). It appears that part of the value of the binaural exponent in the power function must be attributed to the central summation process.

The superiority of the two ears over one becomes greater as the stimulus increases in intensity. In fact, Reynolds and Stevens¹² wrote:

From a minimum of 3 dB at threshold the decibel differences between equally loud binaural and monaural stimuli increases linearly with SPL and reaches 10 dB at a SPL of about 90 dB. The differences appear to keep on growing at still higher levels.

The generally accepted view is that the amount of binaural summation of loudness is directly proportional to the sensation level at which the physical stimulus is presented to each ear (Robinson).¹³

¹¹A.A. Azzi, "Clinical Application of Binaural Audiometry," International Audiology, 3 (1964), p. 205.

¹²G.S. Reynolds and S.S. Stevens, "Binaural Summation of Loudness," Journal of Acoustical Society of America, 32 (1960), p. 1343.

¹³D.W. Robinson, "Statistical Aspects of the Relation Between Binaural and Monaural Thresholds," Acoustica, 10 (1961), p. 74.

3. Binaural Differential Sensitivity.

Binaural difference limens are somewhat smaller than the monaural DL's. Licklider¹⁴ attributes the superiority in differential sensitivity of binaural over monaural hearing to binaural supplementation:

(1) Both ears are continually varying in sensitivity, (2) sometimes the right ear is more acute, sometimes the left, (3) the central nervous system takes advantage of the better of the two incoming signals.

a. Binaural Intensity Discrimination, Difference Limen (DL).

Under conditions usually designed to measure the difference limen (DL), the observer's response is always variable. This phenomenon of fluctuation, familiar to everyone who has made psycho-physical measurements, necessitates the adoption of some statistical criterion for determining the value of the difference limen (DL). The value selected in the following studies referred to in this review of the literature, is the difference in intensity or frequency which the observer was able to detect fifty per cent of the time.

The claim has been made that with binaural listening, it is often possible to detect a change in intensity 15 to 30 per cent smaller than that which is perceptible in

¹⁴J.C.R. Licklider, "Correlates of Auditory Stimulus, (in Handbook of Experimental Psychology, ed. S.S. Stevens, New York: John Wiley and Sons, Inc., 1951), p. 1031.

monaural listening, (Upton and Holway).¹⁵ They reported that the decrease in the size of the difference limen (DL) for intensity, is also related to the exposure time of a tone according to its exponential function.

b. Binaural Frequency Discrimination Difference Limen (DL).

Shower and Biddulph¹⁶ demonstrated that frequency difference limen was smaller binaurally than monaurally. At low frequencies and at low intensities, the DL's are largest for both the binaural and monaural listening condition.

Results similar to those obtained by Shower and Biddulph for frequency difference limen have been reported for tests with bone-conduction, a special case of binaural listening (Stevens and Davis).¹⁷

4. Interaural Time Differences.

The role of difference in time of arrival at the two ears in establishing the location of a sound source has been

¹⁵M. Upton, and A.H. Holway, "On the Psycho-Physics of Hearing," Proceedings of National Academy of Science, 23 (United States: 1937), p. 29.

¹⁶E.G. Shower, and R. Biddulph, "Differential Pitch Sensitivity of the Ear," Journal of Acoustical Society of America, 3 (1931), p. 287.

¹⁷S.S. Stevens and H. Davis, Hearing, Its Psychology and Physiology. (New York: John Wiley & Sons, Inc., 1938), p. 87.

recognized for a long time. The additional advantage of increased intelligibility as a result of interaural time differences with binaural listening has been experimentally demonstrated only recently.

Schubert¹⁸ made comparisons of the intelligibility of continuous speech in noise under three listening conditions: (1) speech arriving simultaneously and in phase at the two ears; (2) speech arriving at one ear later than at the other; (3) and speech arriving simultaneously, but in opposite phase in one ear. Time intervals between the two ears ranged from 200 microseconds to 7 milliseconds. Delaying speech to one ear under these conditions did increase intelligibility but little, if any, better than the simple expedient of wiring earphones so that the wave form at one ear is inverted with respect to the other (antiphasic condition). With the materials and method used by Schubert, the maximum increase in speech discrimination occurred with a time delay between the ears of 0.5 to 1 millisecond; though there was some indication that delays of 1 millisecond and longer might be slightly better under the most difficult listening conditions tried.

When one talks of interaural time differences in auditory localization, one refers to the differences in the

¹⁸E.D. Schubert, "Some Preliminary Experiments on Binaural Time Delay and Intelligibility," Journal of Acoustical Society of America, 28 (1956), p. 895.

time of arrival at the two ears of: (1) the start of the sound, or some sudden change in the sound; or (2) a transient noise in the sound pattern. Which ever of the above time differences is being considered, the ear which receives the prior signal is the ear towards which the source will be localized. Once the decision is made, the neural system is reluctant to change it, even if subsequent information conveyed to the two ears conflicts with its decision. In other words, the initial time difference cue preempts, the decision mechanism against conflicting evidence for some time after the stimulus is sounded. This is known as the precedence effect, and was first noticed by Wallach et al.¹⁹

Klumpp and Eady²⁰ determined thresholds for the detection of interaural time differences for: (1) band limited random noise (150 to 1700 Hz); (2) for a 1000 Hz tone; and (3) for a 1 millisecond click. The average interaural time differences for detection in the symmetrical two alternative tests were: (1) 9 microseconds for the band limited random noise; (2) 11 microseconds for the 1000 Hz tone; and (3) 28 microseconds for the 1 millisecond click.

¹⁹E. Wallach, E.B. Newman, and M.R. Rosenzweig, "The Precedence Effect in Sound Localization," American Journal of Psychology, 62 (1949), pp. 315-336.

²⁰R.G. Klumpp, and H.R. Eady, "Some Measurements of Interaural Time Difference Thresholds," Journal of Acoustical Society of America, 28 (1956), pp. 859-886.

Matzker²¹ wrote:

The central organ is, therefore, only qualified to perceive and recognize as such, time differences which are at least greater than 2 msec. between the right and the left ear specifically, we are dealing here with time differences in discontinuous noise; pure tones are first heard separately when the time difference is about ten times larger. As opposed to this, the central organ converts time differences of less than 2 msec. into a directional impression, more exactly stated, into a louder sensation at the right or the left. There is also a very definite relationship between time and intensity perception, which must be established through specific connections in the central organ, since with the electrically created time difference, both ears are presented with a sound stimulus which remains equally loud and completely similar and which differs in only one aspect: the time of its arrival at the inner ear.

It was observed by Schubert and Schultz,²² that an interaural disparity of 0.5 millisecond of speech signals in the presence of a broad-band random noise gives an improvement of intelligibility over homophasic listening. A delay of this magnitude approximates the condition encountered when a sound source is at the 45° azimuth.

²¹J. Matzker, "Attempts at Explanation of Directional Hearing on the Basis of Very Fine Time Difference Registration," Translation of the Beltone Institute for Hearing Research, 12 (November 1959), pp. 4-5.

²²E.D. Schubert, and M.C. Schultz, "Some Aspects of Binaural Signal Detection," Journal of Acoustical Society of America, 34 (1962), p. 844.

They used the frequency range of speech restricted to one of the three ranges 200-1600, 880-2200, and 1660-6100 Hz. The lowest range showed a binaural improvement of 33 per cent for a change in interaural polarity, and of 28 per cent for an interaural time disparity of 500 microsecond. The middle and high frequency ranges showed less binaural gain, but do afford some advantages to two-eared listening under difficult conditions. The authors of this study found that the binaural system helps most when the interfering sound is the speaker's own voice or a multiple mixture of many voices.

5. Interaural Phase Differences.

Time differences between pure-tones will affect interaural phase differences. With dichotic pure tones of equal intensity which have been on for some time, only the phase difference can serve localization. Thompson²³ was the first to demonstrate the lateral location of a sound was affected by the interaural phase difference. Identical in-phase dichotic sounds are localized in the region of the median plane, as the phase difference increases the auditory phantom is reported to move laterally, for large phase differences the apparent source broadens and eventually splits into two sounds, one opposite each ear (Hughes).²⁴

²³S.P. Thompson, "The Phenomena of Binaural Audition I," Philosophy Magazine, 4 (1877), pp. 274-276.

²⁴J.W. Hughes, "Binaural Localization with Two Notes Differing In-Phase by 180°," British Journal of Psychology, 30 (1939), pp. 52-56.

Licklider²⁵ reported on his observations on the intelligibility of speech heard against the background of white noise under each of six interaural phase relations. The permutations of interaural phase relations were described by Licklider as follows: (1) homophasic condition-speech stimulus in phase at both ears and noise in phase at both ears; (2) homophasic condition-speech stimulus out of phase at both ears and noise out of phase at both ears; (3) antiphasic condition-speech stimulus in phase at both ears and noise out of phase at both ears; (4) antiphasic condition-speech stimulus out of phase at both ears and noise in phase at both ears; (5) heterophasic condition-speech stimulus in phase at both ears and noise randomized in phase at both ears; (6) heterophasic condition-speech stimulus out of phase at both ears and noise randomized in phase at both ears.

Licklider found that the intelligibility for speech was higher when the speech and noise stimuli presented through earphones were in an antiphasic relationship over the homophasic condition. In fact, he reported that when the speech waves and the noise waves were in an antiphasic relationship, word articulation scores increased as much as 25 per cent over the presentation of the stimuli in which both the speech wave and the noise waves in the two ears were in-phase.

²⁵J.C. Licklider, "The Influence of Interaural Phase Relations Upon the Masking of Speech by White Noise," Journal of Acoustical Society of America, 20 (1948), p. 158.

When speech was masked by noise from two independent sources, one for each ear (heterophasic condition), speech perception was intermediate between the respective intelligibilities for the homophasic and the antiphasic conditions. Licklider further reported that the interaural phase effect is greater at low speech-to-noise ratio than at high speech-to-noise ratio (more difficult listening situations show greater effect of antiphasic condition). He explained the increased intelligibility for speech in an antiphasic situation as follows:

The interaural effects may be very marked indeed for intense low frequency tones, so that even when high frequency components make up a large part of the total power of the signal, there still remains a readily measurable phenomenon. White noise masks the high frequency components of speech somewhat more than the low frequency components. This throws the burden of carrying intelligibility over onto the low frequency components for which binaural interactions have been demonstrated. This reasoning is confirmed by the observation that the interaural phase effects are greater for the low frequency components of speech heard separately (speech passed through a 1000-cycle low pass filter) than they are for wide band speech.

Hirsh²⁶ reported that binaural thresholds are lower than the corresponding monaural thresholds when the tone and

²⁶I.J. Hirsh, "The Influence of Interaural Phase on Interaural Summation and Inhibition," Journal of Acoustical Society of America, 20 (1948), p. 544.

the noise have opposite interaural phase relations (antiphase condition). These effects were most prominent in the vicinity of 200 Hz and they became greater as the intensity of the masking noise was increased. He found that for fixed interaural phase relations of binaural noise, interaural summation and inhibition were continuously variable with the interaural phase relation of the pure tone stimulus. The author indicated that based on his observations concerning masking and binaural summation, the theory that masking is entirely a peripheral phenomenon should be revised, as central factors evidently make important contributions to the neural mechanism of masking.

In a later study, Hirsh²⁷ suggested that in a free-field listening situation, the threshold of intelligibility for speech was affected by the relative locations of the sources of the speech stimulus and of the masking noise. He found that when the azimuths of the sources of speech and of noise were changed relative to each other, the threshold of intelligibility for speech changed by small but consistent amounts. When the sources of speech and noise were close together, the threshold for speech was high; when, however, the sources for speech and noise were far apart, the threshold for speech was reduced. He, therefore,

²⁷I.J. Hirsh, "The Relation Between Localization and Intelligibility," Journal of Acoustical Society of America, 22 (1950), p. 200.

reasoned that although this relationship resulted from the effect of the azimuths of the sources of the sounds causing differences in sound pressure levels at the ears, the factor of localization of the sound appeared to play a significant role in speech intelligibility. This relation was especially evident when the two ears were used and the head was free to move.

Hirsh made use of the spondee words in his tests which depended primarily on the low frequency components of speech for intelligibility. He, however, proposed the use of more difficult speech materials, whose intelligibility would depend to a greater degree upon the high frequency components, to determine whether the perception of such speech stimuli would also be increased under antiphase conditions of listening.

Norlund and Fritzell²⁸ demonstrated that the intelligibility of speech under the binaural hearing condition was significantly better than for monaural listening at all azimuths of the sounds presented. The information reaching the ear turned toward the source of sound was markedly greater than at the ear turned away from the source of sound, due to interaural time, intensity and spectrum differences at the two ears.

²⁸B. Norlund and B. Fritzell, "The Influence of Azimuth on Speech Signals," Acta Otolaryngology, 56 (1963), pp. 632-642.

Durlach²⁹ claimed that when a subject is presented with a binaural masking stimulus, his ability to detect a target signal will depend on the interaural relations of both stimuli. If the masking signals presented at the two ears are identical, and the target signals at the ears are also identical, the threshold of detectability would be approximately the same as for the monaural listening condition. However, reversing the phase of the target signal in one ear may lower the threshold for the target signal, by as much as 15 dB. Such a difference in threshold, Durlach referred to as the binaural masking level difference (BMLD).

He further claimed that in general, it has been found that in order for a binaural stimulus to be detected at a threshold that is lower than the corresponding monaural threshold; not only must the total stimuli presented to the two ears be different, but signal components must differ from the interaural relations of the masking components.

In a recent study, Levitt and Rabiner³⁰ found that binaural intelligibility level differences (BILD) were substantially smaller than the corresponding binaural masking

²⁹N.I. Durlach, "Equalization and Cancellation Theory of Binaural Masking Level Differences," Journal of Acoustical Society of America, 35 (1963), pp. 1207-1208.

³⁰H. Levitt, and L.R. Rabiner, "Binaural Release from Masking for Speech and Gain in Intelligibility," Journal of Acoustical Society of America, 42 (1967), p. 608.

level differences (BMLD). They explained this relation as follows:

Furthermore, it would appear that the gain in intelligibility is not especially dependent on low frequency interaural phase information, but rather on phase opposition over a much larger portion of the spectrum. A simple, approximate interpretation of the data suggests that interaural phase information in different regions of the spectrum, contribute independently towards improved intelligibility. Although simplified, this interpretation may be useful as a first step towards relating BMLD and BILD data.

Fletcher³¹ described the results of auditory stimuli with interaural phase differences at the two ears:

It appears that the phase difference produced at the two ears is undoubtedly preserved in the composite nerve current going to the brain. The discharges from any particular nerve fiber occur at intervals which are exact multiples of the period of the sound wave. As the intensity of the sound becomes greater, this interval becomes less and approaches the period of the sound wave. The effect of all of the impulses from the individual nerve fibers is to produce a stimulation pattern in the brain which has a periodicity of the sound wave. The maximum stimulation at the brain center is definitely related to the maximum pressure in the sound wave in front of the eardrum. The two maxima produced in the brain from the stimulation coming from the two ears will occur at approximately the same time, if the phase of the sound vibration at the two ears is the same. However, when this phase is different, there will be a corresponding time interval between the occurrence of the two maxima produced in the brain.

³¹H. Fletcher, Speech and Hearing in Communication. (New York: D. Van Nostrand Company, Inc., 1961), p. 212.

Recently, Feldmann³² reported on his findings of speech intelligibility being improved significantly when speech with noise was presented to the same ear at a signal-to-noise ratio which was critical for the understanding of speech and the opposite ear was presented only with the noise stimulus. He found that when the second ear received speech in addition to the noise, the threshold intelligibility for speech went back to a level approximating the monaural threshold. He observed this binaural phenomenon only when the auditory stimuli presented to one ear was duplicated at the other ear.

Zwislocki and Feldman³³ studied the just noticeable differences in dichotic phase of pure-tone pulses, as a function of frequency and of sensation level, on subjects with normal hearing. The results of their study indicated that the sensitivity to dichotic phase differences was highest at medium sensation levels, and that the just noticeable difference (jnd) increased with positive acceleration as the sound frequency increased. Around 1300 Hz the just

³²H. Feldmann, "Experiments on Binaural Hearing in Noise. The Central Nervous Processing of Acoustic Information," Translations of the Beltone Institute for Hearing Research, 18 (July 1965), p. 39.

³³J. Zwislocki and R.S. Feldman, "Just Noticeable Difference in Dichotic Phase," Journal of Acoustical Society of America, 28 (1956), pp. 860-864.

noticeable difference became so great that it could not be measured. They further found that the dichotic time difference, calculated from the measured jnd for phase had a minimum near 800 Hz.

The results of the study of Zwislocki and Feldman essentially agreed with the results of Klumpp and Eady,³⁴ although Klumpp and Eady changed phase relations by employing time differentials in the signal stimulus between the ears, and Zwislocki and Feldman employed an electronic phase shifting device.

6. Interaural Intensity Differences.

In investigating the role of interaural intensity difference between ears in auditory localization, Mills³⁵ found that interaural intensity differences were effective for the localization of the source of sound for frequencies above 1500 Hz and that interaural time differences were most effective for the frequencies below 1500 Hz.

In his study on binaural hearing, Feldmann³⁶ concluded that the effect of interaural time differences upon signal detection in noise was stronger than that of interaural intensity differences. However, these two effects, he claimed, could not be added to each other, neither would they cancel each other. His data indicated that the interaural time

³⁴Klumpp and Eady, op. cit., pp. 859-860.

³⁵A.W. Mills, "Lateralization of High Frequency Tones," Journal of Acoustical Society of America, 32 (1960), pp. 132-134.

³⁶Feldmann, loc. cit.

differences improved the effective signal-to-noise ratio as much as 20 dB, whereas, the interaural intensity differences increased S/N ratio up to a value of 15 dB.

Guttman³⁷ found that monaural subthreshold stimuli could alter an audible stimulus in the other ear. In his study, clicks were presented with interaural differences of time and intensity, and shifts of the lateralization of the auditory image in the head were observed. The results of these tests suggested that the lateralization mechanism may be more sensitive than the mechanism for auditory detection in the neural pathways. A second major conclusion of Guttman was that the lateralization mechanism may compare binaural stimuli within a memory of about 15 msec., where the range represents the largest interaural time difference having direct localizing effect. With the speech stimulus equally intense in the two ears, fusion appeared to fail at 15-20 msec., delay, although some vague interaction effect persisted up to about 25 msec.

Sayers and Lynn³⁸ wrote on the interaural intensity differences of speech:

³⁷N. Guttman, "A Mapping of Binaural Click Lateralization," Journal of Acoustical Society of America, 34 (1962), p. 91.

³⁸B. McA. Sayers and P.A. Lynn, "Interaural Amplitude Effects in Binaural Hearing," Journal of Acoustical Society of America, 44 (1968), pp. 973-978.

An IAD (interaural amplitude difference) imposed in earphone listening experiments with, say, wide-band transients presented simultaneously at both ears, results in a lateral shift of judged position of the fused sound image towards the louder side. If the same experiment is continued using running speech, or any substantially continuous wide-band signal, the same effect is more obviously accompanied by a noticeable change in the perceived character of the image, a broadening of binaural image is commonly reported.

The authors further suggested that since imposing an IAD with a continuous repetitive wave form seems dominantly to result in a position bias of lateralization trajectories (towards one side), while with transient type signals the time shift of lateralization trajectories seems most important, it might be concluded that separate neural mechanisms are involved for steady state and transient stimuli.

Interaural intensity differences have been explained as effecting localization, by a theory involving time-intensity trading relationships (David et al).³⁹

The physiological results and the fact that the trading is a decreasing function of intensity mean that the neural response to a more intense stimulus is more immediate and travels faster in the nervous system. The binaural lateralization mechanism, located at some point where the outputs

³⁹E.E. David, Jr., N. Guttman and W.A. van Bergeijk, "On the Mechanism of Binaural Fusion," Journal of Acoustical Society of America, 30 (1958), pp. 801-802.

from the two ears converge, is sensitive to time difference only. Under this hypothesis binaural intensity difference at the two ears is converted to time differences according to the time-intensity trading relation.

It has been reported by Moushegian and Jeffress⁴⁰ that differences in the thresholds of subjects can affect the magnitude of the time-intensity trading factor. Subjects differ greatly in the number of microseconds difference of time necessary to offset a one decibel interaural difference of level. The authors further state that the peripheral trading relation cannot explain all the effects of interaural time and intensity differences on the lateralization of tones. They suggested that there was evidence that the central nervous system, too, is affected by the interaural intensity differences as well as by the interaural time differences, and that the effect is different when time and intensity are in opposition than when they are in concert.

7. Fusion.

When dissimilar reproductions of the same speech sample are presented to the two ears, interaural integration can occur. This integration manifests itself in two ways. First, the message is perceived as a fused image rather than as two separate stimulus trains. Fletcher⁴¹ noted this effect

⁴⁰G. Moushegian and L.A. Jeffress, "Role of Interaural Time and Intensity Differences in the Lateralization of Low-Frequency Tones," Journal of Acoustical Society of America, 31 (1959), pp. 1441-1445.

⁴¹H. Fletcher, Speech and Hearing. (New York: Von Nostrand, 1929), pp. 196-197.

when speech was split so that the high frequencies went to one ear and low frequencies to the other. Second, the message is perceived as being heard in the ear in which the stimulus is being presented at a higher sensation level.

Broadbent and Ladefoged⁴² demonstrated that synthetically produced speech will fuse when the first formant is presented to one ear and the second to the other, but it will not do so if the formants are given different fundamental frequencies. Even when both formants are given to the same ear, the latter condition fails to fuse.

Cherry and Sayers⁴³ wrote concerning the fusion effect in binaural hearing:

The two ears of a human subject are regarded as his input terminals and the degree to which the aural mental images cohere into a unit field may be interpreted as an integration. This coherence is assessed in a relatively non-subjective way with a technique which uses a randomized time-delay and which constrains the listener to respond only with "yes" or "no" (or right and left--some two valued response). His responses, plotted as a histogram, or probability function, represent in the analogy a kind of psychocorrelation function.

⁴²D.E. Broadbent and P. Ladefoged, "On the Fusion of Sounds Reaching Different Sense Organs," Journal of Acoustical Society of America, 29 (1957), p. 708.

⁴³E.C. Cherry and B. McA. Sayers, "Human Cross Correlator-A Technique for Measuring Certain Parameters of Speech Perception," Journal of Acoustical Society of America, 28 (1956), p. 889.

Their study showed that interaural fusion of a distorted with an undistorted version of the same message was maintained even though the interaural arrival times of the two signals were made to differ over a span of a few milliseconds. The procedure affected the lateralization of the experience, but a fused image was consistently perceived whenever the undistorted version was in the lead. Moreover, fusion usually appeared even when the distorted version was ahead.

The integration of incomplete stimulus patterns also brings about improved intelligibility. This phenomenon is illustrated when dissimilar filterings of the same method are supplied simultaneously. Bocca⁴⁴ for example, described a clinical test wherein a low-level, high fidelity signal went to one ear while a high-level, low-pass reproduction reached the other ear. Normal hearers achieved binaural scores that approximately equaled the sum of their monaural scores for each version separately.

This has been demonstrated recently by Huizing and Taselaar⁴⁵ using monosyllables that were filtered into a one octave wide high-frequency band and a one octave wide low-frequency band. The two bands were then presented simultaneously to a single ear as well as each to a separate ear.

⁴⁴E. Bocca, Binaural Hearing: Another Approach, Laryngoscope, 65 (1955), pp. 1164-1171.

⁴⁵H.C. Huizing and M. Taselaar, "Experiments on Binaural Hearing," Acta Oto-Laryngologica, 53 (1961), p. 15.

The level of the low-frequency band was kept constant while that of the high-frequency band was varied. Integration was much better binaurally as evidenced by the fact that a given discrimination score could be achieved with a weaker presentation of the high-frequency band to the second ear than was required during listening to both bands with one ear. This study demonstrated the principle that under certain circumstances distorted signals are integrated more effectively binaurally than monaurally.

There are two extreme conditions; complete fusion, when the acoustic stimuli to both ears are identical, and complete lack of fusion when stimuli to both ears are identical, and complete lack of fusion when stimuli at each ear are statistically independent. Sayers and Cherry⁴⁶ have attempted to explain the mechanism of binaural fusion with a mathematical model based on statistical probability processes operating on simple characteristics of the aural signals.

Binaural listening enables the person to make better use of the physiological and psychological mechanism of audition available to him. Broadbent⁴⁷ drew three conclusions from his experiments on multi-channel listening which are pertinent:

⁴⁶B. McA. Sayers and E.C. Cherry, "Mechanism of Binaural Fusion in the Hearing of Speech," Journal of Acoustical Society of America, 29 (1957), p. 973.

⁴⁷D.E. Broadbent, "Growing Points in Multi-Channel Communication," Journal of Acoustical Society of America, 28 (1956), p. 533.

(1) the listener has a limited capacity for handling information; (2) much of the information presented to him is therefore discarded; and (3) the discarding process is facilitated when the sound to be disregarded share physical characteristics with one another which the desired signals do not have.

8. Interaural Spectral Pattern Differences.

Sivian and White⁴⁸ demonstrated that the relative strength of a pure tone stimulus at a listener's two ears changes with the azimuth of the source, of such stimulus.

The magnitude of the diffraction and shadowing effect of the head on the sound wave varies with frequency, (Wiener and Ross).⁴⁹ Therefore, whenever there is a change in either the location of the source or the spectral composition of the sound, the acoustic patterns at the two ears are modified. The shift will not be the same at the two ears, and two sounds will not undergo parallel frequency distortion because of head diffraction influence, unless the sounds are initiated from the same location. The result, when several sources give rise to a sound field, will be a distinctive interaural spectral balance for each sound at each ear. Such dissimilarities in balance furnish additional auditory cues

⁴⁸L.J. Sivian and S.D. White, "On Minimum Audible Sound Field," Journal of Acoustical Society of America, 4 (1933), p. 288.

⁴⁹F.M. Wiener and D.A. Ross, "The Pressure Distribution in the Auditory Canal in a Progressive Sound Field," Journal of Acoustical Society of America, 18 (1946), p. 401.

that can be used to increase efficiency of binaural perception of speech.

9. Spatial Separation of Competing Sounds.

Investigators have long felt that the improved intelligibility provided by two ears is related to the binaural system's ability to separate sounds spatially. Cherry and Bowles⁵⁰ referred to this effect as image-separation in subjective space. These authors stated that:

Such image separation is greatly enhanced by our possession of two ears. It is well known, for example, that two simultaneous voices are more readily distinguished, binaurally, if they are spatially separated, and there is little doubt that a person of normal hearing derives his impression of subjective space, to a major degree, from this image separation enhancement. Subjective space is nothing but the disposition of images in it.

Broadbent⁵¹ emphasized that binaural reception does not increase the channel capacity of the listener greatly, if at all. One may gain the false impression that channel capacity has been increased if the result of changing the balance of stimulation in the two ears is a lessening of the central interference between competing sentences. Performance, he feels, improves in such a circumstance as long

⁵⁰C. Cherry and J. Bowles, "Contributions to a Study of the Cocktail Party Problem," Journal of Acoustical Society of America, 32 (1960), p. 884.

⁵¹Broadbent, loc. cit.

as the amount of usable information has thus been increased and provided the listener's channel capacity is not yet taxed to its maximum.

10. Binaural Separation of Dissimilar Messages.

If the listener's task is to decipher one from among two or more messages, their separation can be facilitated when they possess dissimilar acoustic characteristics. Spieth and Webster⁵² were able to improve listeners' ability to respond to one of two or more simultaneous or overlapping voice messages by differentially filtering the competing message channels.

Competing voice messages are most readily disentangled when the primary message goes to the one ear and the competing message to the other, and there is no peripheral overlapping of stimulation, (Egan et al).⁵³

However, there is an upper limit to the amount of auditory information that a listener can assimilate, to the point where he achieves correct understanding and meaningful response. Cherry⁵⁴ observed that a normal hearer can follow

⁵²W. Spieth and J.C. Webster, "Listening to Differentially Filtered Competing Voice Messages," Journal of Acoustical Society of America, 27 (1955), p. 871.

⁵³J.P. Egan, E.C. Carterette and E.J. Thwing, "Some Factors Affecting Multi-channel Listening," Journal of Acoustical Society of America, 26 (1954), p. 782.

⁵⁴E.C. Cherry, "Some Experiments on the Recognition of Speech With One and With Two Ears," Journal of Acoustical Society of America, 25 (1953), p. 979.

only one of two incoming kinds of speech when they enter opposite ears.

Cherry and Taylor⁵⁵ wrote concerning the ability of an individual to attend to two different speech stimuli presented simultaneously:

One of the most striking facts about our ears is that we have two of them--and yet we hear only one acoustic world; only one voice per speaker.

Roughly speaking, our ears appear to be independent under certain conditions, but not under others, and these conditions may readily be controlled experimentally; in all cases, the final act of recognition can only be performed upon one message at a time.

The authors further stress the fact that in everyday binaural hearing the greatest delay we can experience between our ears corresponds to occasions when the source is to our extreme right or left. In such cases the delay is no greater than one-half to one millisecond.

However, we have learned to correlate the stimuli at the two ears when the delay is as great as 15 msec. If the delay is increased beyond 15 msec. the listener would hear not one person speaking but two.

⁵⁵E.C. Cherry and W.K. Taylor, "Some Further Experiments Upon the Recognition of Speech," Journal of Acoustical Society of America, 26 (1954), p. 559.

As a part of their experiment, Cherry and Taylor presented two unlike samples of continuous speech simultaneously, one to each ear. The listener had no difficulty following whichever train of talk he chose to follow, but he was very largely oblivious to the second train while he did so. Even such gross aspects of the second message, such as whether or not it was a foreign language, usually went unnoticed. One could not ask for a neater demonstration that there exists two central auditory channels which can function independently of one another.

In this regard, Sayers and Cherry⁵⁶ stressed a useful concept when they pointed out that the nervous system forms two types of ongoing correlations upon the incoming information. These are the functions of auto-correlation and cross-correlation. Auto-correlation is the comparison over successive time intervals of the details of the neural signal from a single ear. Whereas, cross-correlation is a subsequent collation of the two incoming signal trains with one another. Of course, it is the cross-correlation process that gives rise to the binaurally fused experience. However, the authors maintained, that such fusion will occur only when the two auditory trains maintain a reasonable degree of commonality. It is reasonable to postulate three different foci for aural perception, one for each ear and the third serving binaural perception of fused sound images.

⁵⁶Sayers and Cherry, op. cit., p. 987.

11. Binaural Facilitation in Noise.

The concept of binaural facilitation in noise has been explained by Carhart⁵⁷ as follows:

Hirsh and others have referred to such improvement as summation, but it seems better here to refer to the improvement in discrimination at a fixed signal-to-noise ratio as facilitation, and to speak of the simple shift of sensation level that occurs when noise is absent as summation.

The binaural masked threshold for speech is poorest when the interaural phase angles of the speech and the noise are the same, that is, in homophasic conditions when both stimuli are either in phase at the two ears or out of phase at the two ears. In this case, the two sounds are perceived as coming from identical locations. Conversely, the threshold is improved when the phase angles of the two stimuli are dissimilar, in which event they are perceived as having separate points of origin. The extreme is anti-phasic listening, with one stimulus in phase at the two ears while the other stimulus is out of phase.

All binaural conditions give thresholds for acoustic stimuli as low or lower than the monaural condition.

Blodgett, et al.⁵⁸ found the homophasic condition appeared

⁵⁷R. Carhart, "Binaural Reception of Meaningful Material," In A.B. Graham (Ed.), Sensori-neural Hearing Processes and Disorders. (Boston, Mass.: Little, Brown and Company, 1967), p. 159.

⁵⁸H.C. Blodgett, L.A. Jeffress and R.W. Taylor, "Relation of Masked Threshold to Signal Duration for Various Interaural Phase Combinations," American Journal of Psychology, 71 (1958), p. 290.

to be identical in threshold value with the monaural condition. They reasoned that the mechanism responsible for masking level differences (MLD's), under a variety of interaural conditions was somewhat less adversely affected by signals of short duration than was that mechanism responsible for monaural detection of acoustic stimuli.

Pierce and David, Jr.,⁵⁹ reported that the detectability of speech in noise is about 10 dB greater when the two sources are at right angles rather than being near each other.

It is well known that when a subject is presented with a binaural-masking stimulus, his ability to detect the target signal will depend on the interaural relations of both the target signal and the masking signal. For example, if the masking signals presented to the two ears are identical and the target signals are also identical, the detection threshold will be approximately the same as for one ear alone. Reversing the phase of the target signal in one ear, however may lower the threshold by as much as 15 dB. Such a difference in thresholds is referred to as a binaural-masking-level difference (BMLD).

A brain mechanism which could account for binaural localization and masking was examined by Kock⁶⁰ who commented as follows:

⁵⁹J.R. Pierce and E.E. David, Jr., Man's World of Sound. (New York: Doubleday and Company, Inc., 1958), p. 204.

⁶⁰W.E. Kock, "Binaural Localization and Masking," Journal of Acoustical Society of America, 22 (1950), pp. 801-802.

If the brain could introduce, at will, a time delay in either of the nerve paths connecting each ear to the brain, the directional pattern of the two ears as a combination could be steered so that the maximum response could be aimed in a given direction. Aiming the directional pattern could favor sounds coming from a given direction over those coming from other directions. This direction finder effect could be made considerably more sensitive if the brain were able furthermore to subtract the signals in the two ears. For no phase delay in either channel this would produce a directional pattern consisting of a null or minimum straight ahead and by varying the amounts of time delay, this null could be pointed in different directions.

The equalization-and-cancellation (EC) model, suggested originally by Kock, was introduced in quantitative terms by Durlach.⁶¹ According to the EC model, when the subject is presented with a binaural-masking stimulus, the auditory system attempts to eliminate the masking components by transforming the total signal in one ear relative to the total signal in the other ear until the masking components are exactly the same in both ears, and then subtracting the total signal in one ear from the total signal in the other ear. Durlach suggests that if this operation is performed with complete precision, the masking signal will be completely eliminated. What happens to the target signal as a result of

⁶¹N.I. Durlach, "Equalization and Cancellation Theory of Binaural Masking Level Differences," Journal of Acoustical Society of America, 35 (1963), pp. 1207-1208.

this operation will depend on how the interaural relations for the target signal compare with the interaural relations for the masking signal.

Relative differences between homophasic and antiphasic conditions were studied by Pollack and Pickett⁶² at high noise levels. They found agreement with the study of Licklider⁶³ that the relative difference between the homophasic and antiphasic conditions tended to increase as the intelligibility level decreased. Their study showed consistent interaural phase effects on speech intelligibility at high noise levels which suggested to them that there was no gross phase distortions at such levels.

In a recent study, Gerber⁶⁴ found there were no significant differences among the intelligibility scores for the various phase conditions with or without noise, even though the subjective differences were quite apparent. The author did, however, find that the intelligibility scores for conditions of no noise were all better than intelligibility scores for conditions with noise, and this was true for all phasic relations. It is possible that

⁶²I. Pollack and J.M. Pickett, "Interaural Effect Upon Speech Intelligibility at High Noise Level," Journal of Acoustical Society of America, 30 (1958), p. 295.

⁶³Licklider, loc. cit.

⁶⁴S.E. Gerber, "Phase and Speech Discrimination in Noise: An Expectation and First Look," International Audiology, 6 (1967), p. 400.

Gerber failed to find differences in intelligibility scores for the various interaural phase conditions because he failed to use sufficient masking under such conditions.

12. Binaural Selectivity.

The ability to listen to one signal, usually speech, while disregarding a competing signal, usually noise, is increased through binaural hearing (Broadbent),⁶⁵ and (Bergman).⁶⁶ Foreground and background relationships can be more effectively crystallized when three dimensionality is preserved in the auditory environment through the use of the binaural mode of listening (Carhart).⁶⁷

13. Perception of Quality of Sound.

Pollack and Pickett⁶⁸ in testing normal listeners under stereophonic conditions reported that their subjects consistently claimed a better quality of sound for the stereophonic listening condition over the monaural. Furthermore, the authors found large gains in word intelligibility of speech presented above a background of speech babble under the stereophonic mode of listening as compared with the monaural mode.

⁶⁵D.E. Broadbent, Perception and Communication. (New York, Oxford, London: Pergamon Press, 1964), p. 34.

⁶⁶M. Bergman, "Binaural Hearing," Archives of Otolaryngology, 66 (1957), p. 573.

⁶⁷R. Carhart, "The Usefulness of the Binaural Hearing Aid," Journal of Speech and Hearing Disorders, 23 (1958), p. 46.

⁶⁸I. Pollack and J.M. Pickett, "Stereophonic Listening and Speech Intelligibility Against Voice Babble," Journal of Acoustical Society of America, 30 (1958), p. 133.

14. Ease of Listening to Speech Binaurally.

Bergman⁶⁹ and Hedgecock and Sheets⁷⁰ listed the additional advantage of binaural hearing as being the functional ease of listening to speech and the improved fidelity of the sound. It is probable that the ease of listening to speech binaurally is related to the superior ability to minimize the effects of room reverberations on speech intelligibility and the release of masking in the binaural hearing condition.

15. Squelching of Room Reverberations Binaurally.

The squelching of room reverberations was first mentioned by Koenig.⁷¹ On the basis of observations that he made with an artificial head, two microphones and two earphones, he found squelching to be an important aspect of binaural hearing. Since then there have been many studies on the effects of reverberation of sound in various acoustic environments. However, very little has been written on binaural versus monaural speech intelligibility in

⁶⁹Bergman, op. cit., p. 575.

⁷⁰L.D. Hedgecock and B.V. Sheets, "A Comparison of Monaural and Binaural Hearing Aids for Listening to Speech," Archives of Otolaryngology, 68 (1958), p. 624.

⁷¹W. Koenig, "Subjective Effects in Binaural Hearing," Journal of Acoustical Society of America, 22 (1950), pp. 61-62.

reverberation. The first quantitative study reporting the advantage of binaural over monaural speech intelligibility in reverberation was done by Moncur and Dirks,⁷² who wrote:

Probably the most important finding in the present study was that binaural hearing was superior to monaural near-end hearing in all situations, excepting only the anechoic-quiet condition where scores were at an optimum.

Their finding that intelligibility increased binaurally compared to monaural listening in a reverberant room supports the conclusion that binaural hearing minimizes room reverberation effects on speech perception. It was further stated by Bergman⁷³ in his study on a blind-deaf population, that binaural hearing definitely aided geriatric clients in that the precedence effect favors speech while suppressing reverberant noises in the room. He found that older blind-deaf individuals had much better intelligibility for speech when using binaural hearing aids under reverberant conditions, than when employing a monaural commercial hearing aid. He cited the example of the blind-deaf attending chapel, and being able to discriminate the

⁷²J.P. Moncur and D. Dirks, "Binaural and Monaural Speech Intelligibility in Reverberation," Journal of Speech and Hearing Research, 10 (1967), p. 192.

⁷³M. Bergman, "Auditory Rehabilitation for Hearing Impaired Blind Persons," In Speech and Hearing Association Monograph No. 12. (Washington, D.C., 1965), p. 24.

voice of the minister much more effectively with binaural amplification than with monaural.

16. Binaural Speech Discrimination Compared to Monaural for Normal Hearing Listeners.

There have been several studies comparing the advantages in speech discrimination of the dichotic mode of listening to the monaural mode of normal hearing people. Chappell et al⁷⁴ attempted to determine if normal hearing subjects discriminate a speech signal better binaurally than monaurally, in a difficult but naturalistic listening situation. Monaural and binaural intelligibility scores were obtained for 18 subjects with normal hearing, who listened to a recording in which monosyllabic words competed with simultaneous conversations. The results of the study showed that the intelligibility score for the binaural condition was approximately 20% higher than the average score for the monaural condition. The authors concluded that image separation provided by binaural listening was a major factor in enhanced intelligibility when compared to monaural listening.

Heffler and Schultz⁷⁵ made use of antiphasic listening

⁷⁴R.G. Chappell, J.F. Kavanagh and S. Zerlin, "Monaural Versus Binaural Discrimination for Normal Listeners," Journal of Speech and Hearing Research, 6 (1963), pp. 263-269.

⁷⁵A.J. Heffler and M.C. Schultz, "Some Implications of Binaural Signal Selection for Hearing Aid Evaluation," Journal of Speech and Hearing Research, 7 (1964), pp. 279-289.

conditions to assess the contribution of the second ear to intelligibility of masked speech. Their subjects were 36 adults with normal hearing. The results of their study indicated that the normal binaural auditory system is able to extract more information from a given stimulus complex if it is presented with antiphase rather than homophase listening conditions. Since the only difference was that the stimulus pattern at one ear changed relative to that of the other, the increased intelligibility must have been due to the change in the binaural pattern. Thus, the authors claimed that it is possible to measure the contribution of the second ear independent of localization, using homophase listening conditions as a control. In order to observe this contribution, however, signal-to-noise ratios must be comparatively poor, so that neither the monaural nor homophase system obtains the score of which it is capable under favorable listening conditions.

A study by Carhart⁷⁶ using normal hearing listeners as subjects and competing sentences as the effective masking stimulus, concluded that the effective signal-to-noise ratio in binaural hearing was only about 3 dB more favorable than the optimal monaural signal-to-noise ratio.

⁷⁶R. Carhart, "Monaural and Binaural Discrimination Against Competing Sentences," International Audiology, 4 (1965), p. 9.

It has been demonstrated by Harris⁷⁷ in a quantitative study of improvement in intelligibility of dichotic over monotic modes of listening, that increased perception for speech was of the order of 25-33 per cent (about plus 4 to plus 5 dB S/N ratio).

One must realize however, that interaural facilitation operates without interaction from other variables only during experimentally controlled listening by earphones. Carhart⁷⁸ has written:

True studies performed in sound fields have demonstrated that separation of two competing sources enhances the intelligibility of the primary message when conditions are properly controlled. Here, however, interaural differences in intensity and in acoustic spectra occur concurrently with interaural differences in time. All three factors are now undoubtedly important, and temporal clues may at times be overshadowed. It is well, for example, to remember that when speech comes from one side and competing sound from the other, head-shadow can cause the signal-to-noise ratios at the two ears to differ by as much as 12 to 13 dB.

B. Literature on Utilization of Binaural Hearing Aids.

1. First Design of Binaural Hearing Aids.

A search of the literature revealed that the basic principle of incorporating two separate amplifiers and power

⁷⁷Harris, op. cit., p. 444.

⁷⁸R. Carhart, "Binaural Reception of Meaningful Material," International Symposium, Henry Ford Hospital, In A.B. Graham (Ed.), Sensori-Neural Hearing Processes and Disorders. (Boston, Mass.: Little, Brown and Company, 1967), Chapter 13, p. 160.

supplies in one hearing aid case was designed by Soret⁷⁹ who applied for a patent on this first binaural hearing aid. Hirsh⁸⁰ constructed an experimental model of a stereophonic hearing aid at the Psycho-Acoustic Laboratory at Harvard University. He stated that the principles of binaural hearing aids should prove advantageous to the hard of hearing. He felt that the benefits to be derived from binaural amplification should at least be brought to the attention of the clinical audiologist. He explained that when binaural hearing aids were provided, they should consist of two independent amplifiers and two power supplies that would result in differences in time, phase and amplitude of the stimulus at each ear. The microphones of the binaural hearing aids, where possible, should be mounted on or near the ears for the best localization effects. He further suggested that a study be initiated applying the principles of binaural hearing aids to a large population of hard-of-hearing listeners.

⁷⁹C. Soret, Audiophone. (U.S. Patent Office, Patent No. 1, 154069, September 21, 1915).

⁸⁰I.J. Hirsh, "Binaural Hearing Aids: A Review of Some Experiments," Journal of Speech and Hearing Disorders, 15 (1950), p. 122.

2. Effects of Binaural Hearing Aids.

Hirsh⁸¹ wrote that:

Hearing aids do not overcome or change the anatomical basis of a hearing loss but rather compensate for the hearing loss simply by supplying more sound.

A hearing aid is designed to convert sound waves of low intensity into sounds of greater amplitude. However, it does not necessarily follow that an increase in the intensity of speech will make it more intelligible to the listener.

Suggestions have come from audiologists, as well as from users of hearing aids that hearing aids might be more effective if both ears of the listener were used. Hirsh stated that binaural hearing aids had been devised and used but the case for their success or failure was confused by both positive and negative reports from both users of binaural hearing aids and researchers as to their effectiveness.

3. Localization Effects of Binaural Hearing Aids.

If localization is to be provided by a hearing aid, it must use the listener's two ears; thus changes in the total auditory stimulus will be produced as the head is moved in space. The usual conventional monaural hearing aid, with the listener's ear on his chest (the usual position of the microphone of a conventional body aid), does not permit

⁸¹Hirsh, op. cit., p. 114.

him to hear separately acoustic sources that may be separated in space. If localization is indeed to some degree responsible for changes in the threshold of intelligibility, as the sources of speech and noise are moved in space, the listener should be provided with an apparatus that will permit him to localize the source of sound.

However, Carhart⁸² wrote concerning binaural hearing:

When one evaluates aspects of binaural interaction, it must be remembered that localization and understanding of speech are two functions that are largely independent of one another. Dichotic stimulation is required to structure auditory space fully while intelligibility is achievable through a single ear.

He further claimed that binaural contribution to the comprehension of meaningful material occurs, but the advantages that do result are superimposed upon the general level of efficiency that monaural reception of the stimulus is offering at the particular moment.

4. Pseudo-Binaural Hearing Aids (Y-Cord Mode).

The usual kind of pseudo-binaural hearing aid that uses one microphone, one amplifier, and two earphones is no better than a monaural system for localization of sound. The listener is merely duplicating the sound stimulus he is receiving with one ear.

That the true virtue of binaural hearing can be expected to operate only when the differences of phase,

⁸²Carhart, R., op. cit., p. 153.

amplitude, and/or timing exist in the two earphones was demonstrated in a study by Black and Hast.⁸³ They asked a talker to speak into two microphones placed as a six-inch sided equilateral triangle with the mouth. Each microphone was led to a separate recording channel, in phase in both channels, mixed with noise, and fed through one or two earphones to American listeners with normal ears or with mild hearing loss, at various signal-to-noise S/N ratios. In this study, using the second ear had no increased effect on speech intelligibility since the signal as well as the noise were practically identical in the two earphones. This investigation established the principle that mere duplication of information at each ear does not enhance perception. It seems perfectly reasonable, Mouzon⁸⁴ argued, to suspect that if two separate microphones can provide a single ear with two sounds from the same source which differ in quality, it may be possible for the individual to locate the direction of the source in terms of its quality.

In order to make a qualitative test of such an idea, Mouzon had two microphones connected, one to a low-pass amplifier and the other to a high-pass amplifier. The out-

⁸³J.W. Black and M.H. Hast, "Speech Reception with a Hearing Signal," Journal of Speech and Hearing Research, 5 (1962), pp. 70-75.

⁸⁴J.C. Mouzon, "Stereophonic Hearing with One Earphone," Journal of Acoustical Society of America, 27 (1955), p. 381.

puts from the two amplifiers were then mixed and fed into a single earphone. A qualitative test of this arrangement seemed to provide conclusive evidence that the direction of a person could be determined roughly by the quality of his voice as heard through a single earphone. The author of this article, however, failed to mention how localization of sound was determined, and whether or not standing waves in the room did not in part account for the ability of the person using one earphone to be able to distinguish, to some degree, the direction of the source of sound.

5. Auditory Perception with Binaural Hearing Aids.

Auditory perception is the way in which the human being organizes, structures, and uses the sound in his environment. Myklebust stated that another significant factor audiologically is the relationship of auditory perception to the use of hearing aids. He claimed that one of the most difficult aspects of the use of a hearing aid is the manner in which it affects the individual's ability to structure the world of sound. Myklebust stated that the use of a hearing aid apparently altered the normal auditory perceptual processes in a critical manner. He further stated that the typical hearing aid made it possible for the user to function only in a foreground manner. This could be considered as a basic cause of the hearing aid user's inability to understand speech in a noise environment, or

when in a group conversational situation. Myklebust⁸⁵ therefore, encouraged the use of binaural hearing aids by writing as follows:

Through a hearing aid the fundamental process of separating the world of sound into foreground, background, important and unimportant is grossly disturbed. The ways in which hearing aids affect auditory perception is urgently in need of scientific study. Perhaps the new hearing aid equipment using two microphones which makes depth, perception (foreground-background) possible will bring untold benefits to the hearing impaired during the next few years.

Carhart⁸⁶ claimed that binaural hearing factors were not as essential to the understanding of speech as they were to three-dimensionalized sound perception. He suggested that the interpretation of speech is relatively independent of whether or not the listener achieves precise localization of its point of origin. In the ordinary listening situation the two functions (localization and speech perception) occur concurrently and therefore have been judged by many to be manifestations of a single process.

Licklider⁸⁷ stated in regard to this question of the effects of localization on perception:

⁸⁵H.R. Myklebust, "Changing Concepts in Audiology," Laryngoscope, 66 (1956), p. 439.

⁸⁶Carhart, op. cit., p. 154.

⁸⁷Licklider, op. cit., p. 158.

That the degree to which a speech stimulus and a noise stimulus involve the same form of interaural interaction is what controls the masking of speech by noise. However, the subjective separation of the speech source from the noise source is not the prime determinant.

Thus Licklider concluded that localization in phenomenal space is related to interaural phase in one way, while central masking is related to it in another way.

6. Advantages of Binaural Hearing Aids.

Although there has been much reported in the literature on the psychoacoustics of binaural hearing and the advantages of binaural hearing aids, the majority of investigators were concerned with either summation binaurally at threshold (absolute threshold) or the summation of loudness at supra-threshold levels.

Many additional advantages of two-eared hearing over the monaural listening condition were claimed by Bergman.⁸⁸

He wrote:

More recently in the field of hearing impairment there has been a rapidly expanding interest in the functional differences between monaural and binaural hearing and in the relative advantages of the latter. The revival of clinical and experimental activities in the area has been stimulated in part by the recent development of new surgical techniques for the relief of deafness and by the practical miniaturization of the modern hearing aid.

⁸⁸Bergman, op. cit., p. 572.

Bergman then listed the following advantages of the dichotic mode of listening:

(a) localization; (b) selectivity (the ability to listen to speech while disregarding the noise); (c) better discrimination both in quiet and in noise; (d) the ability to recognize and identify common sounds; (e) ease of listening; and (f) better quality of sound.

The study by Bergman concluded that the ability to localize the source of sounds occurs in people with ears which are markedly different in sensitivity from each other, provided the sound is above the audibility threshold of the poorer ear. Selectivity, the process of listening to one signal, usually speech, while disregarding a competing signal, usually noise, was facilitated by the binaural mechanism.

C. Literature on Comparison of Speech Discrimination Between Binaural and Monaural Modes of Listening Using Commercial Hearing Aids.

1. Study by Markle and Aber.

A definite advantage of binaural hearing aids was found by Markle and Aber⁸⁹ in a study they conducted with ten subjects with conductive (clinical otosclerosis) hearing losses. The noise stimulus was fed through one loudspeaker and the signal through another loudspeaker,

⁸⁹D.M. Markle and W.A. Aber, "Clinical Evaluation of Monaural and Binaural Hearing Aids," Archives of Otolaryngology, 67 (1958), pp. 606-608.

placed four feet away and at a 45° angle to the right and 45° angle to the left of the center of the subject's head. The authors reported significantly better discrimination scores were obtained with binaural hearing aids, when the test words, PB-50, were presented at the same intensity as the noise, and at a level of 10 dB below the intensity of the noise. (S/N ratios of 0 and -10).

The authors concluded that there was a definite advantage to binaural hearing aids when the signal and noise were presented to the subject from different directions. The authors of this study used a conventional body aid for the monaural test and two conventional body aids placed at ear level for the binaural test.

Nichols et al⁹⁰ reported that when a hearing aid is worn by a person, its apparent response is different from that measured in the laboratory, owing to the action of the wearer's person as an acoustic baffle behind the instrument.

In their study, Markel and Aber, overlooked the difference in response of a body worn hearing aid as compared to a head worn hearing aid, due to the body baffle effect described above. In addition, head shadow

⁹⁰R.H. Nichols, Jr., R.J. Marquis, W.G. Wiklund and A.S. Filler, "The Influence of Body-baffle Effects on the Performance of Hearing Aids," Journal of Acoustical Society of America, 19 (1947), p. 943.

and head movements would affect speech discrimination when comparing a hearing aid worn on the body and a post-auricular hearing aid. Head movements and sidedness effects were uncontrolled in the design of their study. Their failure to control head shadow effects has rendered their results and conclusions as to the advantages of binaural hearing aids open to attack.

2. Study by Bergman.

In his experiment, Bergman⁹¹ tested five subjects with conductive hearing losses, and his results indicated that the discrimination scores were indeed considerably better when listening with binaural hearing aids than with a monaural aid. But, he felt that this aspect should be more thoroughly investigated with a large number of hard of hearing individuals. In this particular study, Bergman reported on the results of only five subjects who had undergone surgery of the stapes for the improvement of hearing but who still needed hearing aids. Since all of his subjects had conductive hearing losses, and because of the small size of his sample, it was difficult to generalize his binaural versus monaural results to the hard of hearing population.

⁹¹Bergman, op. cit., p. 575.

3. Study by Belzile and Markle.

In an experiment conducted by Belzile and Markle⁹² 15 subjects with bilateral conductive deafness and 15 subjects with bilateral sensori-neural deafness were tested. All subjects had bilateral hearing losses with the three mid-frequency averages of 35 to 65 dB (A.S.A.). Within the structure of this clinical experiment, whereby each subject was tested with a body aid monaurally, and with two body aids placed on each side of the head binaurally, there was definite evidence of the superiority of binaural over monaural hearing aids.

Those subjects with bilateral conductive deafness showed an improvement when the aids were worn in listening conditions representing signal-to-noise ratios between plus 20 and minus 10 dB. Subjects with bilateral sensori-neural deafness provided evidence of the superiority of binaural hearing aids when worn in listening conditions representing signal-to-noise ratios between plus 10 and 0 dB. For both groups, the improvement was most evident at zero signal-to-noise ratio.

This study further showed that for both groups fifty per cent discrimination can be achieved in the presence of

⁹²M. Belzile and D.M. Markle, "A Clinical Comparison of Monaural and Binaural Hearing Aids Worn by Patients with Conductive or Perceptive Deafness," Laryngoscope, 69 (1959), pp. 1317-1323.

10 dB more noise while wearing a binaural hearing aid, than can be achieved while wearing a conventional monaural instrument.

It has been suggested by Hirsh and others that since Belzile and Markle mounted the single hearing aid on the body for the monaural condition, that the apparent binaural advantage that they observed may have derived from the difference between a single aid on the body and binaural hearing aids on the head. Furthermore, the physical array of the sources of sound was not structured to eliminate head shadow effects.

4. Study by Hedgecock and Sheets.

The hypothesis that binaural sound amplification as provided by commercial hearing aids results in better speech comprehension than monaural amplification was tested by Hedgecock and Sheets.⁹³ They reported:

Comparisons between the results of test subjects presenting conductive and perceptive hearing losses and those presenting (only) perceptive losses would be of value; but since only 5 of the 30 subjects in this series presented losses of mixed or conductive types, the significance of the results would have been questionable.

The authors administered Harvard PB word lists and P.A.L. Auditory Test No. 14 spondaic words to the 30

⁹³L.D. Hedgecock and B.V. Sheets, "A Comparison of Monaural and Binaural Hearing Aids for Listening to Speech," Archives of Otolaryngology, 68 (1958), pp. 628-629.

subjects at the Mayo Clinic. Subjects were selected regardless of type of hearing loss and irrespective of severity of hearing loss existing between the two ears.

Twenty-four of the subjects fell into a group having less than 10 dB difference between the thresholds of each ear. These subjects tended to do better with the binaural fittings in terms of speech reception thresholds and speech comprehension tests. Hedgecock and Sheets⁹⁴ further stated:

Differential results were not statistically significant, however, there appears to be a trend favoring binaural over the monaural hearing aid fitting in respect to speech comprehension in quiet surroundings.

This study did not attempt to answer the question of localization and what effect noisy environments impose on relative (binaural versus monaural) test performances.

A result of this study was the observation that nine subjects who had had previous experience in wearing hearing aids did better in discrimination than those without prior experience, suggesting the importance of auditory training for new users of hearing aids.

A further result of this experiment was that those subjects with moderate hearing losses tended to achieve greater benefit from the binaural hearing aids than those with more severe or profound hearing loss.

⁹⁴Ibid., p. 629.

5. Study by Carhart.

Cases who exhibit moderate hearing losses with reasonable bilateral balance often receive benefits from a binaural system which a monaural hearing aid cannot match (Carhart).⁹⁵ He wrote:

These benefits show themselves, (a) through increased ability to cope with noisy situations, (b) through greater effective gain when the reception of faint sounds is critical, and (c) through a marked improvement in the precision of auditory orientation when the environment is complex. The child for whom these benefits can be achieved has both educational progress and social adjustment facilitated.

He reported on the testing of a woman with a sensorineural hearing loss with several hearing aids, both monaurally and binaurally. He found that with the binaural fitting the woman was able to retain added clarity in discrimination and to resist the encroachments of competing background sounds more effectively than with a monaural hearing aid. Carhart suggested that the binaural fitting would prove advantageous in various ways in every day listening situations. Granting that such a suggestion needs validation, it nonetheless stands as an hypothesis which should not be ignored in the clinical management of the patient, until it is demonstrated as untenable. Meanwhile, he felt empirical trial had shown that present-day

⁹⁵R. Carhart, "The Usefulness of the Binaural Hearing Aid," Journal of Speech and Hearing Disorders, 23 (1958), p. 46.

instruments (hearing aids) can, through binaural fittings, bring enough added improvement to many persons with mild and with moderate losses, so that their difficulties in everyday hearing would be greatly alleviated.

6. Study by Wright.

The difference between stereophonic sound and binaural sound was explained by Wright.⁹⁶ He stated that the aim of stereophonic sound is to create for the listener a sound space which is a faithful recreation of an original acoustic event. In binaural sound, the recording microphones are set approximately eight inches apart to reproduce the distance between the ears of the average listener.

Intensity, time, and differences in spectral composition at each ear should provide the additional cues necessary for a more reasonable approximation of the hearing experience of the normal hearing person. In the normal listener both ears are usually functioning equivalently at both threshold and supra-threshold levels.

However, Wright claimed that the hearing sensitivity of each ear may be different in the individual with a hearing involvement, and that the utility and presumed advantages of binaural hearing may not be as effectual for the hard of hearing as for the normal listener.

⁹⁶H.N. Wright, "Binaural Hearing and the Hearing Impaired," Archives of Otolaryngology, 70 (1959), pp. 485-494.

Additional factors which appear to affect threshold determination are the tone-decay phenomenon, the atonal gap, and tinnitus. Wright stated that tinnitus, for example, is frequently masked by the binaural hearing aids making it more desirable for those persons where head noise is a primary complaint.

Wright assumed that effective binaural hearing aid use is dependent upon achieving a balance between the ears. Briefly, Wright questions whether it is possible to achieve a balance between ears of many hearing impaired persons by means of differential amplification. He wrote that there are many differences between impaired ears in the matter of intensity sensitivity, frequency acuity and adaptation. Actually, he claimed it appears increasingly remarkable to him that some people with defective hearing receive any benefit whatsoever from binaural hearing aids. On the other hand, Wright stated that the fact that one ear may differ markedly from the other in some of the factors mentioned does not prevent necessarily, the beneficial use of binaural hearing aids.

7. Study by Wright and Carhart.

A study on subjects who had binaural losses of at least 40 dB was done by Wright and Carhart.⁹⁷ Each subject

⁹⁷ H.N. Wright and H. Carhart, "The Efficiency of Binaural Listening Among the Hearing Impaired," Archives of Otolaryngology, 72 (1960), pp. 789-797.

received the sound through one or two hearing aids mounted on a dummy head. The use of the dummy head eliminated the effects of the subject's head movement, which is one variable associated with everyday listening. The use of a dummy head also avoided feedback problems with the hearing aid when high gain and power output was required, since the distance between the microphone and the receiver was increased.

This experiment demonstrated that the performance with the diotic (Y-cord) system (one amplifying system to both ears), was equivalent to the performance with the monaural hearing aid, and was not better, as previously explained under dichotic modes of listening in this review of the literature.

A comparison of differences between the spondee thresholds during monaural and dichotic (binaural) hearing aid use revealed three effects:

(a) the binaural effect, (b) the noise effect, and (c) the sidedness effect.

The binaural (dichotic) effect showed that binaural thresholds were better than monaural thresholds and that this advantage was enhanced both by the introduction of competing noise and by having the speech source contralateral to the monaural hearing aid.

The noise effect showed that an evaluation procedure should employ some sound competing with the signal and thus a substantial disturbance in the reception of the primary test material should be produced.

The sidedness effect showed that spatial relations between signal and noise stimuli must exist in order for differences between monaural and binaural (dichotic) performance to occur.

The authors concluded that a binaural (dichotic) system will exhibit superiority only in certain listening situations and only for some patients. They claimed a pressing clinical need was the development of standardized testing procedures which will induce these two effects in a manner which is economical of time and definitive in outcome:

(a) the sidedness effect, (a testing arrangement should incorporate spatial relationship such that differences between monaural and binaural hearing can be expected to occur) and (b) the hearing aid evaluation should employ some competing sound.

8. Comments by Victoreen on Binaural Hearing.

In discussing hearing with two ears Victoreen⁹⁸ wrote:

⁹⁸J.A. Victoreen, Hearing Enhancement. (Springfield, Illinois: Charles C. Thomas, 1960), p. 18.

Only a part of the value of stereophonic listening is due to space perception or locating ability. Its greater value lies in the ability of a hearing mechanism to concentrate upon sound pressure cycles coming from a selected location. This is the process which permits an individual with normal hearing to maintain a conversation with one of several individuals in a group where a background of speech noise exists. Indeed, it may often be more important not to hear a particular sound at all than to hear it and not be able to separate it from other confusing sounds, for this leads to frustration.

Victoreen further stated that stereophonic perception and its advantages are difficult to measure because most of the advantages are in ease of listening, and are felt by the individual rather than heard. The effects of binaural hearing become a matter of subjective opinion, like those of stereoscopic vision, and are not easily describable. He feels that maximum stereophonic perception cannot be obtained until each ear has been provided with an instrument which enables it to operate under conditions of optimum audibility.

The author claimed that the startling progress in the reduction in the size of hearing aids, particularly since the advent of the transistor, has stimulated renewed interest in the production of binaural hearing aids. Hearing aid eyeglasses, postauricular and all in the ear hearing aids with complete separate instruments on each

side of the head, which could closely approximate nature's design for two-eared hearing, should be encouraged by clinical audiologists.

9. Study by DiCarlo and Brown.

The question of the comparative value of these binaural amplifiers for individuals with impaired hearing provided the impetus for a detailed study by DiCarlo and Brown.⁹⁹ Their experiment included 20 normal hearing individuals and 60 hard of hearing individuals. The 60 hypacusics were diagnosed as having either conductive, mixed, or sensori-neural hearing losses. PB word lists were presented to each subject at a sensation level of 36 dB above SRT, if this sound intensity was comfortable to the subject, otherwise, the level was adjusted to that of the subject's most comfortable loudness level. The authors found that the discrimination scores were not significantly different for any of the groups for the binaural, pseudo-binaural, or monaural listening conditions when the better monaural score was used as a basis for comparison. They also found that the most comfortable listening level for discrimination testing was a sensation level of 34.5 dB for the conductive group, 31.94 dB for the mixed group, and 28.52 dB for the sensori-neural group, above the speech reception threshold.

⁹⁹L.M. DiCarlo and W.J. Brown, "The Effectiveness of Binaural Hearing for Adults with Hearing Impairments," Journal of Auditory Research, 1 (1960), pp. 35-76.

The study was conducted with head movements of the subject permitted, which may have affected the speech discrimination scores in comparing monaural versus binaural conditions. DiCarlo and Brown suggested that since the testing in their investigation was conducted under novel conditions of binaural listening, without any training, it might be advisable to investigate the effects of auditory training on performance. This study may have failed to elicit any binaural advantage because the stimulus was presented with competitive noise at a low intensity, so that the subject's monaural listening enabled the achievement of high intelligibility scores and the addition of the second ear could not contribute in any significant degree to such a maximal monotic response.

10. Enigma of Jerger and Dirks.

In a letter to the editor of the Journal of the Acoustical Society of America, Jerger and Dirks¹⁰⁰ wrote:

During the past four years we have devised and tested a number of procedures designed to compare binaural and monaural hearing aids with respect to speech intelligibility. On the whole we have been remarkably unsuccessful in demonstrating objectively that the hearing impaired derive any significant gain in speech intelligibility from binaural as opposed to monaural hearing aids.

¹⁰⁰ J. Jerger and D. Dirks, "Binaural Hearing Aids: An Enigma," Journal of Acoustical Society of America, 33 (1961), p. 537.

Jerger and Dirks attempted to replicate the study of Belzile and Markle previously described. Their results failed to confirm the binaural superiority for speech intelligibility evidenced in the Belzile and Markle study, in spite of measures taken to duplicate the procedures, test materials, and hearing aids that were used as closely as possible. Their failure to duplicate the results of Belzile and Markle has been explained as being due to the fact that Belzile and Markle employed a conventional body aid as the monaural test and two conventional hearing aids at ear level for the binaural test, whereas Jerger and Dirks employed a post-auricular hearing aid monaurally and compared the results with the employment of two post-auricular hearing aids for the binaural condition. In any event, by virtue of head mounting of the single aid, the procedure used by Jerger and Dirks in their study provided a more exact test than the procedure employed by Belzile and Markle in a study which compared a hearing aid worn on the body versus two hearing aids placed at ear position. In this study by Jerger and Dirks, the monaural and binaural conditions of the aids were such that they were mounted in the vicinity of the pinna, and it is expressly stated that the head was free to move. When the speech came from the right, what was more natural than for the subject to move the head so that the loudspeaker delivering the speech looked directly into the right ear. In this case, the head was turned to look directly at the noise loudspeaker so that

noise was coming from the 0° azimuth; but in the binaural situation, also, the head would be turned to a favorable position with respect to the speech loudspeaker, and the signal-to-noise ratio in the right ear would be exactly as in the monaural condition. Thus the only difference between monaural versus binaural would be what happens to the left ear. Now, the speech comes to the left ear at an angle of 135° from the line looking into the ear canal, that is, attenuated effectively by the full shadow of the head, while the noise comes to the left ear at an angle of only 0° azimuth, that is, with almost no attenuation. The sound shadow of the whole head upon an ear creates about 10 dB attenuation for speech threshold; thus, if the signal-to-noise ratio at the right ear is plus 5 for the binaural situation, it may be as poor as minus 5 for the left ear. In such a situation, one would not expect the left ear (additional ear) to contribute significantly to the monaural performance of the right ear.

11. Study by Haskins and Hardy.

A series of critical observations and comments on clinical findings of binaural hearing aids were made by Haskins and Hardy.¹⁰¹ They reported that (a) in subjects with complicated neural hearing problems about one-fourth

¹⁰¹H.L. Haskins and W.G. Hardy, "Clinical Studies in Stereophonic Hearing," Laryngoscope, 70 (1960), pp. 1427-1433.

found binaural aids helpful in control situations where signal-to-noise ratio was not troublesome, (b) in subjects with problems of imbalance between the two ears, with mild loss in one and moderate to severe loss in the other, amplification in the poorer ear which established a working balance between the two ears was effective, (c) in those subjects with moderate to severe bilateral neural impairment with fair to good discrimination, all enjoyed binaural hearing after a period of adjustment and auditory training, (d) all subjects showing moderate to severe bilateral mixed type impairments profited sufficiently to choose binaural hearing aids, (e) and those individuals having moderate to severe bilateral conductive losses were satisfied with the binaural effect, even though those willing to try the binaural hearing aids were few, because of the expense and relative effectiveness of the monaural aids.

Haskins and Hardy¹⁰² concluded by stating:

There are important subjective factors involved in the use of binaural hearing aids and that these factors do not readily lend themselves to formal testing and statistical manipulation.

¹⁰²Haskins and Hardy, op. cit., p. 1433.

12. Study by Jerger, Carhart, and Dirks.

A study on 48 subjects with sensori-neural hearing losses was conducted by Jerger, Carhart and Dirks.¹⁰³ The purpose of this study was to seek objective verification of subjective reports that binaural hearing aids improved the user's ability to understand speech in difficult listening situations; specifically in the presence of competing speech or noise, and in noisy environments when the source of speech is not stable. To this end, two quantifiable test procedures were devised. Both tests involved a primary signal from one direction to which the listener must attend in the presence of secondary or competing signals from another direction. In one procedure, the primary signal was a PB-50 word and the secondary signal was a complete sentence. In the second procedure, the primary signal was a complete sentence and the secondary signal was continuous discourse. Both procedures were specifically designed to recreate, as closely as possible within the confines of quantifiable measurement, the kinds of listening situations in which the reputed advantage of the binaural hearing aid ought to be maximal, according to subjective reports available to the authors. The subject was seated in the test chamber at a point

¹⁰³J. Jerger, R. Carhart and D. Dirks, "Binaural Hearing Aids and Speech Intelligibility," Journal of Speech and Hearing Research, 4 (1961), pp. 137-148.

equidistant from two loudspeakers. Each loudspeaker faced the subject in a plane displaced 45° from his median plane. For both tests the primary to secondary ratio at the two loudspeakers was always 0 dB. That is, primary and secondary signals were always of equal intensity.

The authors evaluated the results as indicating binaural amplification produced little or no objectively demonstrable improvement in the ability to understand speech in quiet or in noise, against competing sentences or competing discourse, whether the speech material be isolated words or meaningful sentences. They wrote:¹⁰⁴

In spite of theoretical considerations which would imply significant advantages for a true binaural amplifying system, in spite of some patients' reports that they like binaural aids much better than monaural aids, in spite of subjective clinical observations of dramatic improvement in the performance of some patients with binaural aids, in spite of more than six years of extensive experimentation throughout the country, there remains little concrete evidence that binaural amplification actually produces any significant improvement in the ability to understand speech.

Jerger, Carhart, and Dirks structured the experiment

¹⁰⁴ Jerger, Carhart and Dirks, op. cit., p. 148.

so that the loudspeakers were the same geometrically as in the study of Jerger and Dirks.¹⁰⁵ They found only a small improvement, and this existed only in one of their dichotic listening tasks, that of a single aid being moved from the body to ear level. It would seem that the subjects in their study, somehow, did not take the full advantage of the possibility of partially shadowing out the noise by moving their heads. Apparently, the same failure to eliminate localization or sidedness effects on speech intelligibility was made in this study as existed in the prior study of Jerger and Dirks.

13. Study by Decroix and Dehaussy.

Two cases of bilateral conductive losses were studied by Decroix and Dehaussy.¹⁰⁶ They recommended that the microphone or, if possible, the entire hearing aid be mounted within the pinna to take advantage of the sound shadow by that structure. They concluded that their study demonstrated the advantages which binaural aids confer on conductive hearing losses in the improvement of intelligibility by re-establishing auditory figure-ground or perspective, raising the intelligibility threshold with the least amount of amplification, and improving discrimination of speech in noise.

¹⁰⁵ Jerger and Dirks, loc. cit.

¹⁰⁶ G. Decroix and J. Dehaussy, "Binaural Hearing and Intelligibility," Journal of Auditory Research, 4 (1964), pp. 115-134.

D. Comparison of Speech Discrimination Using Various Monotic and Dichotic Modes of Listening.

1. Study by Harris.

In an attempt to finally resolve the question of the superiority of a dichotic over a monotic system of listening, for speech discrimination, Harris¹⁰⁷ devised an experiment for testing various modes of listening. In the design of his study, he sought to avoid the troublesome question of head shadows and head movements by utilizing the stereophonic effect in producing sound sources for monaural versus binaural comparison.

In his experiment, three 15-inch triaxial loudspeakers were utilized in an echo-free room. They were placed in 45° steps along a circle of 12 ft. radius, all facing two Western Electric 640 AA microphones in the center of the circle. The microphones were separated from each other by 12 inches with no baffle between, so that the inputs to the Ampex 300-2C tape recorder differed only in the temporal cueing.

The midline speaker was fed by a tape playback upon which had been recorded 100 sentences P.A.L. Test #8 and to which the patient could respond by multiple-choice. The left and right loudspeakers were fed by a second and third tape

¹⁰⁷J.D. Harris, "Monaural and Binaural Speech Intelligibility and the Stereophonic Effect Based Upon Temporal Cues," Laryngoscope, (1965), pp. 428-446.

recorder, respectively, from a woman reading from "Gentlemen Prefer Blondes," and a man reading an amusing eulogy to the Model T, "Farewell, my Lovely."

These stimulus tapes were played back in a second echo-free room from two loudspeakers eight feet apart and facing a point 12 feet away. A subject could at that point sit comfortably in a chair and experience the authentic stereophonic illusion. Based on testing 24 normal-hearing subjects in a comparison of loudspeakers versus earphones at equal S/N ratio for binaural listening, Harris was convinced that it was possible to abandon the loudspeaker administration and to lead the two taped channels to earphones.

Nine models of patching channels to earphones were then devised, using isolating networks and attenuators for loudness balancing between ears: four monotic modes (one channel to better ear; one channel to poorer ear; two channels to better ear; and two channels to poorer ear); one diotic mode (one channel to both ears); and four dichotic modes (each channel to a separate ear; one channel to poorer ear and two channels to better ear; one channel to better ear and two channels to poorer ear; and two channels to both ears).

By means of the comparisons among modes on 89 normal and 36 subjects with hearing loss, the following principles were established (Harris):¹⁰⁸

¹⁰⁸Harris, op. cit., pp. 445-446.

a. The Principle of Binaural S/N Gain: on a truly appropriate test, the improvement in intelligibility of dichotic over monotic modes is of the order of 25-33 per cent (about +4 to +5 db S/N ratio).

b. The Principle of Redundancy: a significant gain of 8-30 per cent is achieved by adding a second channel to the monotic ear. Whether that ear is normal or defective.

c. A possible though minor Principle of Blurring: there is a slight indication that adding a second channel from a noncongruent point in space may somewhat blur intelligibility; but this tendency would usually be overcome by the stronger Principle of Redundancy.

d. The Principle of Degradation: the contribution of a defective ear in the Stereo Mode decreases binaural intelligibility as compared with leading two channels to the better ear.

Harris, however, failed to classify his subjects with hearing loss as to type of loss or severity of the disorder. He did not reveal the interaural threshold differences of his subjects, which would contribute information in evaluating the results of dichotic listening. He did however, encourage further investigation of a sensori-neural hearing loss population, using commercial hearing aids, monaurally and binaurally.

2. Observations by Harris and Miller on Binaural Hearing Aids.

Harris and Miller¹⁰⁹ wrote:

¹⁰⁹J.D. Harris and M.H. Miller, "Monaural vs. Binaural, Are Two Hearing Aids Better Than One?" Issues in Current Medical Practices, 3 (1966), p. 5.

Where it becomes important to obtain the maximum information on a first presentation, it is obvious that a monaurally fitted hypacusic is at a disadvantage.

Those to whom this consideration applies includes infants and young children, who often desperately need to obtain every possible bit of information (acoustic) from the environment, and also adults who must work against backgrounds ranging from office to factory noise. For these people, one should seriously consider a binaural fitting, Harris and Miller argued, if only on the basis of the Principle of Acoustic Advantage, obtaining the optimal signal-to-noise ratio at whichever ear is better placed at the moment. A further conclusion of the authors was that binaural hearing aids can have a significantly beneficial effect on intelligibility of speech in a broad noise background, or with competing talkers, and also in localizing the sources of sound.

They believed that binaural fitting should be considered in the case of infants and very young children. When language is being formed, the need is exceptionally critical. No possibility should be overlooked in the attempt to stimulate them with language acoustics at the most favorable voice-to-noise ratio. Such meaningful exposure to sound will contribute to the healthy and productive social development of a hypacusic child.

E. Psychological Studies Involving Binaural Hearing Aid Users.

1. Report by Bender and Wilg.

Parents who were interviewed by Bender and Wilg¹¹⁰ expressed a decided preference for the use of binaural over monaural hearing aids, by their children. These parents claimed that their hard of hearing children had better hearing response when wearing their binaural hearing aids.

2. Study by Kodman.

A survey of binaural hearing aid users was conducted by Kodman.¹¹¹ A sample of 50 successful binaural eye-glass hearing aid users were polled by questionnaire to determine their reactions toward their hearing aids.

The results of the questionnaire suggested that there may be parameters of interaural effect of wearing binaural hearing aids which is reflected in better sound balance and ease of perception. The latter benefit may not be reflected in the speech discrimination score.

The binaural hearing aid users reported a number of subjective advantages which are not measured by any clinical technique in the evaluation of binaural versus monaural hearing aids.

¹¹⁰R. E. Bender and E. Wilg, "Binaural Hearing Aids for Young Children," Volta Review, 62 (1960), pp. 113-115.

¹¹¹F. Kodman, "Successful Binaural Hearing Aid User," Archives of Otolaryngology, 74 (1961), pp. 302-304.

Although there are other factors, the authors contended that the patient's attitude toward his hearing aid, may, in the final analysis, be the most important single criterion influencing the successful use of the aid, either monaurally or binaurally. The author, therefore, summed up by saying:

It appears that with a binaural aid the patient hears 'easier', or with less effort, even though the intelligibility scores are comparable or even identical with the scores using monaural aids.

3. Survey by Dirks and Carhart of Hearing Aid Users.

Dirks and Carhart¹¹² wrote:

Despite the fact that experimental studies have not revealed dimensions of listening wherein binaural hearing aids give users advantages over monaural hearing aids, a strong impression that such advantage exists can be found among clinical audiologists, hearing aid dealers, and hearing aid users.

The question which they raised was whether binaural hearing aids might be superior in some features of listening not explored by previous studies. One step in answering this question was to obtain reports from users of hearing aids on those everyday advantages which they experience with binaural instruments. The authors reasoned further,

¹¹²D. Dirks and R. Carhart, "A Survey of Reactions from Users of Binaural and Monaural Hearing Aids," Journal of Speech and Hearing Disorders, 27 (1962), p. 321.

that if situations having these advantages could be found, it would be possible to develop tests which could recreate such situations, and thus use them in the laboratory and the clinic.

A questionnaire was designed by Dirks and Carhart covering various aspects of efficiency in every day listening and of hearing aid use and was completed by 206 users of binaural instruments, 211 monaural hearing aid users, and 155 non-users with relatively normal hearing. The normal hearing group reported substantially greater success in listening under each of the 26 different environmental conditions than did either group of hearing aid users. For 9 of these 26 listening conditions, some 7 of them in quiet backgrounds, binaural users rated their efficiency somewhat higher than did monaural users. Both groups reported relatively poor performance in conditions with strong background sounds. In general, the circumstances for which binaural listeners tended to report particular advantageous performance was for situations that were not extremely noisy.

The authors suggested that the findings of their questionnaire pointed up, first, the need to investigate further whether binaural hearing aids offer extra efficiency which is limited to situations with low background sounds. Second, the need to determine whether the strong commitments some users have for binaural hearing aids may not arise primarily from an emotional conviction that two aids are better than one.

4. Observations by Whetnall on Binaural Hearing Aids.

Whetnall¹¹³ claimed that the benefits of listening with two ears were without question superior to hearing with only one. In the author's opinion, the only reason for not using two aids on every hard of hearing child, with residual hearing in both ears, was the financial consideration.

She further claimed that the deaf child learned much more rapidly with two aids, was more oral, and more sociable, and that every young child who got the chance to have binaural hearing aids, was happier with the two aids than with one.

5. Observations by Lewis and Green on Binaural Hearing Aids.

The importance of the clinical audiologist fitting the hard of hearing child with two hearing aids (binaural) rather than one was stressed by Lewis and Green.¹¹⁴ The authors gave their subjective observations of the improvement derived by children in elementary schools, where use had been made of binaural hearing aids. They recommended that the binaural fitting be made for hard of hearing children whenever feasible.

¹¹³E. Whetnall, "Binaural Hearing," Journal of Laryngology and Otology, 78 (1964), p. 1089.

¹¹⁴D. Lewis and R. Green, "Value of Binaural Hearing Aids for Hearing Impaired Children in Elementary Schools," Volta Review, 64 (1962), pp. 537-542.

F. Hearing Aids for the Unilateral Hearing Loss.

1. Suggestions by Fowler for Unilateral Hearing Loss.

In writing on monaural total deafness Fowler¹¹⁵

stated:

Of course there will be no normal stereophonic effect from the use of the binaural microphones but the patient will be able to hear sounds coming from any direction. If one microphone has a slightly different quality response than the other, this will give aid in locating the direction from which the sound comes as will also the differing variation in volume which occur on turning the head or changing position in respect to the source of sound.

Two microphones will intensify the sound coming from either the front or the rear of the head. Incidentally, there will also be a slight phase difference in the received sounds, depending on the position of the head in relation to the sound source.

It is questionable whether localization can be achieved by differences in the frequency response of two microphones leading into one amplifying system as Fowler suggested. The studies reported on localization effects have demonstrated that two completely independent amplifiers would be required to identify azimuth and elevation of the source of sound.

¹¹⁵E.P. Fowler, "Bilateral Hearing Aids for Monaural Total Deafness," Archives of Otolaryngology, 72 (1960), p. 41.

Fowler further observed that some people do not derive much, if any, significant benefit from the device, one hearing aid with two microphones, which he described in this article.

2. Suggestions by Wullstein and Wigand as to Unilateral Hearing Loss.

Wullstein and Wigand¹¹⁶ described a hearing aid instrument for the unilaterally deaf, whereby the microphone was inserted in the deafened ear, the receiver outlets directed toward the hearing ear. By this means, there may be improved discrimination due to the use of the hearing aid. It could also be shown, qualitatively, according to the authors, that with amplification through the hearing aid, there was an improvement of auditory localization.

The authors however, failed to mention how the receiver outlet would be channeled to the good ear (usually accomplished by plastic tubing running into an earmold). They also neglected to explain what type of earmold would be used in the good ear, though usually an open mold is recommended when amplified sound from the contralateral side is conducted into a good ear.

¹¹⁶H.L. Wullstein and M.E. Wigand, "Concerning the Application of Hearing Aids for Binaural Hearing in the Unilaterally Deaf," Acta-Otolaryngology, 54 (1962), p. 142.

3. Study by Malles on Unilateral Hearing Loss.

A person hearing with only one ear finds a great deal of difficulty within the realm of social group discussions (Malles).¹¹⁷ He therefore, selected 8 adults who had unilateral conductive or mixed hearing losses. The subjects were fitted with conventional ear level eyeglass hearing aids and then tested for speech discrimination with the CID revision of the phonetically balanced (PB) word lists. Each subject was seated equidistant from two loudspeakers; one loudspeaker delivered the speech stimulus and the other loudspeaker delivered the noise; in the same geometric arrangement as used by Belzile and Markle.¹¹⁸ All the subjects tested by Malles showed an increased ability for speech discrimination in every test condition when wearing the hearing aid, compared to normal listening conditions. The speech discrimination scores achieved under aided conditions showed greater improvement under more difficult listening situations (lower signal-to-noise ratios).

The author made the suggestion that people having unilateral conductive hearing losses of 30 dB or more should be fitted with an ear-level hearing aid whenever possible.

¹¹⁷I. Malles, "Hearing Aid Effect in Unilateral Conductive Deafness," Archives of Otolaryngology, 77 (1963), pp. 405-408.

¹¹⁸Belzile and Markle, loc. cit.

Unfortunately, Malles failed to report as to whether the ear which was fitted with the hearing aid, faced the loudspeaker which delivered the speech stimulus or the loudspeaker for noise. Furthermore, the study does not reveal whether the subjects were permitted to move their heads during the test for speech discrimination. It appears that the sidedness effects due to localization may have contaminated the results of improvements in speech perception.

4. Study by Harford and Musket.

Harford and Musket¹¹⁹ wrote:

It is our purpose to present preliminary evidence which indicated that some patients having unilateral hearing loss with usable residual hearing in the bad ear can derive appreciable benefit from a hearing aid on the impaired ear. Furthermore, this benefit is probably due to binaural hearing which results from the combination of one good ear and the other ear being improved by amplification.

In the past it was the impression of most audiologists that unilaterals could not achieve enough improvement in communication to warrant the use of wearable amplification.

This impression was greatly influenced by an inability clinically to measure improvement under aided conditions. Most clinicians tended to agree with Carson¹²⁰ who stated:

¹¹⁹E. Harford and C.H. Musket, "Binaural Hearing with One hearing Aid," Journal of Speech and Hearing Disorders, 29 (1964), p. 133.

¹²⁰E.T. Carson, "Rehabilitation of the Deafened," In G.M. Coates (Ed.), Otolaryngology. (Hagerstown: W.F. Prior, 1960), p. 10.

A hearing aid is not the answer to this problem (unilateral hearing loss), for bilateral hearing cannot be restored in this way...even if there is enough residual hearing in the deafened ear to use a hearing aid it is impossible to balance a normal hearing ear and an aided ear as done for eyes by glasses. The patient will not tolerate the hearing aid but will resort to using his good ear, adjusting his position as best he can.

Harford and Musket¹²¹ presented audiological case reports on each of eight patients with normal hearing for speech in one ear and with various degrees of a moderate hearing loss in the other ear. Two of the patients had a pure sensori-neural involvement in the impaired ear, while six had primarily a unilateral conductive involvement. All of the patients reported upon in this article were using hearing aids full-time, with the exception of one patient who used his aid on a part-time basis as it was needed. Each of the eight patients was using an ear-level hearing aid.

The results of aided test scores, using PB-50 word lists, at a hearing level of 40 dB was compared to each patient's unaided performance at the same hearing level. The goal was to find out if the patient manifested any measurable improvement for PB material with a hearing aid at a hearing level which represented ordinary conversation loudness. All PB material in the sound field was directed

¹²¹Harford and Musket, loc. cit.

toward the patient's poorer and/or aided ear at approximately a 45° azimuth. Reasonable freedom of head movement was allowed, but the patient was cautioned not to turn his head so that his good ear was facing the speaker.

Naturally, one would expect the sound field measurements for the patients with very good hearing in the unaided ear to be virtually identical for the unaided and aided condition, and this did occur in this experiment.

No other testing was done to provide information about the patient's communication with and without a hearing aid. To date, it appears that sufficient psychoacoustical techniques to measure differences in listening performance between monaural and binaural hearing, which the authors were convinced do exist, have not been developed to the point where they consider them to be clinically valid. Considerable time was devoted simply to talking with each patient and trying to determine how he justified the expense and inconvenience of a hearing aid.

Based on the results of eight clinical cases with unilateral hearing loss the authors were convinced that it is entirely possible and practical for a person with normal or nearly normal hearing for speech in one ear and with usable residual hearing for speech in the other ear, to derive enough benefit from a hearing aid to warrant use of amplification. The authors further stressed that conventional hearing tests cannot be relied upon to prognosticate the satisfaction of hearing-aid use for uni-

laterals. In some, one can make a guarded prognosis, especially where improvement in speech discrimination can be measured under the aided condition at a 40 dB hearing level. There is indeed the possibility that speech discrimination tests in the presence of noise, and tests which simulate the cocktail-party effect, will ultimately assume a valuable role in selecting appropriate amplification for unilaterals. In the meantime, when questioning the value of a hearing aid for persons with a unilateral hearing loss for speech, the authors feel the most valuable and meaningful test is how the patient uses a hearing aid in his daily activities. For this reason they strongly advocate a trial hearing-aid plan, preferably in conjunction with a local hearing aid representative. Of course, the authors pointed out, one could not expect all unilaterals to be successful hearing-aid users any more than one would expect every person with a hearing loss to be a successful hearing aid user.

5. Study by Harford and Barry.

Harford and Barry¹²² believed that many persons with unilateral loss do in fact have a genuine difficulty hearing and that the clinical audiologist has a responsibility to investigate techniques which would help one-eared listeners

¹²²E. Harford and J.A. Barry, "Rehabilitation Approach to the Problem of Unilateral Hearing Impairment, The Contralateral Routing of Signals (CROS)," Journal of Speech and Hearing Disorders, 30 (1965), pp. 121-138.

enjoy more satisfactory communication. In their paper they presented a principle of hearing-aid use which the authors have applied to persons with no aidable hearing in one ear and with normal or nearly normal hearing in the opposite ear. This technique has proven to be very successful in a substantial number of cases.

The authors further claimed that the persistence of reports from unilaterally hearing impaired individuals stating serious difficulty encountered in many common listening situations have convinced audiologists that these complaints are legitimate. Typically, these include (a) increased difficulty hearing in groups and noisy places, (b) much difficulty hearing when persons speak on the side of the impaired ear and (c) confusion in locating the source of sound.

The authors suggested a hearing aid arrangement involving the routing of signals from the vicinity of the impaired ear, across the head to the good ear. They refer to this principle as contralateral routing of signals, or CROS. A polyethylene tube carried the acoustic signal from the hearing aid earphone to an open earpiece inserted into the good ear. The open earpiece is an essential element of the CROS system, since the good ear must be left unoccluded to allow normal reception of sound, yet at the same time a device must be used to hold the polyethylene tube firmly in the ear canal. The polyethylene tubing terminating in an open ear canal undoubtedly alters the

frequency response of any hearing aid utilized, as the open ear canal will tend to filter out low frequency component of sounds.

The results of this study with 20 individuals with no aidable hearing in one ear and with normal or nearly normal hearing in the opposite ear had proven to the authors that this type of hearing aid use was practical for a segment of the unilateral hearing impaired population. A follow-up study, conducted eight months after the major investigation, revealed that 7 of the originally 20 subjects in this study voluntarily procured CROS hearing aids in eyeglasses and found them to be satisfactory in many activities of daily living. Not one person who purchased a CROS hearing aid, found it unsatisfactory.

Harford and Barry relied completely on the subjective evaluation of their 20 subjects, as to whether the CROS hearing aid helped them in their daily activities. No attempt was made on the part of the authors to measure whether speech discrimination was improved by the use of this new type of hearing aid.

6. Study by Schaudinischky.

Schaudinischky¹²³ has written:

¹²³L.H. Schaudinischky, "New Hearing Aid for the Monaurally Deaf Restoring Binaural Hearing," Acta-Otolaryngology, 60 (1965), p. 462.

The monaurally deaf (in the acoustical sense) occupy a peculiar position among their fellow-afflicted. Apparently unimpeded by any external handicap, they manage to conceal their infirmity surprisingly well. The secret often remains hidden for years even from close bystanders, and it is only revealed often by some silly accident. Still, monaural deafness is a severe blow of fate. The afflicted live in an acoustically lopsided world - one side bright and filled with sound, the other dull and constricted - and lack the capability of acoustical orientation and location.

The "audiomon" hearing aid designed by Schaudinischky, represents an attempt to create acoustically normal conditions for the individual with a unilateral hearing loss. This device consisted of a tiny microphone which was attached to a plastic in the shape of an olive, and inserted into the deaf ear. Thus, the microphone was not only positioned in the natural position as an artificial eardrum, but at the same time, utilized the sound collecting and orientating properties of the outer ear (pinna). The microphone was connected to a microamplifier, connected in turn to a bone conductor (hearing aid bone oscillator), and placed against the mastoid process of the subject's head.

Schaudinischky sought, with his amplifying system, to have a two-fold utilization of the healthy ear. While the air-borne sounds are taken up in the normal manner, the signals received near the drum of the defective ear are re-transmitted by the bones of the skull to the healthy ear. Theoretically, this provides conditions similar to that of

binaural hearing, since the second signal satisfies the following requirements:

(a) distance differences and time differences; (b) distortions in the range of the higher harmonics caused by the head; and (c) amplitude differences.

The question still arises, however, whether these two successive stimuli with their slight time delay provide sufficient information for the brain to permit directional interpretation, even though conveyed through a single auditory pathway.

The author of this study undertook a series of tests of localization effects, using the "audiomon" model with 8 subjects.

The directional effect provided by the special amplifying instrument established to the author's satisfaction that localization was definitely aided and this result he considered to be incontrovertible proof of the binaural effect provided by the "audiomon" hearing aid.

Unfortunately, Shaudinischky failed to test whether speech discrimination was improved by the use of his hearing aid. However, he did propose in his paper that future research be initiated as to possible improvement in speech perception with the use of his instrument.

7. Bilateral CROS Hearing Aid by Harford.

Harford¹²⁴ has described a new instrument for the

¹²⁴E. Harford, "Bilateral CROS," Paper presented at ASHA Convention. (Washington D.C.: 1966).

individual with complete loss of hearing on one ear, and a mild to moderate hearing loss on the better ear. He called this new aid, the Bilateral CROS. In this hearing aid, which was primarily designed in the temples of an eyeglass (it could also be assembled in two post auricular hearing aid cases), one microphone would be mounted in the temple on the side of the head whose ear had complete or a profound hearing loss. The microphone of the hearing aid would then be connected through the frame by a wire to a complete hearing aid assembled in the temple on the other side of the head. Essentially, the mechanism suggested would be an eyeglass hearing aid with two microphones, one microphone on each side of the head so that sound would be received at 360° , which the author believed would increase speech discrimination over the unaided condition.

Harford has basically depended on the subjective evaluation of the CROS and the Bilateral CROS by his subjects, and has made few quantitative tests to determine the advantage of these hearing aids for both localization and speech perception.

G. Clinical Binaural Hearing Aid Evaluation

Procedures.

1. Suggestions by Heffler and Schultz for Binaural Hearing Aid Evaluation.

Clinical audiologists are generally agreed that the index of significance in the comparison of monaural with binaural amplification is the improvement in discrimination

score when binaural hearing aids are used. In effect, what is required is a measurement of the increase in intelligibility made by the addition of a second ear, (Heffler and Schultz).¹²⁵

The authors suggested that a procedure for comparing monaural and binaural aided discrimination should include the following characteristics:

(a) the presence of a competing sound, (b) signal-to-noise ratio which permits improvement due to the second ear to be measured, (c) elimination of localization and sidedness factors, (d) and long duration speech signals with partial credit possible.

The authors interpreted the results of their study to indicate that the normal binaural auditory system is able to extract more information from a given stimulus complex, if it is presented with antiphasic rather than homophasic listening conditions. Since the only difference is that the stimulus pattern at one ear changes relative to that of the other, the increase in intelligibility must be due to the change in binaural pattern. Thus it becomes possible to measure the contribution of the second ear independent of localization, and using homophasic listening as a control. In order to observe this contribution, an adverse listening situation must be structured, low signal-to-noise ratio, so that neither the monaural nor the

¹²⁵Heffler and Schultz, op. cit., pp. 285-287.

homophasic system obtains the score of which it is capable under favorable listening conditions. It should be understood that this listening situation is a highly artificial one and does not occur except under the experimental conditions of the laboratory.

Tests for potential gains in intelligibility by this method might find the greatest value as a quickly administered prognostic test at the time of initial contact with the clinical patient. The procedure for the suggested test would be to determine the masked threshold for spondaic words presented homophasically, either in a sound field, or binaurally under earphones. Once the masked threshold has been established, the audiologist could reverse the phase of the speech signal at one of the transducers, and note whether a marked change occurs in intelligibility at the same signal-to-noise ratio. If the subject is then able to respond correctly to a greater number of test words, thus indicating that the phase reversal has improved his masked threshold, the clinician can conclude that amplification to the second ear would contribute to the patient's useful hearing and recommend use of binaural hearing aids.

2. Suggestions by O'Neill and Oyer for Binaural Hearing Aid Evaluation.

O'Neill and Oyer¹²⁶ have suggested the use of three

¹²⁶J.J. O'Neill and H.J. Oyer, Applied Audiometry. (New York: Dodd, Mead & Company, Inc., 1966), pp. 251-252.

loudspeakers in the clinical evaluation of binaural hearing aids. One loudspeaker should be placed in front of the subject and the other two loudspeakers arranged so that one speaker is lateral to each ear. This type of test, the authors believed, allows for sidedness measurements, as well as binaural effects. The loudspeakers on each side of the subject can be used to deliver the signal and noise simultaneously or separately. The test routines would be identical to those that have been suggested for conventional hearing aid evaluation (Watson¹²⁷ Carhart).¹²⁸ The only difference would be that individual detection settings would have to be made for each hearing aid. With the volume control settings established, the testing routine would continue for speech reception tests, discrimination tests, and tests of tolerance. The stimuli would be delivered from the left speaker, then from the right speaker, and finally, from the front speaker. Thus, there would be three measures for each test of speech reception and speech discrimination. Only one measure would be required for tolerance and that would be from the front loudspeaker.

¹²⁷L.A. Watson, "Certain Fundamental Principles in Prescribing and Fitting Hearing Aids," Laryngoscope, 54 (1944), pp. 531-558.

¹²⁸R. Carhart, "Selection of Hearing Aids," Archives of Otolaryngology, 44 (1946), pp. 1-18.

In the instance of speech-to-noise ratios, there would be five measurements: (a) noise and signal from the front speaker; (b) noise and signal from the right speaker; (c) noise and signal from the left speaker; (d) noise from the left speaker, and signal from the right speaker; (e) and noise from the right speaker and signal from the left speaker.

The above procedure would mean that the evaluation routine with binaural hearing aids would be lengthy. However, the authors felt it would be worth an extra visit for the client, as a correct evaluation as to the value of binaural hearing aids would mean much in terms of financial saving and communication efficiency to the subject involved.

3. Suggestions by Groen of Increased Dynamic Range.

Groen¹²⁹ claimed that the dynamic range of hearing was increased with the use of binaural amplification. His results of testing subjects with hearing loss showed that the upper limit of the useful dynamic range was shifted upwards by as much as 11.0 ± 5.0 dB in 12% of the cases. Thresholds of discomfort could be tested monaurally and binaurally by the clinician for additional information in making a decision as to the mode of amplification to be prescribed for the client.

¹²⁹J.J. Groen, "Theory and Practice of Binaural Hearing," Proceedings of the 2nd International Course in Paediatric Audiology, (Groningen University, 1961), pp. 82-89.

H. Summary.

A review of the literature on binaural interactions of acoustic stimuli has revealed that different investigators have reported the superiority of binaural over monaural hearing in such functions as localization (Bergman,¹³⁰ Carhart,¹³¹ Hirsh,¹³² and Wright),¹³³ threshold sensitivity (DiCarlo and Brown,¹³⁴ and Shaw et al),¹³⁵ and loudness summation (Causse and Chavasse,¹³⁶ and Fletcher and Munson).¹³⁷

Discrimination of signal in noise has also appeared to be improved when two ears rather than one ear are utilized (Feldmann,¹³⁸ Kock,¹³⁹ and Pollack and Pickett).¹⁴⁰

¹³⁰Bergman, op. cit., pp. 572-578.

¹³¹Carhart, op. cit., pp. 41-51.

¹³²Hirsh, op. cit., pp. 196-200.

¹³³Wright, op. cit., pp. 485-494.

¹³⁴DiCarlo and Brown, op. cit., pp. 35-76.

¹³⁵Shaw, et al, op. cit., pp. 229-236.

¹³⁶Causse and Chavasse, op. cit., p. 405.

¹³⁷Fletcher and Munson, op. cit., pp. 82-108.

¹³⁸Feldmann, loc. cit.

¹³⁹Kock, op. cit., pp. 801-804.

¹⁴⁰Pollack and Pickett, op. cit., pp. 292-296.

Investigations involving normal hearing subjects have concluded that binaural listening enhances speech intelligibility (Chappel, et al¹⁴¹ Heffler and Schultz¹⁴²).

A study conducted by Harris¹⁴³ suggested that the use of dichotic modes of listening increased speech intelligibility over monotic modes of listening for both normal and defective hearing listeners.

However, in studies dealing with pathological ears the theoretical advantages of two-eared listening have not been as apparent.

Studies conducted on subjects with conductive hearing losses have reported increased speech discrimination, especially in a background of noise (poor listening situation), when binaural hearing aids were compared to monaural hearing aids (Belzile and Markle,¹⁴⁴ Bergman,¹⁴⁵ Decroix and Dehaussy,¹⁴⁶ and Markle and Aber¹⁴⁷).

Malles¹⁴⁸ reportedly improved speech discrimination for subjects with unilateral conductive hearing losses, by fitting the poor ear with a hearing aid.

¹⁴¹Chappell, op. cit., pp. 263-269.

¹⁴²Heffler and Schultz, op. cit., pp. 279-289.

¹⁴³Harris, op. cit., pp. 428-446.

¹⁴⁴Belzile and Markle, op. cit., pp. 1317-1323.

¹⁴⁵Bergman, loc. cit.

¹⁴⁶Decroix and Dehaussy, op. cit., pp. 115-134.

¹⁴⁷Markle and Aber, op. cit., pp. 606-608.

¹⁴⁸Malles, op. cit., pp. 405-408.

The literature contains inconsistent information concerning the comparative value of binaural hearing aids for subjects with sensori-neural hearing losses. There was no significant increase reported for speech perception of subjects with sensori-neural hearing losses utilizing binaural hearing aids compared to the monaural hearing aid (DiCarlo and Brown,¹⁴⁹ Hedgecock and Sheets,¹⁵⁰ Jerger, Carhart and Dirks,¹⁵¹ Jerger and Dirks,¹⁵² and Wright).¹⁵³

In spite of many clinical studies concluding that there was no appreciable advantage for speech intelligibility for binaural hearing aids over the monaural, the preponderance of subjective reports from users of binaural hearing aids was highly favorable. Questionnaires mailed to hearing aid users revealed that those who had binaural instruments expressed strong beliefs in their superiority (Dirks and Carhart¹⁵⁴ and Kodman).¹⁵⁵

¹⁴⁹DiCarlo and Brown, loc. cit.

¹⁵⁰Hedgecock and Sheets, op. cit., pp. 624-629.

¹⁵¹Jerger, Carhart and Dirks, op. cit., pp. 137-148.

¹⁵²Jerger and Dirks, op. cit., pp. 537-538.

¹⁵³Wright, loc. cit.

¹⁵⁴Dirks and Carhart, op. cit., pp. 311-321.

¹⁵⁵Kodman, op. cit., pp. 302-314.

Clinical audiologists have encouraged the use of binaural hearing aids for individuals with bilateral moderate sensori-neural hearing losses based on the hearing aid users experience with such instruments (Carhart¹⁵⁶ and Haskins and Hardy).¹⁵⁷

The author of this study has attempted to profit from this review of the literature by designing a research procedure which would take advantage of those features which researchers have creatively innovated for the elimination of head movements and head shadow effects in order to compare speech perception between monotic and dichotic modes of listening for subjects with bilateral approximately symmetrical sensory hearing losses.

¹⁵⁶Carhart, loc. cit.

¹⁵⁷Haskins and Hardy, op. cit., pp. 1427-1433.

CHAPTER III
PROCEDURE OF INVESTIGATION

This study, structured to compare discrimination scores of subjects suffering from sensory hearing losses utilizing various monotic and dichotic modes of listening, consisted of two experiments. The first experiment employed high fidelity amplifiers and earphones and will, hereafter in the description of the procedure and equipment of this investigation, be referred to as Experiment I. The second experiment employed commercial hearing aids and will, hereafter be described as Experiment II.

A. Description of Subjects Used.

Each experimental group consisted of 25 adults, males and females varying in age from twenty-one years to sixty-five years, who demonstrated approximately symmetrical bilateral sensory hearing losses. The average pure-tone hearing level varied from 45 dB HL to 70 dB HL, (ISO 1964),¹ for the three mid-frequencies for speech, with hearing loss not less than 35 dB HL at the best frequency of 500, 1000, and 2000 Hz. Each subject did not reveal more than a 15 dB differential between their two ears for the pure-tone averages of the three mid-frequencies tested.

¹I.O.S., International Organization for Standardization. Standard Reference Zero for Calibration of Pure-tone Audiometers, ISO/R, International Organization for Standardization. (1964), 389; for additional information see H. Davis and F.W. Kranz, "The International Standard Reference Zero for Pure-tone Audiometers and Its Relation to the Evaluation of Impairment of Hearing," Journal of Speech and Hearing Research, 7 (1964), pp. 7-16.

All subjects had essentially cerumen free external auditory canals, intact tympanic membranes and no significant history of outer or middle ear pathology. Those persons indicating any possibility of retrocochlear or central nervous system dysfunction (history, SISI test, and tone decay test), were excluded from the experiment. It is reasonable to assume that the results of the hearing tests described indicated there was an absence of neural involvement.

Those individuals indicating obvious emotional disturbances or intellectual immaturity were also eliminated from this experiment. Older subjects showing signs of early senility or phonemic regression were excused from further testing. All subjects included in this study appeared to have good familiarity with the English language. The subjects finally selected showed moderate bilateral, approximately symmetrical sensory hearing losses, however, they appeared to be normal in all other physiological and psychological aspects. These subjects experienced no difficulty in understanding instructions and showed cooperation and consistency of response to both pure-tone and speech tests.

The individuals selected for testing had no previous experience in the use of hearing aids nor had they been subjects for previous speech audiometric procedures.

None of the subjects used in Experiment I were subjects of Experiment II, and all of the 50 individuals tested in both experiments met the criteria described.

B. Description of Experimental Equipment.

The actual procedure with the subjects selected was carried out in a three room testing suite.

For the most part, tests were conducted on Sundays, at which time the noise level (as measured with General Radio sound level meter), of the entire building and surroundings was at a minimum.

1. Description of Sound-Treated Room.

A three room testing suite was used as shown in block diagrams of the equipment used in Figures 1 and 2. The ambient noise level inside test room 1 was approximately 50 dB SPL on the C scale of the General Radio #1565-A sound level meter.

The walls, ceiling, and floor of test room 1 were lined with thick sound-absorbant material. The usable inside dimensions of this test room were approximately eight feet long, seven feet wide, and eight feet high.

2. Description of Equipment in Test Room 1.

The equipment located inside test room 1 consisted of three loudspeakers, each consisting of an Electrovoice Speaker Model SP-12, enclosed in a KD6A Electro Voice Enclosure, dimension of the enclosure being 29 1/2" high, 19" wide, and 16" deep.

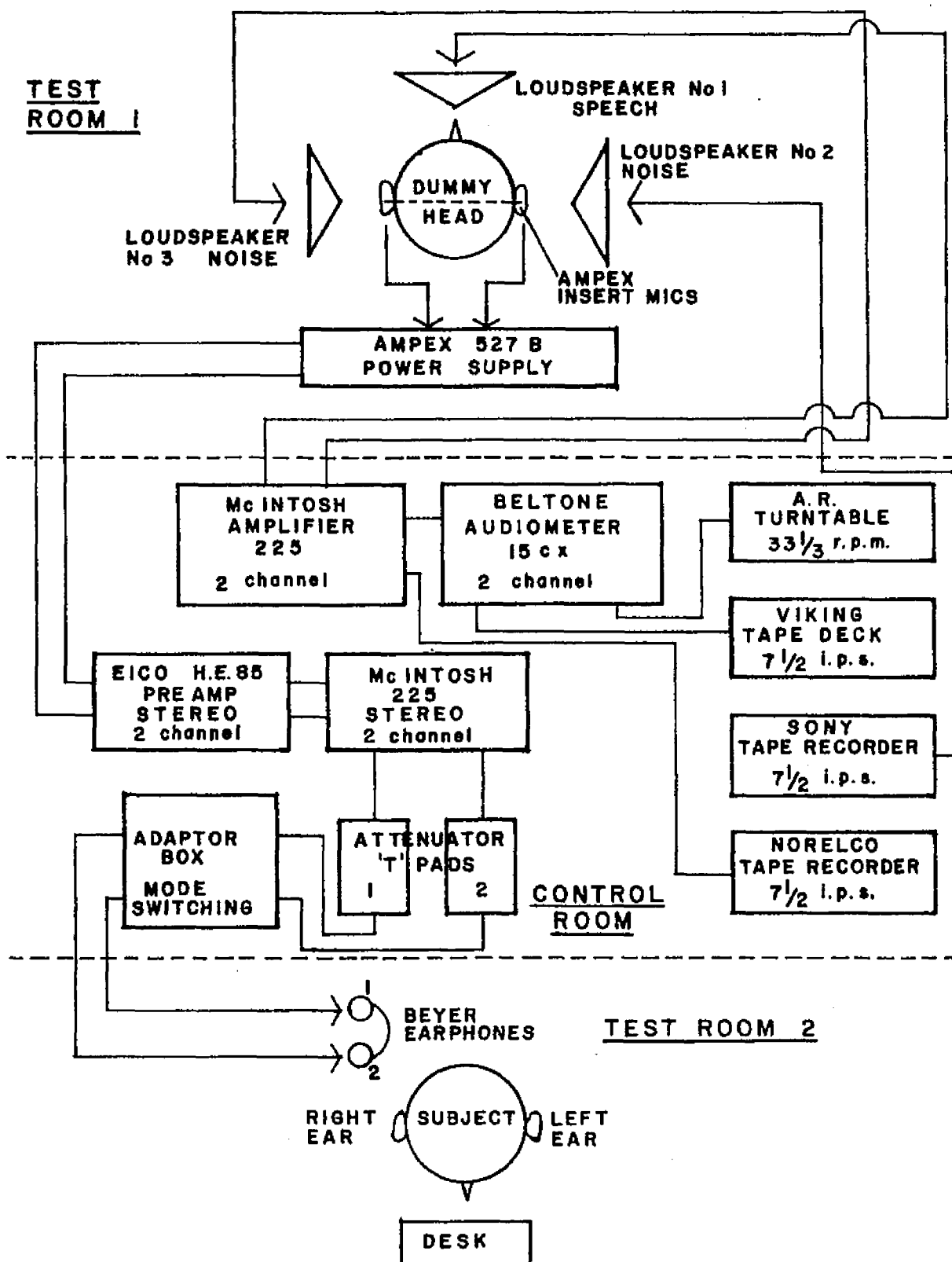


Figure 1. Block diagram of equipment used in control room, test room 1 and test room 2 for Experiment I, using high fidelity amplifiers and earphones, in this study.

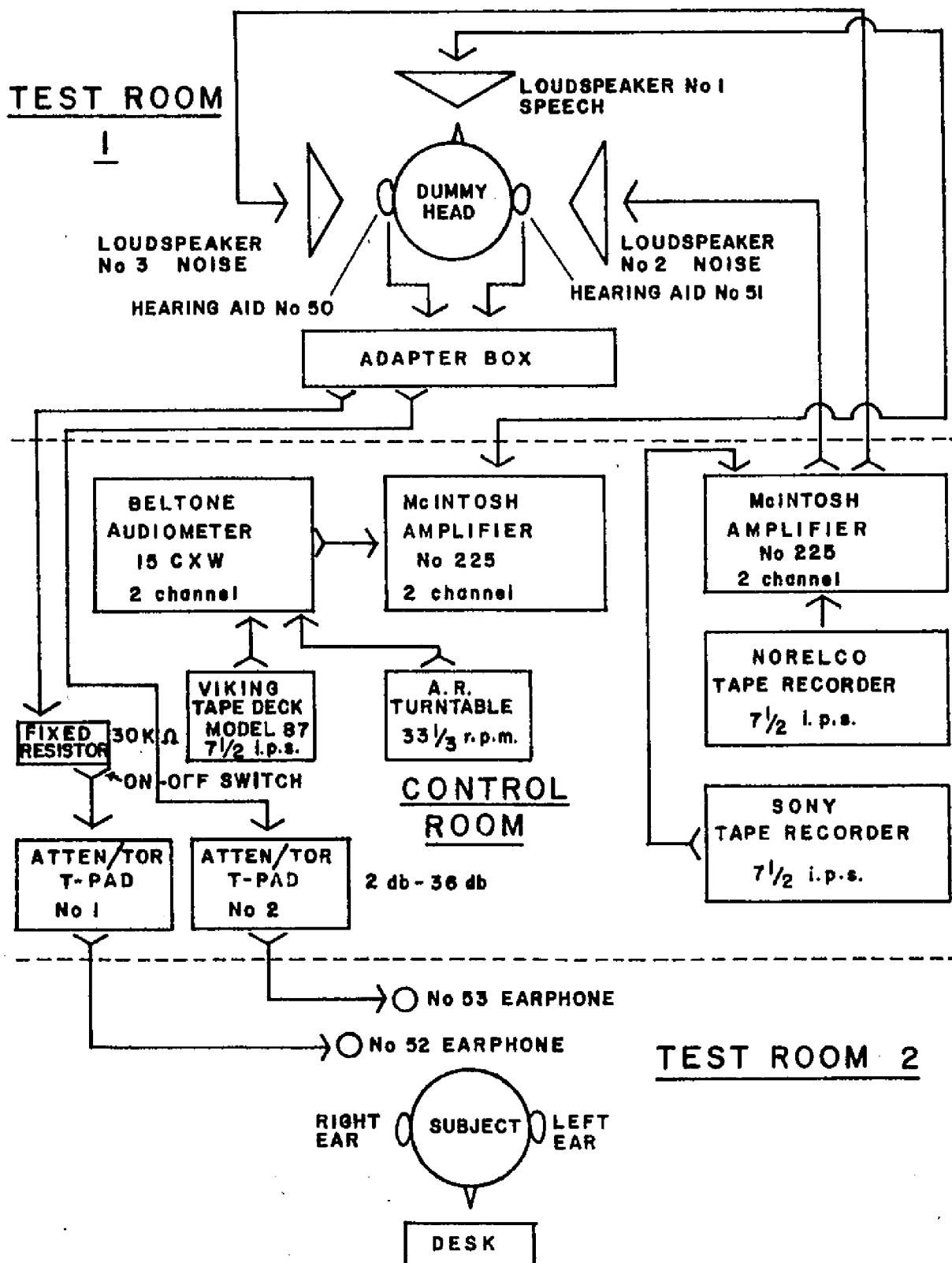


Figure 2. Block diagram of equipment used in control room, test room 1 and test room 2 for Experiment II, using commercial hearing aids, in this study.

3. Description of the Dummy Head.

A dummy head was placed on a pedestal at mid-height (base of head was 8 inches from the floor), and equidistant from each of the loudspeakers in test room 1. This artificial head, a plastic mannequin head, had been covered with three layers of diluted silicone rubber, in order to give a texture similar to human skin to the dummy head.

Wiener² reported on the effects of diffraction by the head (human) and pinna on sound waves, as a function of frequency and the angle of incidence, by measuring sound pressure levels at the ear drums of observers exposed to a progressive sound wave. In a recent study, Dirks and Moncur³ found that the diffraction effects on sound waves caused by a dummy head coated with diluted silicone rubber, were substantially the same as reported by Wiener.

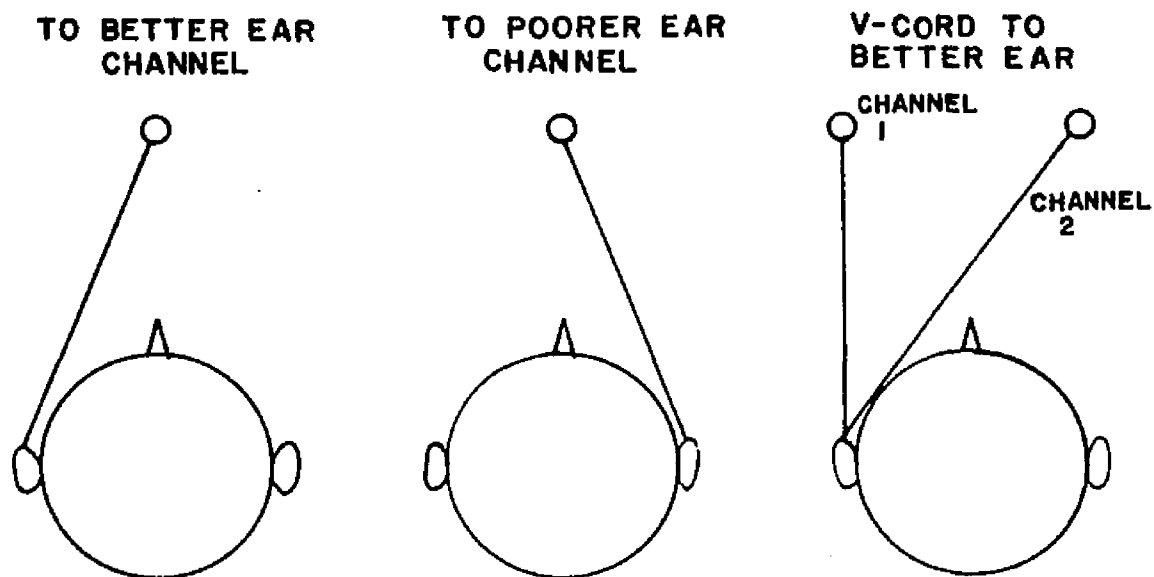
4. Description of Equipment in Control Room.

As a part of the experimental equipment located in the control room, there was a recently calibrated Beltone 15 CX Audiometer (ISO 1964), which was used as the pure-tone generator and fed into TDH-39 earphones with MX/41 AR

²F.M. Wiener, "On the Diffraction of Progressive Sound Waves by the Human Head," Journal of Acoustical Society of America, 19 (1947), pp. 143-146.

³D. Dirks and J.P. Moncur, "Interaural Intensity and Time Differences in Anechoic and Reverberant Rooms," Journal of Speech and Hearing Research, 10 (1967), p. 178.

MONOTIC MODES



DICHOTIC MODES

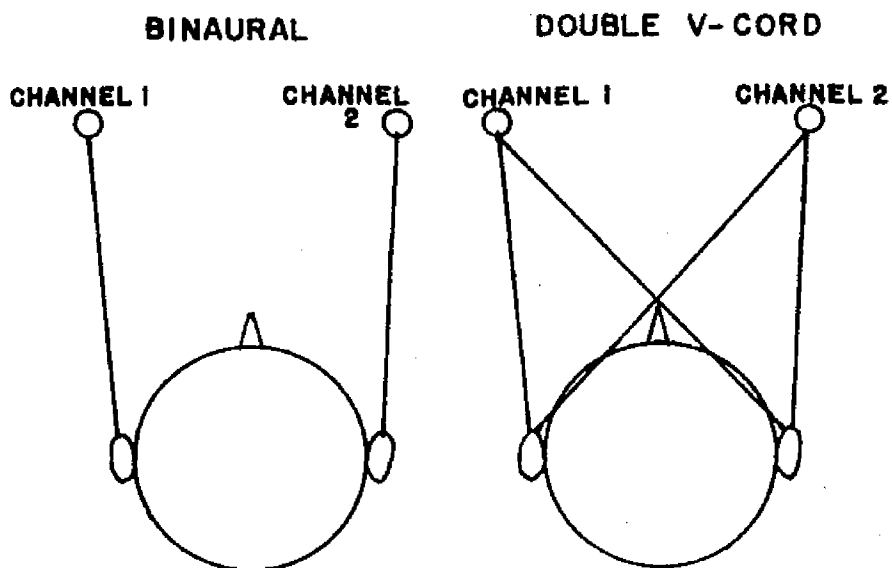


Figure 3. Four modes of listening for testing speech perception in Experiment I and Experiment II of this study.

cushions located in test room 1. The signals generated from the audiometer were fed through a suitable matching network into a power amplifier, McIntosh Amplifier Model #225, and then to the center loudspeaker located in test room 1.

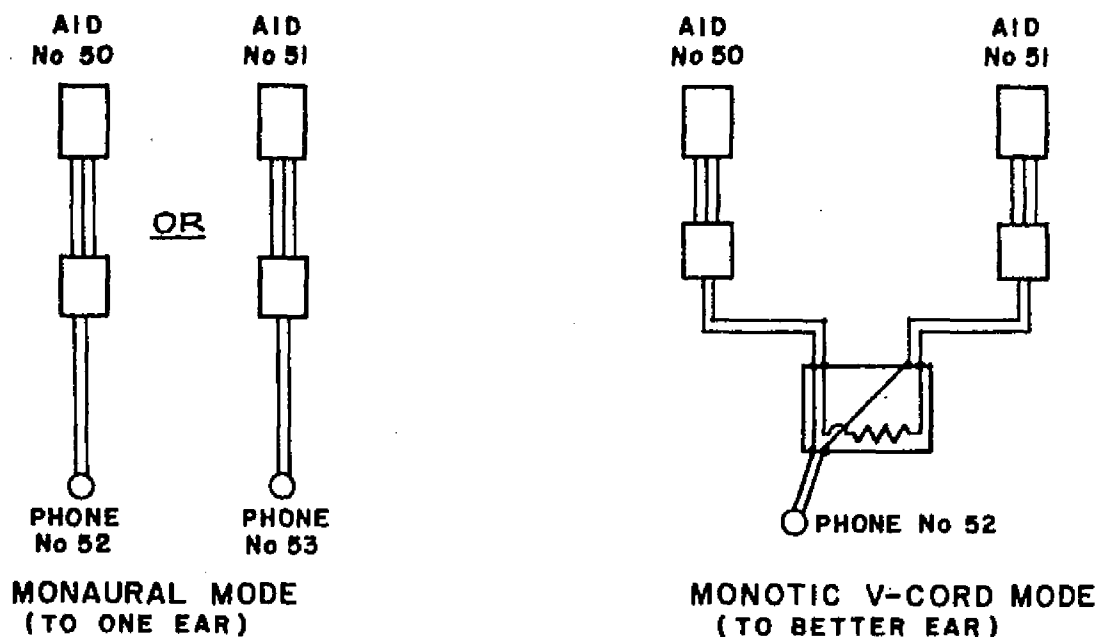
A Viking tape deck Model #87 was connected to the Beltone 15 CX Audiometer and when used was played at a speed of 7 1/2 I.P.S.

A turntable, manufactured by Acoustic Research Inc., was connected to the Beltone Audiometer and was played at 33 1/3 R.P.M., when spondee W-1 word records were used for speech reception threshold tests.

Two separate tape players were used for the masking noise. One a Sony tape recorder Model #305, the output being fed through a suitable matching network into a separate channel of a two channel power amplifier, McIntosh Amplifier Model #225, and then to one of the lateral loudspeakers located in test room 1. The speech spectrum noise tape, (analysis of noise tape shown in Tables 8 and 9), was played at 7 1/2 I.P.S., when the Sony tape recorder was being used.

The second tape player, a Norelco Model #701, was also employed for the masking noise. The output of the Norelco tape player was fed through a suitable matching

MONOTIC MODES



DICHOTIC MODES

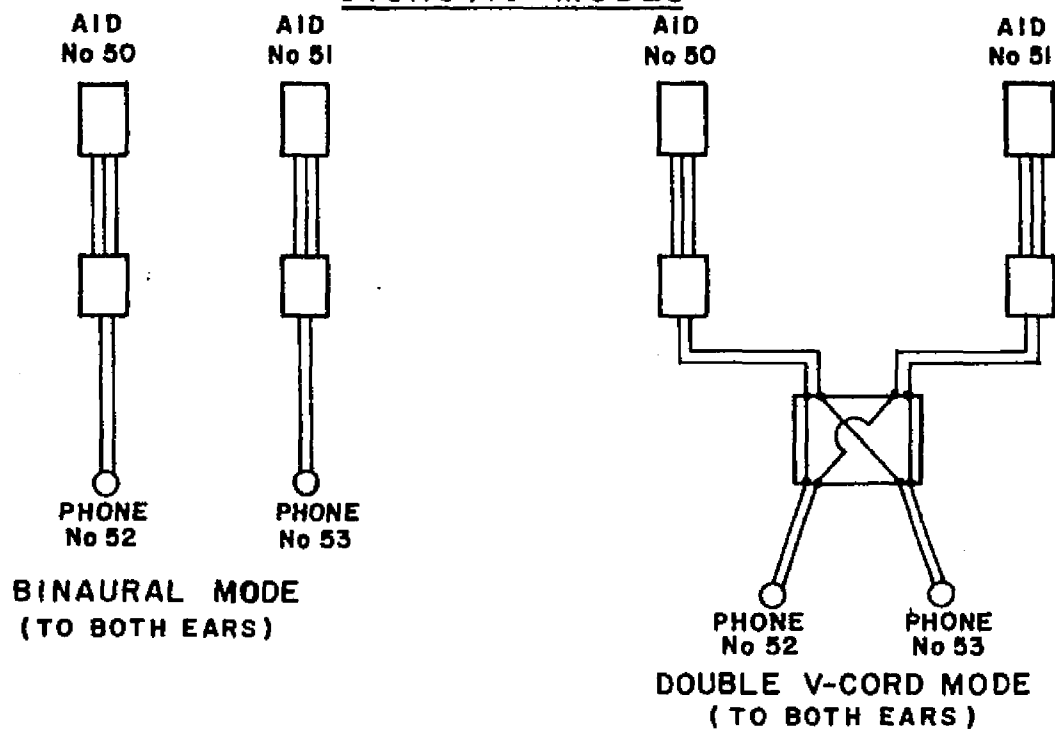


Figure 4. Block diagram of hearing aids #50 and #51 with earphones #52 and #53 in four modes of listening used in Experiment II of this study.

network into a separate channel of a two channel power amplifier, McIntosh Amplifier Model #225, and then to the second lateral loudspeaker located in test room 1. The noise tape was played at 7 1/2 I.P.S., when the Norelco tape player was being used.

5. Speech Spectrum Noise.

Three tapes of speech spectrum noise were recorded from a Grason-Stadler 162 Speech Audiometer. The speech spectrum noise tapes were analyzed by leading the tape output into a General Radio sound level meter, #1565-A, placed in test room 1, at the position to be occupied by the dummy head. When the reading on the sound level meter was 60 dB SPL on the sound level meter, the noise was fed from the meter into a General Radio Octave Band Analyzer Model 1550 A, and the results are reported in Tables 8 and 9. The two tapes which were finally used on each tape player were those showing the closest correlation of sound pressure levels at the various octave bands, when played on a particular tape player.

Each tape player played the tape of speech spectrum noise into separate amplifier channels and then through one of the lateral loudspeakers located in test room 1. The volume control of each of the tape players was adjusted so that the reading on the sound level meter, placed at the position of the dummy head in test room 1, read exactly 60 dB SPL.⁴ When the two tape players were played

⁴SPL represents sound pressure level in re 0.0002 dyne per cm.²

simultaneously, through each of the two lateral loudspeakers in test room 1, the sound pressure level meter read 63 dB SPL, when placed at the position of the dummy head.

6. Calibration of Speech Stimuli.

A third speech spectrum noise tape was placed on the Viking tape deck and the attenuator of the Beltone Audiometer was adjusted so that the reading on the sound level meter was 68 dB SPL (5 dB above sound pressure level of two lateral loudspeakers played simultaneously). The sound level meter was placed in the same position as the dummy head, and only this noise tape was being played through the center loudspeaker into test room 1.

The power summation from all three loudspeakers was slightly higher than 68 dB SPL (68 dB from center speaker plus 63 dB from two lateral loudspeakers played simultaneously), as read on the C Scale of the General Radio sound level meter. The meter was placed in the same position as the dummy head. The sound source was the two tape players and tape deck previously described. Each lateral loudspeaker had a fixed output of 60 dB SPL.

In the design for this study the average peak levels of the Revised Peterson-Lehiste CNC words, were to deliver the approximate average peak levels as that of the speech spectrum noise. Therefore, the attenuator of the Beltone audiometer was fixed at that setting which had given a reading of 68 dB SPL, when speech spectrum noise was played,

through the center loudspeaker. A comparison made between the use of the speech tape and the noise tape showed sound pressure levels at the dummy head to be approximately the same. When the three noise tapes were played simultaneously, through the two lateral and center loudspeakers, the readings on the sound level meter indicated very small deviations from the readings when the two speech spectrum noise tapes were played through the lateral loudspeakers and the Revised Peterson-Lehiste CNC word tape was presented through the center loudspeaker. Readings of sound pressure level were made on the General Radio sound level meter and the output from this meter was fed into the General Radio Octave Band Analyzer (see Tables 8 and 9).

7. Signal-to-Noise Ratio.

The relative levels of competing sounds is a matter of significance when discrimination for speech is measured. This relationship, usually designated Signal-to-Noise Ratio (S/N), has no standard operational definition and different investigators have established it in different ways as described by Heffler and Schultz.⁵ The method of equating the speech stimulus with the noise stimulus, thus establishing a constant signal-to-noise ratio, was employed. The S/N +5 was used in the present study and was main-

⁵A.J. Heffler and M.C. Schultz, "Some Implications of Binaural Signal Selection for Hearing Aid Evaluation," Journal of Speech and Hearing Research, 7, (1964), p. 280.

tained at a constant level for all speech discrimination tests utilizing the various monotic and dichotic modes of listening.

The speech spectrum noise summated from the two lateral loudspeakers in test room 1, at an SPL of 63 dB, and the Revised Peterson-Lehiste CNC word lists were presented through the center loudspeaker at a approximate SPL of 68 dB, calibrated with speech spectrum noise as previously described in this study.

8. Description of High Fidelity Amplifier and Earphones, Experiment I.

An Ampex Insert Microphone Model No. 21D used with 165A Base was inserted into openings, representing ear canals, on each side of the dummy head. The output of each insert microphone was fed into an Ampex 527B power supply. The output of the power supply was then led into an Eico H.H. 85 pre-amplifier (stereo, two channel), and then into a McIntosh Model No. 225, stereo two channel amplifier. The output from the amplifier was then led through a T-pad for each channel to an Adaptor Box designed for the purpose of switching the modes of listening, and then to the Beyer Earphones Model No. DT 48S (see Figures 13 and 14) located in test room 2.

9. Description of Hearing Aids, Experiment II.

Two specially designed hearing aids for this study, labeled #50 and #51, (see Figure 5, schematic of Hearing Aids), built by Zenith Hearing Aid Sales Corp., for the

purpose of this study, were placed over each ear of the dummy head in test room 1. Output of each hearing aid was wired into a special adaptor box, (see Figure 6), which enabled the conversion through an electrical network, from conventional monaural one channel hearing aids, into a two channel amplification system (V-cord arrangement). The output from the adaptor box was fed into each of two attenuators in the control room. The two attenuators each had an attenuation range of 36 dB in 2 dB steps designed so that the impedance of the circuits were not changed. Impedance was not changed with the use of a T-pad because the resistors are arranged in a bridge and total resistance of the attenuator remains constant as the attenuation setting is changed (arrangement of three wire wound variable resistors enables the bridge to be balanced). A conductor cord then fed the output from each attenuator into each earphone labeled earphone #52 and earphone #53 which were placed on a desk in an adjoining room, designated as test room 2 in Figure 2. The two earphones were attached to custom earmolds, whenever they were used with a subject. The earphone and mold was inserted in the ear under test for monotic modes and in both ears for the dichotic modes, in accordance with the test being administered.

C. Test Procedure.

The battery of tests as administered to the subjects in this study lasted generally from two to two and one-half

Table 1. Pure-tone thresholds of hearing for subjects tested with Beltone 15CX audiometer calibrated (I.S.O., 1964) in Experiment I.

Subj.										
<u>No.</u>	<u>Ear</u>	<u>125</u>	<u>250</u>	<u>500</u>	<u>1000</u>	<u>2000</u>	<u>3000</u>	<u>4000</u>	<u>6000</u>	<u>8000</u>
1.	R A	15	25	35	45	55	70	75	80	90
	L A	20	25	45	55	65	65	70	85	95
	R B	-	20	30	45	55	65	NR	-	-
	L B	-	25	40	50	60	65	NR	-	-
2.	R A	25	40	50	60	65	70	75	85	95
	L A	25	30	40	55	65	70	75	80	90
	R B	-	35	45	55	60	65	65	-	-
	L B	-	30	40	55	60	65	65	-	-
3.	R A	20	25	40	50	60	65	75	75	85
	L A	25	35	45	55	55	60	70	75	85
	R B	-	25	40	50	55	60	65	-	-
	L B	-	30	40	55	55	60	NR	-	-
4.	R A	25	35	45	50	65	70	75	80	90
	L A	30	45	50	60	65	75	75	85	95
	R B	-	30	40	50	65	65	NR	-	-
	L B	-	40	50	55	65	65	NR	-	-
5.	R A	25	30	40	45	60	70	75	90	95
	L A	30	35	45	55	55	70	75	85	95
	R B	-	30	40	45	55	65	65	-	-
	L B	-	30	40	50	55	65	NR	-	-
6.	R A	25	30	35	45	55	65	70	80	90
	L A	30	40	45	55	60	65	75	80	90
	R B	-	30	35	45	55	65	NR	-	-
	L B	-	35	40	50	55	65	NR	-	-
7.	R A	30	35	40	60	70	75	80	85	95
	L A	30	40	45	50	65	75	80	85	90
	R B	-	30	40	50	60	65	65	-	-
	L B	-	35	40	50	60	65	65	-	-

R A right ear air conduction thresholds.
 L A left ear air conduction thresholds.
 R B right ear bone conduction thresholds.
 L B left ear bone conduction thresholds.

Table 1. (continued). Pure-tone thresholds of hearing for subjects tested with Beltone 15CX audiometer calibrated (I.S.O., 1964) in Experiment I.

Subj. No.	Ear	125	250	500	1000	2000	3000	4000	6000	8000
8.	R A	35	45	55	65	65	75	80	90	95
	L A	35	40	45	60	65	70	80	85	90
	R B	-	35	50	55	60	65	NR	-	-
	L B	-	40	45	55	65	65	NR	-	-
9.	R A	20	30	35	45	55	65	70	75	85
	L A	25	35	40	55	60	65	75	80	95
	R B	-	25	35	45	55	65	65	-	-
	L B	-	30	40	50	60	65	65	-	-
10.	R A	35	40	50	60	65	70	75	85	95
	L A	40	45	55	65	70	75	80	85	95
	R B	-	40	50	60	65	NR	NR	-	-
	L B	-	40	55	65	65	NR	NR	-	-
11.	R A	40	50	55	65	70	80	90	95	NR
	L A	45	55	55	70	70	80	95	100	NR
	R B	-	45	55	65	65	NR	NR	-	-
	L B	-	50	55	65	65	NR	NR	-	-
12.	R A	30	40	55	60	60	70	75	85	90
	L A	35	40	50	65	75	80	85	95	NR
	R B	-	35	50	60	60	65	NR	-	-
	L B	-	40	50	60	65	65	NR	-	-
13.	R A	30	35	45	55	65	70	70	75	85
	L A	25	35	35	50	65	65	70	80	85
	R B	-	30	35	50	60	65	NR	-	-
	L B	-	30	35	50	65	NR	NR	-	-
14.	R A	35	40	55	60	60	70	75	85	95
	L A	25	30	40	55	65	70	75	85	85
	R B	-	35	45	55	60	65	NR	-	-
	L B	-	30	40	55	60	65	65	-	-

R A right ear air conduction thresholds.
 L A left ear air conduction thresholds.
 R B right ear bone conduction thresholds.
 L B left ear bone conduction thresholds.

Table 1. (continued). Pure-tone thresholds of hearing for subjects tested with Beltone 15CX audiometer calibrated (I.S.O., 1964) in Experiment I.

Subj.										
No.	Ear	125	250	500	1000	2000	3000	4000	6000	8000
15.	R A	30	35	45	60	65	75	85	95	NR
	L A	30	35	45	60	70	80	90	NR	NR
	R B	-	30	45	55	65	NR	NR	-	-
	L B	-	35	45	60	65	NR	NR	-	-
16.	R A	30	35	45	55	60	65	75	85	90
	L A	25	35	45	55	60	70	80	85	95
	R B	-	30	40	50	60	65	65	-	-
	L B	-	30	45	55	60	65	65	-	-
17.	R A	35	40	50	55	65	75	80	90	NR
	L A	30	35	45	55	65	70	80	95	NR
	R B	-	35	45	50	55	65	NR	-	-
	L B	-	35	45	50	60	65	NR	-	-
18.	R A	35	40	50	60	70	75	80	90	95
	L A	35	40	60	70	75	85	90	100	NR
	R B	-	40	45	60	65	65	NR	-	-
	L B	-	40	55	60	65	65	NR	-	-
19.	R A	30	35	45	55	60	60	65	75	90
	L A	35	40	45	55	65	70	80	90	95
	R B	-	35	45	50	60	65	65	-	-
	L B	-	35	45	55	65	65	65	-	-
20.	R A	35	45	50	65	65	70	75	85	95
	L A	40	45	55	60	70	75	80	90	95
	R B	-	40	45	60	65	65	NR	-	-
	L B	-	40	50	60	65	65	65	-	-
21.	R A	25	35	45	55	65	65	75	85	100
	L A	30	35	50	60	65	70	80	90	NR
	R B	-	30	40	55	65	NR	NR	-	-
	L B	-	35	45	60	65	65	NR	-	-

R A right ear air conduction thresholds.
 L A left ear air conduction thresholds.
 R B right ear bone conduction thresholds.
 L B left ear bone conduction thresholds.

Table 1. (continued). Pure-tone thresholds of hearing for subjects tested with Beltone 15CX audiometer calibrated (I.S.O., 1964) in Experiment I.

Subj.										
<u>No.</u>	<u>Ear</u>	<u>125</u>	<u>250</u>	<u>500</u>	<u>1000</u>	<u>2000</u>	<u>3000</u>	<u>4000</u>	<u>6000</u>	<u>8000</u>
22.	R A	25	40	50	60	70	85	90	NR	NR
	L A	30	40	55	60	70	80	90	100	NR
	R B	-	40	50	55	65	NR	NR	-	-
	L B	-	40	50	60	65	NR	NR	-	-
23.	R A	20	25	40	55	60	70	75	85	90
	L A	20	35	45	60	70	70	80	85	90
	R B	-	25	40	55	60	65	65	-	-
	L B	-	30	45	55	60	65	65	-	-
24.	R A	25	30	45	55	70	70	80	90	95
	L A	20	30	45	55	65	70	80	90	95
	R B	-	25	40	50	65	65	65	-	-
	L B	-	30	40	55	60	65	65	-	-
25.	R A	30	40	55	65	65	70	70	80	95
	L A	30	35	45	60	70	75	80	95	NR
	R B	-	35	45	60	65	65	NR	-	-
	L B	-	35	40	60	65	NR	NR	-	-

R A right ear air conduction thresholds.
 L A left ear air conduction thresholds.
 R B right ear bone conduction thresholds.
 L B left ear bone conduction thresholds.

Table 2. Pure-tone thresholds of hearing for subjects tested with Beltone 15CX audiometer calibrated (I.S.O., 1964) in Experiment II.

Subj.										
No.	Ear	125	250	500	1000	2000	3000	4000	6000	8000
1.	R A	25	25	45	50	60	60	65	70	80
	L A	20	25	40	45	50	55	65	75	80
	R B	-	20	35	45	50	50	60	-	-
	L B	-	20	35	40	45	50	60	-	-
2.	R A	15	20	50	45	55	65	70	75	85
	L A	20	20	45	45	60	65	75	75	85
	R B	-	15	40	45	50	65	NR	-	-
	L B	-	20	40	45	55	65	NR	-	-
3.	R A	15	20	45	50	55	60	75	80	90
	L A	15	25	45	55	55	65	75	85	90
	R B	-	15	30	40	50	65	NR	-	-
	L B	-	15	35	45	55	65	NR	-	-
4.	R A	20	20	45	55	60	65	70	85	90
	L A	20	20	50	60	65	65	75	90	90
	R B	-	20	35	50	60	65	NR	-	-
	L B	-	20	40	55	65	65	NR	-	-
5.	R A	25	30	55	65	70	75	75	85	NR
	L A	30	30	50	65	75	75	80	85	NR
	R B	-	25	45	55	65	NR	NR	-	-
	L B	-	30	45	55	65	NR	NR	-	-
6.	R A	20	25	45	55	65	65	70	75	90
	L A	15	25	40	50	60	65	70	70	85
	R B	-	15	35	50	60	60	65	-	-
	LB	-	20	35	50	60	65	65	-	-
7.	R A	25	40	55	65	70	70	75	75	85
	L A	25	35	55	60	60	60	70	75	85
	R B	-	30	40	50	55	65	65	-	-
	L B	-	25	45	50	55	60	65	-	-

R A right ear air conduction thresholds.

L A left ear air conduction thresholds.

R B right ear bone conduction thresholds.

L B left ear bone conduction thresholds.

Table 2. (continued). Pure-tone thresholds of hearing for subjects tested with Beltone 15CX audiometer calibrated (I.S.O., 1964) in Experiment II.

Subj.										
No.	Ear	125	250	500	1000	2000	3000	4000	6000	8000
8.	R A	15	20	35	45	55	55	65	75	85
	L A	15	25	40	55	65	70	70	75	90
	R B	-	15	25	45	50	50	65	-	-
	L B	-	15	35	50	50	60	65	-	-
9.	R A	25	35	45	55	65	75	80	90	NR
	L A	25	30	45	55	60	75	80	85	90
	R B	-	25	30	50	55	65	NR	-	-
	L B	-	25	35	50	55	NR	NR	-	-
10.	R A	15	20	45	60	70	75	85	NR	NR
	L A	20	20	55	65	75	75	90	NR	NR
	R B	-	15	40	60	NR	NR	NR	-	-
	L B	-	20	50	65	NR	NR	NR	-	-
11.	R A	20	20	35	45	55	60	75	80	90
	L A	25	30	35	45	60	70	75	85	NR
	R B	-	20	30	40	55	55	65	-	-
	L B	-	25	30	40	55	60	65	-	-
12.	R A	20	25	40	50	60	65	70	85	NR
	L A	20	20	35	45	60	65	65	85	NR
	R B	-	20	35	45	55	65	NR	-	-
	L B	-	25	35	45	50	65	NR	-	-
13.	R A	15	25	35	50	60	65	70	80	85
	L A	20	25	40	55	60	65	75	80	90
	R B	-	20	35	45	55	60	65	-	-
	L B	-	25	35	50	55	65	65	-	-
14.	R A	30	30	40	45	60	70	75	85	90
	L A	35	40	40	55	65	75	80	85	90
	R B	-	30	40	45	55	65	65	-	-
	R L	-	35	40	50	55	65	NR	-	-

R A right ear air conduction thresholds.

L A left ear air conduction thresholds.

R B right ear bone conduction thresholds.

L B left ear bone conduction thresholds.

Table 2. (continued). Pure-tone thresholds of hearing for subjects tested with Beltone 15CX audiometer calibrated (I.S.O., 1964) in Experiment II.

Subj.										
<u>No.</u>	<u>Ear</u>	<u>125</u>	<u>250</u>	<u>500</u>	<u>1000</u>	<u>2000</u>	<u>3000</u>	<u>4000</u>	<u>6000</u>	<u>8000</u>
15.	R A	20	30	40	50	65	65	75	85	90
	L A	30	35	45	55	70	75	80	85	NR
	R B	-	25	35	50	55	65	NR	-	-
	L B	-	30	45	50	60	65	NR	-	-
16.	R A	20	30	45	60	65	75	85	90	NR
	L A	20	30	45	55	65	70	80	90	90
	R B	-	25	40	55	65	NR	NR	-	-
	L B	-	25	35	55	65	NR	NR	-	-
17.	R A	15	25	40	55	60	65	70	80	90
	L A	20	25	45	55	65	75	75	85	90
	R B	-	25	35	50	55	60	65	-	-
	L B	-	25	40	55	55	60	65	-	-
18.	R A	25	30	35	50	65	70	80	85	90
	L A	30	35	40	55	65	75	80	90	NR
	R B	-	25	35	45	60	65	65	-	-
	L B	-	25	35	50	60	65	NR	-	-
19.	R A	25	30	40	60	70	75	80	90	NR
	L A	25	35	40	55	65	75	80	85	NR
	R B	-	25	35	55	60	65	NR	-	-
	L B	-	30	35	50	60	60	NR	-	-
20.	R A	20	35	45	55	65	75	80	85	90
	L A	20	40	55	65	65	75	80	90	NR
	R B	-	30	40	55	60	65	NR	-	-
	L B	-	35	45	60	65	65	NR	-	-
21.	R A	20	20	35	45	55	65	80	85	90
	L A	30	30	40	45	60	70	80	85	95
	R B	-	20	30	45	50	60	65	-	-
	L B	-	25	35	45	55	65	NR	-	-

R A right ear air conduction thresholds.
 L A left ear air conduction thresholds.
 R B right ear bone conduction thresholds.
 L B left ear bone conduction thresholds.

Table 2. (continued). Pure-tone thresholds of hearing for subjects tested with Beltone 15CX audiometer calibrated (I.S.O., 1964) in Experiment II.

Subj.											
No.	Ear	125	250	500	1000	2000	3000	4000	6000	8000	
22.	R A	25	30	40	65	65	75	80	90	NR	
	L A	30	30	40	45	60	75	80	85	90	
	R B	-	25	40	55	60	65	NR	-	-	
	L B	-	25	35	45	55	65	NR	-	-	
23.	R A	25	35	40	65	65	80	80	90	95	
	L A	25	30	45	50	65	75	80	85	90	
	R B	-	30	35	55	65	65	NR	-	-	
	L B	-	30	40	50	60	60	65	-	-	
24.	R A	20	30	40	60	65	75	80	90	90	
	L A	25	30	40	65	65	75	85	95	NR	
	R B	-	30	35	55	65	NR	NR	-	-	
	L B	-	30	35	60	65	NR	NR	-	-	
25.	R A	15	25	45	55	55	60	70	80	85	
	L A	20	25	40	55	60	65	75	80	90	
	R B	-	20	35	50	55	65	65	-	-	
	L B	-	25	35	50	60	65	NR	-	-	

R A right ear air conduction thresholds.
 L A left ear air conduction thresholds.
 R B right ear bone conduction thresholds.
 L B left ear bone conduction thresholds.

hours, depending upon the individual case. The testing took place on Sunday mornings and afternoons.

Prior to the arrival of a subject, the experimental equipment was checked to make certain that it was in proper functional condition. New batteries were checked on a battery meter, and inserted in the hearing aids used before each subject was tested. Lotterman et al⁶ claim that an interaction appears to exist between battery performance and non-linear distortion for some hearing aid battery type combinations.

1. Pure Tone Thresholds.

The testing sequence began with a pure tone audiometric examination, air and bone, for both ears. The audiograms were made in sound treated test room 1, which has been previously described. This test was administered with the Beltone 15 CX Audiometer, terminating in a matched pair of Telephonic TDH-39 headphones with MX 41/AR cushions. The ambient noise level of test room 1 was below 50 dB SPL measured on the C scale of the General Radio sound level meter. Pure tone and speech circuits of the audiometer were calibrated to ISO 1964 standards on a Allison Model 300 calibration unit.

Each subject was seated so that he was unable to receive visual cues from the actions of the tester who

⁶S.H. Lotterman, R.N. Kasten, and D.M. Majerus, "Battery Life and Non Linear Distortion in Hearing Aids," Journal of Speech and Hearing Disorders, 32 (1967), pp. 274-278.

operated the audiometer. Headphones were carefully placed over both ears and each ear was tested separately. The subject was instructed to raise his finger each time he heard the stimulus tone, as a signal to the experimenter. The complete instructions to the subject are described in the Appendix C of this study.

The pure-tone air conduction thresholds for the frequencies 125 through 8000 Hz were determined in this manner. Pure-tone thresholds by bone conduction for the frequencies 250 through 4000 Hz were determined in a similar manner, using a Radioear bone oscillator furnished with the Beltone 15 CX audiometer. The results of these tests are reported in Tables 1 and 2.

2. Unaided Speech Reception Thresholds.

In determining the speech reception threshold, a turntable manufactured by Acoustic Research Inc., was used, the output from the record player being fed into the Beltone audiometer. A recording of W-1 spondee list C, obtained from Technisonic Laboratories⁷ was heard by the subject through the TDH-39 earphone with MX 41/AR cushions. The intensity of the sound delivered through the headphone was controlled through the attenuator of the audiometer. The speech zero reference level⁸ was set at 20 dB re 0.0002

⁷Auditory Test No. W-1 was developed at the Central Institute for the Deaf, St. Louis, Missouri and obtained on phonograph records from Technisonic Laboratories, Brentwood, Missouri.

⁸American Standard Specification for Speech Audiometers. Z24.13-1953, American Standards Association, (1953).

dyne per cm^2 , the input stimulus was a 1000 Hz tone and the output from the TDH-39 earphone into an American Standard Type 1 Coupler was measured with General Radio sound level meter.

A pre-trial period was allowed for familiarization with the spondee words before the testing was started by giving to the subject an alphabetized listing of word list C and he was instructed to read the words as described in the instructions (see Appendix C).

The speech reception threshold test was given on each ear, and the subject was instructed to repeat back the words as he heard them through each headphone. His answers were received by the tester through a talkback system, and the verbal responses of the subject were also tape recorded, so that replies could be rechecked. The stimulus was first administered at a SL (sensation level) of 20 dB, above the averaged pure-tone threshold, for the ear being tested. This procedure allowed him to hear the words easily and made him familiar with the method of repeating them back. A three second interval separated the words, thus giving ample time for the subject's response.

Once the subject was responding satisfactorily, the intensity was decreased gradually until he missed one half of the stimulus words. This 50% response point was taken as the criterion for the establishment of the threshold for speech reception and is reported in Tables 5 and 6. Speech

reception threshold for each subject for each ear was thus obtained, using the procedure suggested by Chaiklin and Ventry.⁹

3. Short-Increment-Sensitivity Index (SISI) Test.

Each subject was given the Short-Increment-Sensitivity Index Test (SISI), as proposed by Jerger et al¹⁰. The SISI unit of the Beltone 15 CX audiometer was employed. The test was administered on each ear of the subject at SL of 20 dB above pure tone threshold at 2000 Hz with 1 dB increments introduced every five seconds. Twenty 1 dB increments were introduced during the course of the test. The tone, which had rise-and-decay times of 50 milliseconds, was on for 200 milliseconds. The patient was instructed to signal, when he detected the slight increase in intensity. This test was administered in order to further corroborate the presence of cochlear dysfunction and to insure the adequacy of criterion of selection of subjects (Jerger)¹¹. All patients selected for this study had positive SISI scores as reported in Tables 3 and 4.

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J. B. Chaiklin and I.M. Ventry, "Spondee Threshold of Measurement; A Comparison of 2-and 5-dB Methods," Journal of Speech and Hearing Disorders, 29 (1964), pp. 47-59.

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J. Jerger, J.L. Shedd, and E. Harford, "On the Detection of Extremely Small Changes in Sound Intensity," Archives of Otolaryngology, 69 (1959); pp. 200-211.

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J. Jerger, "Recruitment and Allied Phenomena in Differential Diagnosis," Journal of Auditory Research, 1 (1961), pp. 145-151.

Table 3. Percentage of correct recognitions of twenty 1dB increments presented in administering the short - increment - sensitivity-index (SISI) test for subjects tested in Experiment I with the SISI unit of the Beltone 15CX audiometer.

<u>SUBJECT</u>	<u>RIGHT EAR</u>	<u>LEFT EAR</u>
1.	85%	80%
2.	75%	80%
3.	65%	75%
4.	90%	85%
5.	70%	65%
6.	85%	90%
7.	90%	80%
8.	65%	75%
9.	70%	80%
10.	80%	85%
11.	75%	85%
12.	65%	80%
13.	85%	80%
14.	90%	85%
15.	85%	85%
16.	90%	80%
17.	70%	75%
18.	75%	65%
19.	85%	90%
20.	95%	85%
21.	65%	75%
22.	80%	80%
23.	85%	80%
24.	85%	75%
25.	80%	85%

Stimulus was administered through Beltone 15 CX audiometer at sensation level of 20 dB above subject's hearing level at 2000 Hz.

Every five seconds an intensity increment of exactly 1 dB was superimposed on the constant signal. The exact nature of the signal was such that the tone rose to full intensity in 50 milliseconds, remained at 1 dB above the constant signal for 200 milliseconds, and decayed in 50 milliseconds.

Minimum percentage of 60% correct recognition was criterion used for determination of positive SISI and inference of cochlear involvement (in addition to air and bone pure tone thresholds).

Table 4. Percentage of correct recognitions of twenty 1dB increments presented in administering the short - increment - sensitivity-index (SISI) test for subjects tested in Experiment II with the SISI unit of the Beltone 15CX audiometer.

<u>SUBJECT</u>	<u>RIGHT EAR</u>	<u>LEFT EAR</u>
1.	85%	80%
2.	80%	85%
3.	75%	80%
4.	75%	75%
5.	80%	85%
6.	60%	65%
7.	65%	70%
8.	75%	85%
9.	80%	75%
10.	80%	75%
11.	65%	60%
12.	85%	75%
13.	70%	80%
14.	60%	70%
15.	65%	80%
16.	80%	70%
17.	75%	85%
18.	85%	85%
19.	65%	75%
20.	80%	70%
21.	80%	75%
22.	85%	85%
23.	75%	85%
24.	65%	70%
25.	80%	85%

Stimulus was administered through Beltone 15 CX audiometer at sensation level of 20 dB above subject's hearing level at 2000 Hz.

Every five seconds an intensity increment of exactly 1 dB was superimposed on the constant signal. The exact nature of the signal was such that the tone rose to full intensity in 50 milliseconds, remained at 1 dB above the constant signal for 200 milliseconds, and decayed in 50 milliseconds.

Minimum percentage of 60% correct recognition was criterion used for determination of positive SISI and inference of cochlear involvement (in addition to air and bone pure tone thresholds).

4. Tone Decay Test.

Tone decay test was administered to each subject on each ear, modified in a manner suggested by Rosenberg¹² to measure auditory adaptation at threshold. A sustained tone was presented to the subject at his threshold level. The subject signaled by keeping his finger raised as long as he heard the tone. The tone was first presented at 2000 Hz and then at 4000 Hz. Any subject showing abnormal adaptation to the extent that the threshold shift at either frequency during the one minute duration of the tone was more than 20 dB was eliminated from the study. This test was administered for the purpose of having additional evidence of the possibility of cochlear involvement being responsible for the hearing losses of the subjects used in this study (Stark).¹³

5. Aided Speech Reception Thresholds, Experiment I.

The aided speech reception threshold of each ear of each subject was obtained by placing the Beyer Earphones Model No. DT 48S, over the ears of the subject who was seated at a desk in test room 2. The dummy head containing an Ampex Insert Microphone inserted in an opening on each side of the head was placed on a pedestal, equidistant from

¹²P. Rosenberg, "Modified Tone Decay Test," In W.F. Carver (Ed.), Major Audiometric Measurements. (Chicago, Illinois: Beltone Electronics Corporation, 1965), p. 31.

¹³E.W. Stark, "An Evaluation of the Tone Decay Test and its Clinical Implications," Unpublished Master's thesis, Ohio State University, Columbus, Ohio (1958).

each of the three loudspeakers in test room 1.

The aided speech reception threshold was determined by the use of the phonographic unit, (Acoustic Research, Inc.) playing W-1 spondees, list D, through the Beltone audiometer into the center loudspeaker in test room 1. The subjects were permitted to familiarize themselves with an alphabetized listing of word list D of the spondee words, as previously described in the procedure for the determination of unaided speech reception thresholds.

The stimuli, spondee words, were delivered through the center loudspeaker at a fixed setting of the attenuator dial of the Beltone audiometer which was measured as being 68 dB SPL when the General Radio sound level meter was placed in the position of the dummy head in test room 1. The output of the Ampex Insert Microphone was fed into an Ampex 527B power supply and then into an Eico H.E. 85 pre-amplifier. The output was then reduced by 39 dB when a fixed resistor was switched into the circuit between the amplifier and variable T pad. This could be done when necessary in order to determine the sound pressure level of a lowered aided speech reception threshold. The variable T pad attenuator, having a range, 2 dB through 36 dB, in 2 dB steps, made it possible to determine aided speech reception thresholds as low as 47 dB SPL (27 dB HL).

The subject sat in test room 2 and his replies were relayed to the control room by a talkback system, and were also tape recorded for recheck. Once the subject was

responding satisfactorily, the intensity was gradually decreased until the subject correctly reported 50% of the spondee words. The output of the Beyer earphone was then checked by coupling the earphone to the sound level meter. The sound pressure levels measured from the Beyer earphone for the twenty-five subjects tested are reported as their aided speech reception thresholds in Table 5.

6. Aided Speech Reception Thresholds, Experiment II.

The speech reception threshold of each ear of each subject was obtained with the use of a hearing aid. Hearing aid #50 was placed on the dummy head at ear level, in test room 1. The volume control of the hearing aid #50 was fixed at such position, that when the output of the hearing aid through hearing aid receiver #52 was placed into a 2 cc coupler of the General Radio sound level meter, the reading on the meter was 105 dB SPL. The input into test room 1 of the speech stimulus (spondee words) through the center loudspeaker was fixed at 68 dB SPL, as measured on the sound level meter, when placed at the position of the dummy head. All tests using hearing aids, were therefore conducted at fixed settings of the gain controls of such aids. The experiment was structured in this manner in order that harmonic distortion of the hearing aid would be the same for testing under the various modes of listening. It has been demonstrated that harmonic and intermodulation distortion effect speech intelligibility

Table 5. Comparison of average pure-tone thresholds, unaided speech reception thresholds, and aided speech reception thresholds using high fidelity amplifiers and earphones for subjects tested in Experiment I.

<u>Subj. No.</u>	<u>Ear</u>	<u>Pure Tone Average</u>	<u>Unaided SRT</u>	<u>*Aided SRT</u>
1.	R	45	50	29
	L	55	55	33
2.	R	58	60	35
	L	53	55	31
3.	R	50	50	31
	L	52	55	33
4.	R	53	55	31
	L	58	60	35
5.	R	48	50	29
	L	52	50	31
6.	R	45	50	27
	L	53	55	33
7.	R	57	55	31
	L	53	55	31
8.	R	62	65	35
	L	57	60	33
9.	R	45	50	27
	L	52	55	31
10.	R	58	65	33
	L	63	65	37

* Aided speech reception thresholds were determined in sound pressure levels in re.0002dynes/cm², and were adjusted by deducting 20 dB in order to compare the aided SRT with the unaided SRT, which were determined in re audiometric zero (in Beltone Audiometer 15 CX speech circuit 0 level established at 20 dB above .0002 dynes/cm²),

Pure tone average consists of mean of thresholds for 500, 1000 and 2000 Hz.

Table 5. (continued). Comparison of average pure-tone thresholds, unaided speech reception thresholds, and aided speech reception thresholds using high fidelity amplifiers and earphones for subjects tested in Experiment I.

Subj. No.	Ear	Pure Tone Average	Unaided SRT	*Aided SRT
11.	R	63	65	35
	L	65	70	37
12.	R	58	65	33
	L	63	65	37
13.	R	55	55	31
	L	50	55	29
14.	R	58	60	33
	L	53	55	31
15.	R	57	60	33
	L	58	60	35
16.	R	53	55	31
	L	53	50	29
17.	R	57	60	35
	L	55	60	33
18.	R	60	65	37
	L	57	65	35
19.	R	53	55	31
	L	55	55	33
20.	R	60	65	37
	L	62	65	39

*Aided speech reception thresholds were determined in sound pressure levels in re.0002dynes/cm², and were adjusted by deducting 20 dB in order to compare the aided SRT with the unaided SRT, which were determined in re audiometric zero (in Beltone Audiometer 15 CX speech circuit 0 level established at 20 dB above .0002 dynes/cm²),

Pure tone average consists of mean of thresholds for 500, 1000 and 2000 Hz.

Table 5. (continued). Comparison of average pure-tone thresholds, unaided speech reception thresholds, and aided speech reception thresholds using high fidelity amplifiers and earphones for subjects tested in Experiment I.

<u>Subj. No.</u>	<u>Ear</u>	<u>Pure Tone Average</u>	<u>Unaided SRT</u>	<u>*Aided SRT</u>
21.	R	55	60	35
	L	58	60	37
22.	R	60	65	37
	L	62	65	39
23.	R	52	55	29
	L	58	60	31
24.	R	57	60	31
	L	55	60	29
25.	R	62	65	37
	L	58	60	33

* Aided speech reception thresholds were determined in sound pressure levels in re.0002dynes/cm², and were adjusted by deducting 20 dB in order to compare the aided SRT with the unaided SRT, which were determined in re audiometric zero (in Beltone Audiometer 15 CX speech circuit 0 level established at 20 dB above .0002 dynes/cm²),

Pure tone average consists of mean of thresholds for 500, 1000 and 2000 Hz.

(Harris)¹⁴ and that changing gain of a hearing aid changes the percentage of harmonic and intermodulation distortion.

The aided speech reception threshold was determined by the use of the phonographic unit, previously described, playing W-1 spondee words, list D, through the audiometer into the center loudspeaker in test room 1. The subjects were permitted to familiarize themselves with an alphabetized listing of word list D of the spondee words, as previously described in the determination of unaided speech reception thresholds.

The aided speech reception threshold was determined by the attachment of hearing aid receiver #52 to a custom made earmold, and then placing the earmold in the ear of the subject for which it was made.

The variable T pad attenuator was then adjusted until a sound pressure level was attained at which the subject reported 50% of the spondee words correctly. This point was then taken as the criterion for the subject's aided speech reception threshold for the ear under test. The aided speech reception threshold was then determined for the other ear, by using the same procedure, with the same earphone #52, attached to a custom earmold made for that particular ear.

¹⁴J.D. Harris, H.L. Haines, P.A. Kelsey, and T.D. Clark, "The Relation Between Speech and Intelligibility and the Electro-Acoustic Characteristics of Low Fidelity Circuitry," Journal of Auditory Research, 1 (1961), pp. 357-381.

A fixed resistor was placed in the circuit between the hearing aid and the variable T pad. A switching arrangement for the fixed resistor was used, whereby the level of sound pressure from earphone #52 going into the ear canal of the subject, was reduced by 40 dB when the resistor was switched into the circuit. This could be done when necessary, in order to measure the sound pressure level at the earphone, for a lowered aided speech reception threshold, than would be possible without the fixed resistor in the system. For example, the sound pressure level of hearing aid #50, with the gain control at a fixed position for this experiment, had an output of 105 dB SPL at earphone #52. The fixed resistor when switched into the circuit, reduced the output from the earphone #52 to 65 dB SPL. The variable T pad attenuator, having a range of 2 dB through 36 dB, in 2 dB steps, made it possible to determine aided speech reception thresholds from 29 dB to 65 dB HL.

The subject sat at a desk in test room 2, whereas the dummy head with hearing aids placed laterally over each ear was placed on a pedestal in test room 1 equidistant from each loudspeaker. The subject's responses were relayed to the control room by a talkback system, and were also tape recorded so that they could be rechecked. Once the subject was responding satisfactorily, the intensity was decreased gradually until the subject reported 50% of the spondee words. The output of the hearing aid receiver was then checked by coupling the earphone to the sound level meter.

Table 6. Comparison of average pure-tone thresholds, unaided speech reception thresholds, and aided speech reception thresholds using commercial hearing aids for subjects tested in Experiment II.

<u>Subj. No.</u>	<u>Ear</u>	<u>Pure Tone Average</u>	<u>Unaided SRT</u>	<u>*Aided SRT</u>
1.	R	52 dB	55 dB	37 dB
	L	45 dB	50 dB	35 dB
2.	R	50 dB	55 dB	39 dB
	L	50 dB	55 dB	37 dB
3.	R	50 dB	55 dB	37 dB
	L	52 dB	55 dB	37 dB
4.	R	53 dB	55 dB	41 dB
	L	58 dB	60 dB	45 dB
5.	R	63 dB	70 dB	45 dB
	L	63 dB	65 dB	39 dB
6.	R	55 dB	55 dB	33 dB
	L	50 dB	55 dB	31 dB
7.	R	63 dB	65 dB	39 dB
	L	58 dB	60 dB	33 dB
8.	R	45 dB	50 dB	31 dB
	L	53 dB	60 dB	37 dB
9.	R	55 dB	60 dB	37 dB
	L	53 dB	60 dB	33 dB
10.	R	58 dB	65 dB	39 dB
	L	65 dB	70 dB	43 dB

* Aided speech reception thresholds were determined in sound pressure levels in re.0002dynes/cm², and were adjusted by deducting 20 dB in order to compare the aided SRT with the unaided SRT, which were determined in re audiometric zero (in Beltone Audiometer 15CX speech circuit, 0 level established at 20 dB above .0002 dynes/cm²),

Pure tone average consists of mean of thresholds for 500, 1000, and 2000 Hz.

Table 6. (continued). Comparison of average pure-tone thresholds, unaided speech reception thresholds, and aided speech reception thresholds using commercial hearing aids for subjects tested in Experiment II.

<u>Subj. No.</u>	<u>Ear</u>	<u>Pure Tone Average</u>	<u>Unaided SRT</u>	<u>*Aided SRT</u>
11.	R	45 dB	50 dB	35 dB
	L	47 dB	50 dB	37 dB
12.	R	50 dB	55 dB	37 dB
	L	47 dB	50 dB	33 dB
13.	R	48 dB	50 dB	35 dB
	L	52 dB	55 dB	39 dB
14.	R	48 dB	55 dB	37 dB
	L	53 dB	55 dB	41 dB
15.	R	52 dB	55 dB	35 dB
	L	57 dB	60 dB	39 dB
16.	R	57 dB	60 dB	37 dB
	L	55 dB	60 dB	35 dB
17.	R	52 dB	55 dB	33 dB
	L	55 dB	60 dB	39 dB
18.	R	50 dB	55 dB	35 dB
	L	53 dB	60 dB	41 dB
19.	R	57 dB	60 dB	41 dB
	L	53 dB	55 dB	37 dB
20.	R	53 dB	60 dB	35 dB
	L	62 dB	65 dB	41 dB

*Aided speech reception thresholds were determined in sound pressure levels in re.0002dynes/cm², and were adjusted by deducting 20 dB in order to compare the aided SRT with the unaided SRT, which were determined in re audiometric zero (in Beltone Audiometer 15 CX speech circuit 0 level established at 20 dB above .0002 dynes/cm²),

Pure tone average consists of mean of thresholds for 500, 1000, and 2000 Hz.

Table 6. (continued). Comparison of average pure-tone thresholds, unaided speech reception thresholds, and aided speech reception thresholds using commercial hearing aids for subjects tested in Experiment II.

<u>Subj. No.</u>	<u>Ear</u>	<u>Pure Tone Average</u>	<u>Unaided SRT</u>	<u>*Aided SRT</u>
21.	R	45 dB	50 dB	33 dB
	L	48 dB	55 dB	37 dB
22.	R	57 dB	60 dB	39 dB
	L	48 dB	55 dB	35 dB
23.	R	57 dB	55 dB	41 dB
	L	53 dB	50 dB	39 dB
24.	R	55 dB	60 dB	35 dB
	L	57 dB	60 dB	37 dB
25.	R	52 dB	50 dB	33 dB
	L	52 dB	55 dB	35 dB

*Aided speech reception thresholds were determined in sound pressure levels in re.0002dynes/cm², and were adjusted by deducting 20 dB in order to compare the aided SRT with the unaided SRT, which were determined in re audiometric zero (in Beltone Audiometer 15 CX speech circuit 0 level established at 20 dB above .0002 dynes/cm²).

Pure tone average consists of mean of thresholds for 500, 1000, and 2000 Hz.

The sound pressure levels measured from the earphone for the twenty-five subjects tested are reported as their aided speech reception thresholds in Table 6.

7. Tests Conducted on Hearing Aids Used in Experiment II.

The hearing aids #50 and #51 used in the experiment were designed specifically for this study by Zenith Hearing Aid Sales Corp. A schematic of such hearing aids is shown in Figure 5.

a. Response Curves.

Hearing Aids #50 and #51 were tested with Bruel and Kjaer instrumentation. A Bruel and Kjaer Microphone Amplifier Model No. 2603, a Beat Frequency Oscillator Model No. 1022, a Graphic Level Recorder Model No. 2305, and Hearing Aid Chamber Model No. 4212 were employed. Frequency response curves on the hearing aids with the earphones were obtained by inserting the receiver of each hearing aid into a 2 cc coupler of the Bruel and Kjaer equipment for measuring the response of the aids. The input sound pressure level of 68 dB SPL at 1000 Hz and output sound pressure level of 105 dB SPL at 1000 Hz were used in obtaining frequency response curves for each hearing aid with earphone as shown in Figures 7, 8, 9, 10, 11 and 12.

Examination of the response curves for hearing aids #50 and #51 with earphones #52 and #53 substantiate the conclusion made that both hearing aids have approximately the same response characteristics and also that both earphones have substantially the same response curves.

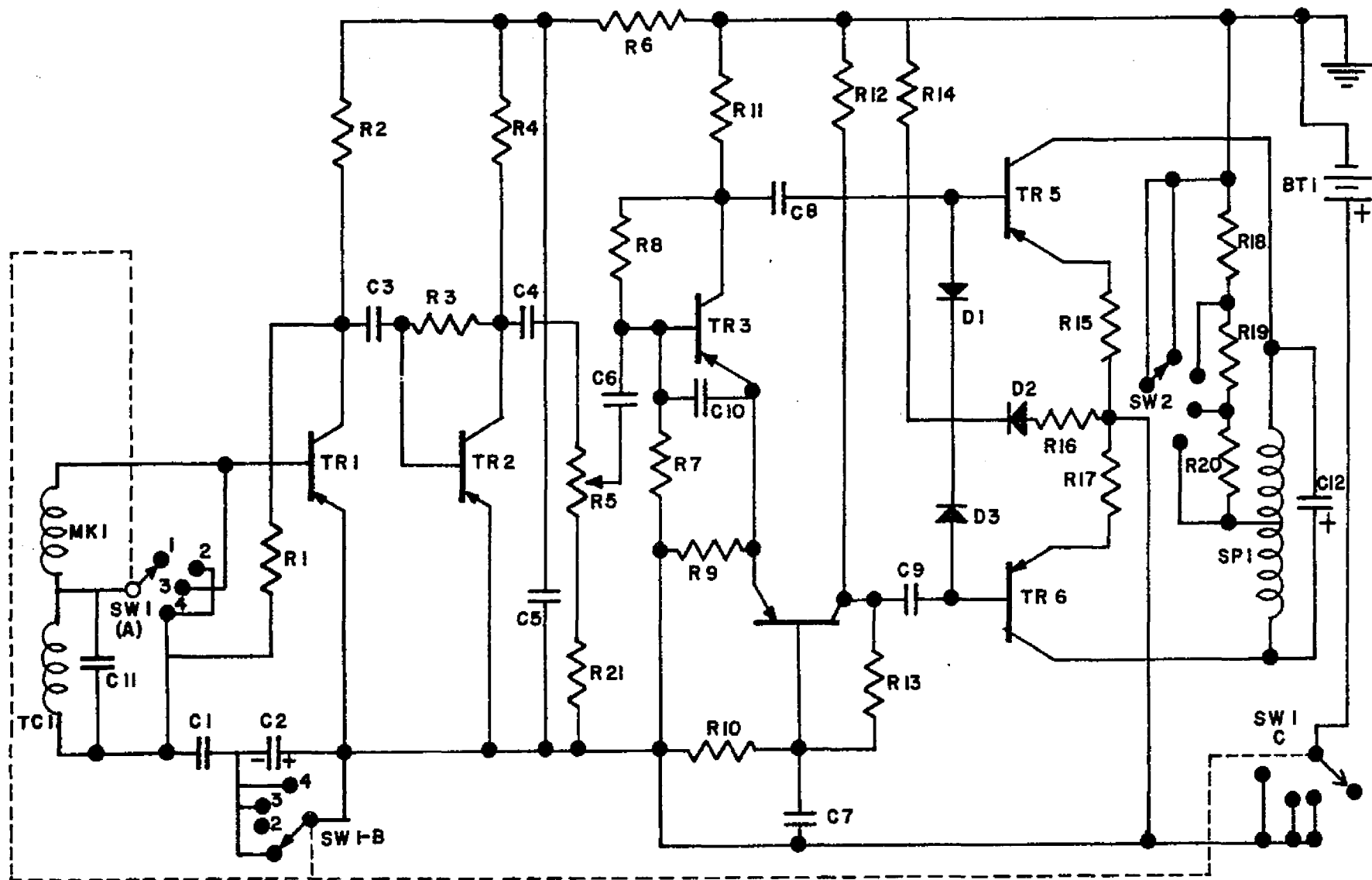


Figure 5. Schematic of commercial hearing aids #50 and #51 used in Experiment II of this study.

Table 7. Components of hearing aids #50 and #51 used in Experiments II, as shown in schematic Figure 5.

<u>NUMBER</u>	<u>VALUE</u>		<u>NUMBER</u>	<u>VALUE</u>	
C 1	1.0	MFD	R 13	33	K
C 2	0.01	MFD	R 14	6800	
C 3	1.0	MFD	R 15	4.7	
C 4	1.0	MFD	R 16	220	
C 5	10.0	MFD	R 17	4.7	
C 6	1.0	MFD	R 18	82	
C 7	1.0	MFD	R 19	33	
C 8	1.0	MFD	R 20	33	
C 9	1.0	MFD	R 21	1000	
C10	0.02	MFD	TR 1		Transistor
C11	0.02	MFD	TR 2		Transistor
C12	.5	MFD	TR 3		Transistor
R 1	180	K	TR 4		Transistor
R 2	1800		TR 5		Transistor
R 3	120	K	TR 6		Transistor
R 4	2700		D 1		Diode
R 5	200 K	V.C.	D 2		Diode
R 6	7800		D 3		Diode
R 7	22	K	MK 1		Microphone
R 8	33	K	TC 1		Tel-Coil
R 9	100		SP 1		Earphone
R 10	22	K	BT 1		Battery
R 11	820		SW 1		
R 12	1200		SW 2		

NOTES:

1. SW 1 POSITION FUNCTIONS AS FOLLOWS:
 - Pos. #1 Power Off
 - Pos. #2 Microphone-Low Cut
 - Pos. #3 Telephone Pickup
 - Pos. #4 Microphone-Full Response
2. SW 2 POWER OUTPUT SWITCH - SHOWN IN HIGH POWER POSITION.

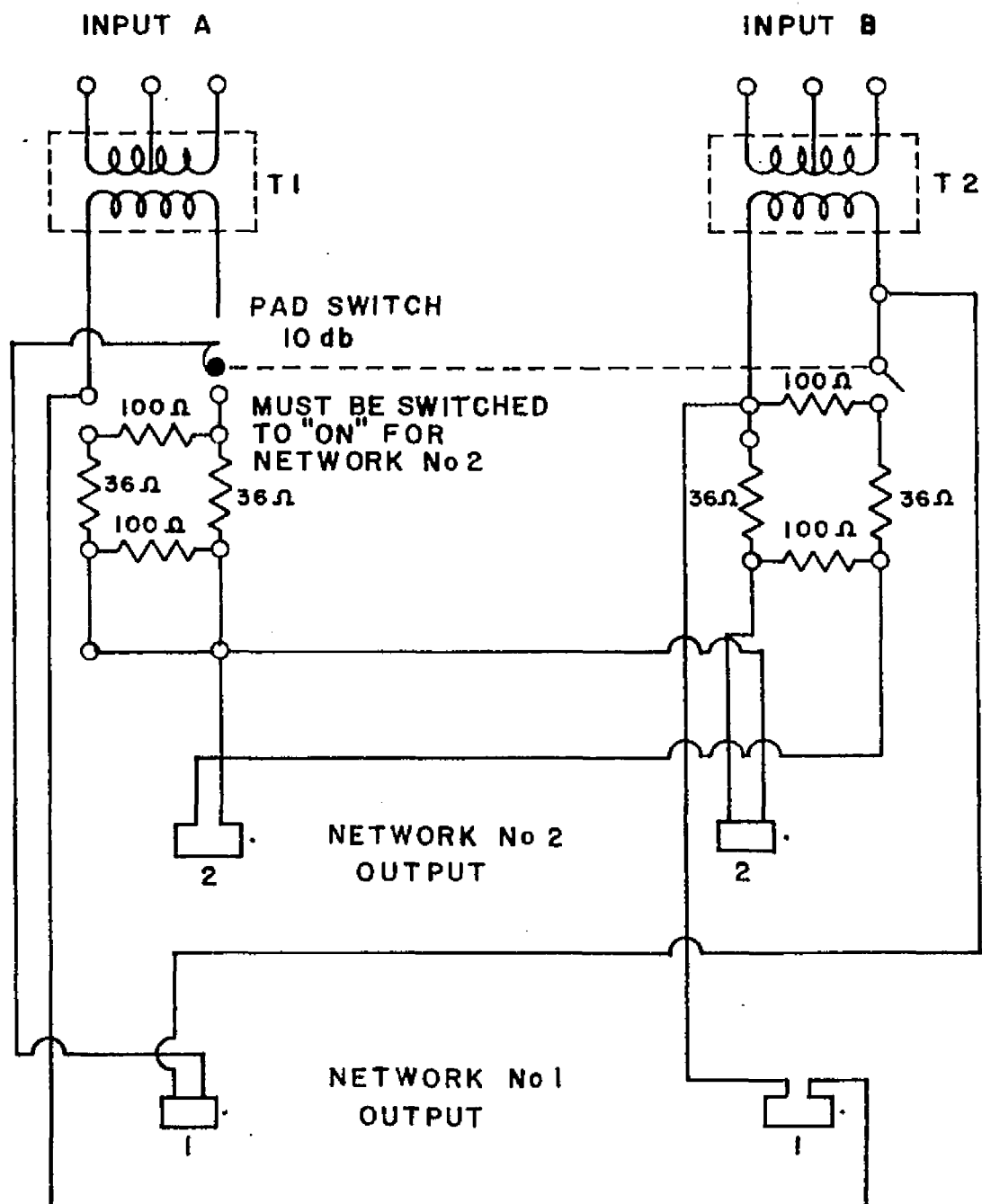


Figure 6. Schematic of adapter box for changing modes of listening using commercial hearing aids #50 and #51 in Experiment II of this study.

Figure 7. Response curve of hearing aid #50 with earphone #52, input sound pressure level at 68 dB and output sound pressure level 105 dB at 1000 Hz.

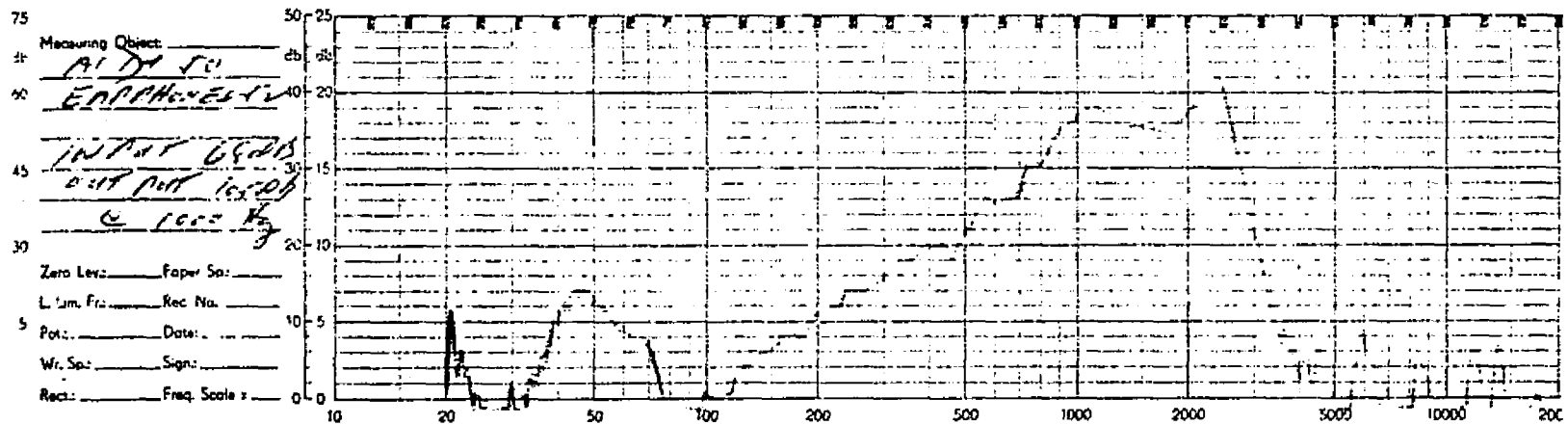


Figure 8. Response curve of hearing aid #50 with earphone #53, input sound pressure level 68 dB and output sound pressure level 105 dB at 1000 Hz.

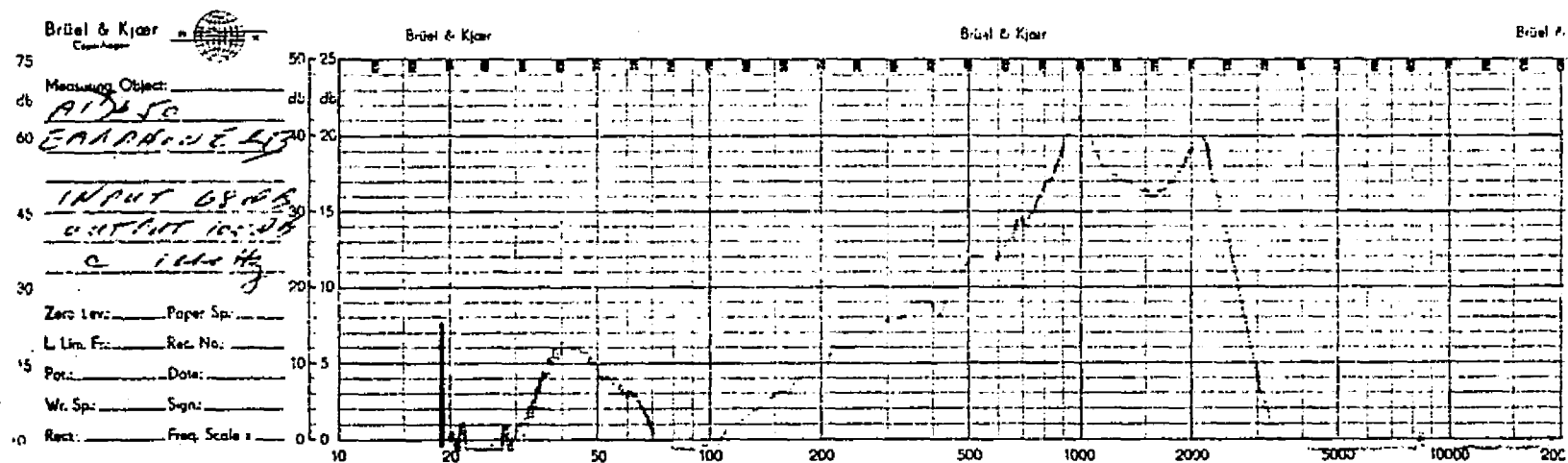


Figure 9. Response curve of hearing aid #51 with earphone #52, input sound pressure level 68 dB and output sound pressure level 105 dB at 1000 Hz.

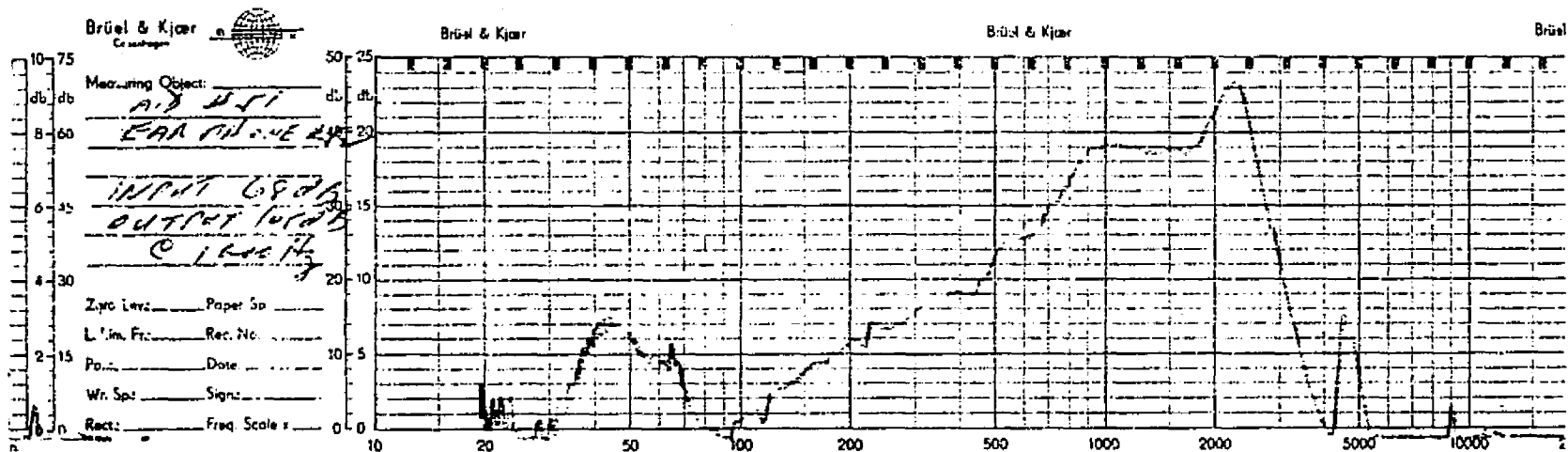


Figure 10. Response curve of hearing aid #51 with earphone #53, input sound pressure level 68 dB and out put sound pressure level 105 at 1000 Hz.

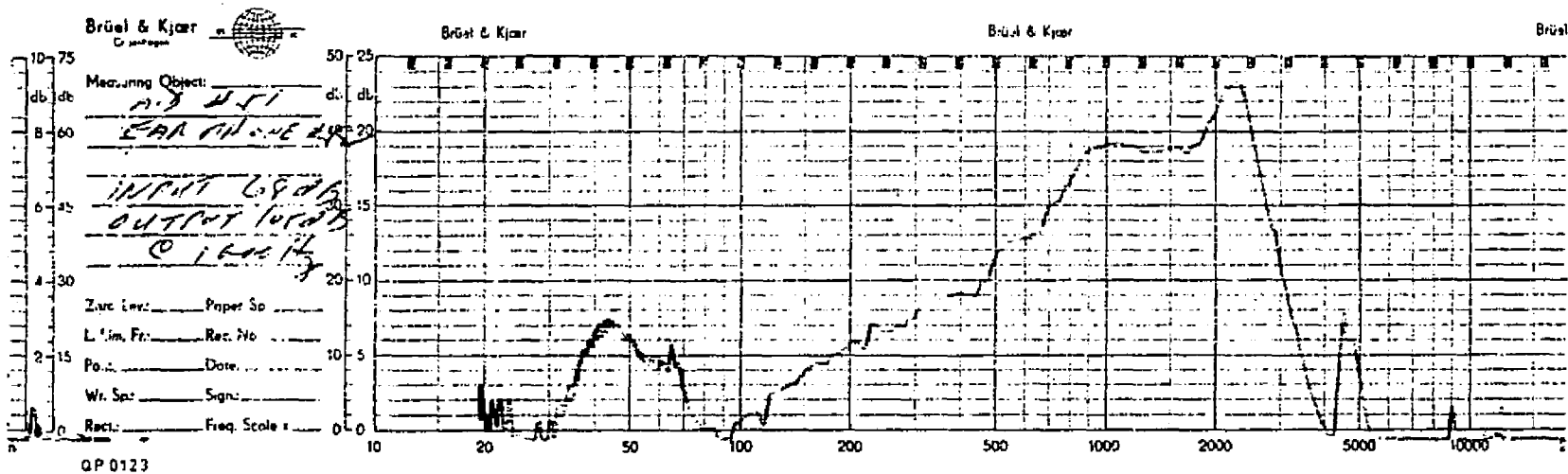


Figure 11. Response curve of hearing aids #50 and #51 with earphone #52, input sound pressure level 68 dB and output sound pressure level 105 at 1000 Hz.

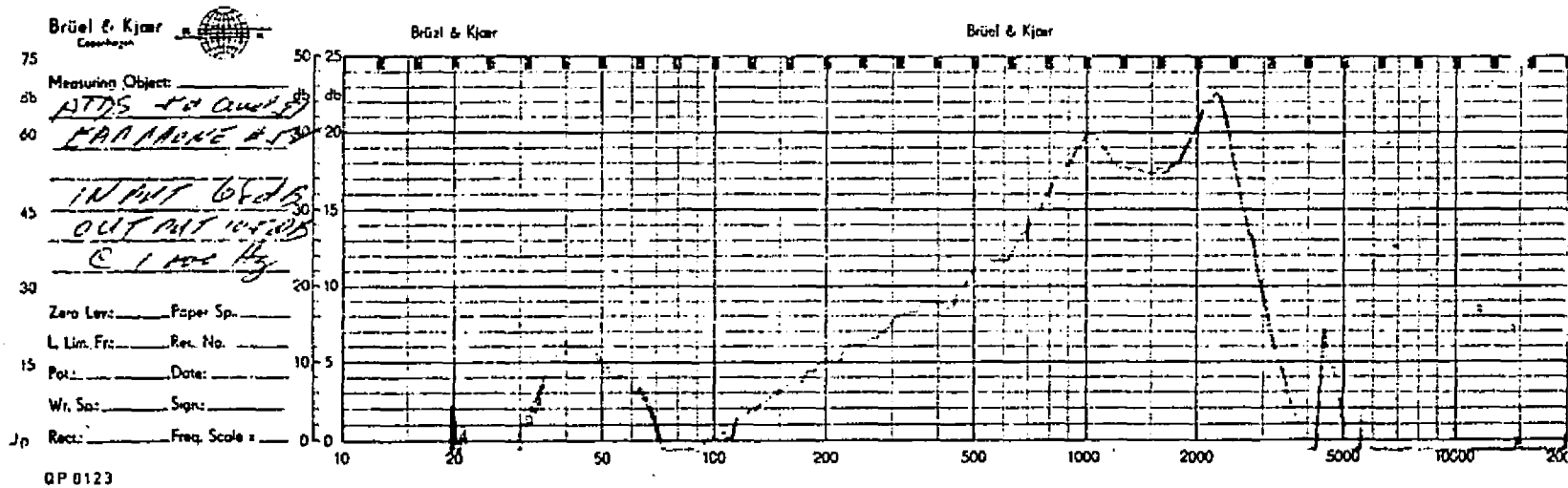


Figure 12. Response curve of hearing aids #50 and #51 with earphone #53, input sound pressure level 68 dB and output sound pressure level 105 at 1000 Hz.

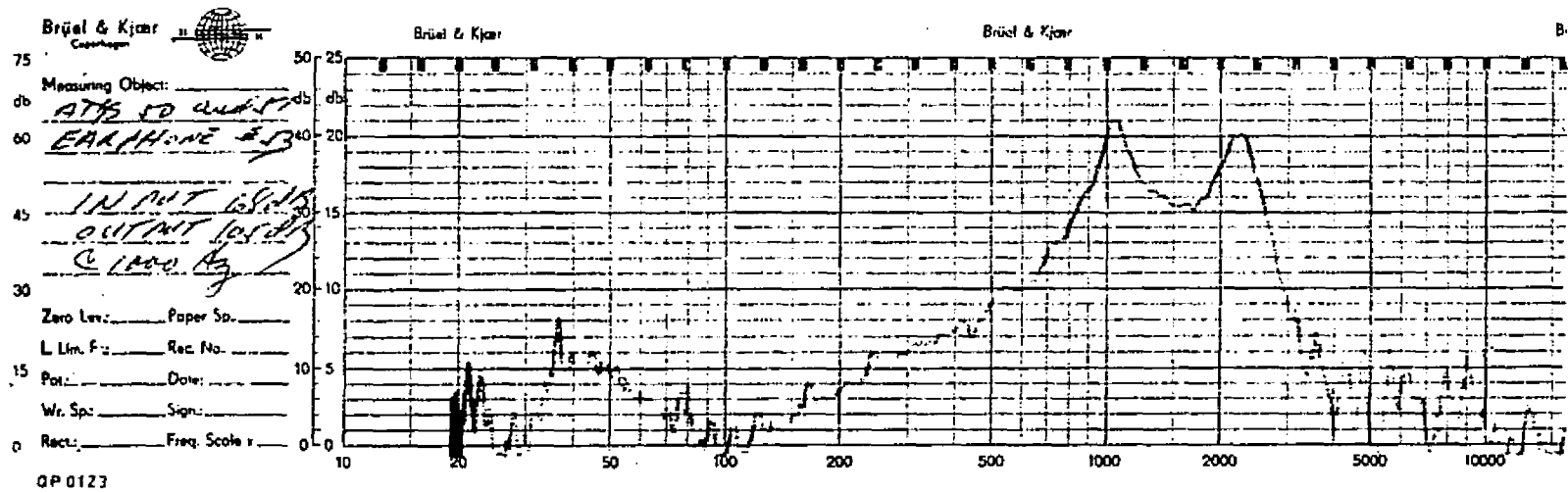


Table 8. Analysis of speech spectrum noise tapes used in Experiments I and II with General Radio Octave band analyzer Model No. 1550A.

		<u>TAPE # 1</u>				<u>TAPE # 2</u>			
		<u>SONY</u>		<u>NORELCO</u>		<u>SONY</u>		<u>NORELCO</u>	
		<u>RECORDER</u>		<u>RECORDER</u>		<u>RECORDER</u>		<u>RECORDER</u>	
		RT.	LT.	RT.	LT.	RT.	LT.	RT.	LT.
20 Hz	- 10 KHz	60	60	60	60	60	60	60	60
20	- 75 Hz	46	48	46	46	48	48	48	48
75	-150 Hz	42	42	47	46	43	43	48	49
150	-300 Hz	48	44	51	48	47	44	52	49
300	-600 Hz	51	49	52	52	48	49	52	52
600	-1200 Hz	54	54	54	54	53	53	55	54
1200	-2400 Hz	56	56	55	54	55	56	54	54
2400	-4800 Hz	51	53	48	49	50	53	46	48
4800	-10 KHz	43	43	37	37	42	43	37	37
20 Hz	-10 KHz	60	60	60	60	60	60	60	60

Input as measured on General Radio Sound Level Meter
60 dB SPL.

RT right loudspeaker - placed lateral to right ear
of dummy head.

LT left loudspeaker - placed lateral to left ear of
dummy head.

Noise Tape #1 and noise Tape #2 were recorded from
speech spectrum noise of Grason-Stadler 1962 speech audio-
meter.

All of above readings on General Radio Octave Band
Analyzer are sound pressure levels in re 0.0002 dyne/cm².

Table 9. Analysis of speech spectrum noise tapes and speech tape played simultaneously with General Radio octave band analyzer Model No. 1550A.

SUMMATION ANALYSIS
OF LOUDSPEAKERS PLAYED AS FOLLOWS:

		<u>Tape 1 on Norelco on LT Tape 2 on SONY on RT</u>	<u>Tape 1 on Norelco on LT Tape 2 on SONY on RT Tape 3 on Viking in CT</u>	<u>Tape 1 on Norelco on LT Tape 2 on SONY on RT Peterson- Lehiste Tape on Viking in CT</u>
20 Hz	-10 KHz	63	68	*69
20	-75 Hz	48	49	*54
75	-150 Hz	48	50	*54
150	-300 Hz	51	54	*60
300	-600 Hz	52	61	*69
600	-1200 Hz	55	63	*66
1200	-2400 Hz	55	62	*63
2400	-4800 Hz	50	58	*58
4800	-10 KHz	42	44	*45
20 Hz	-10 KHz	63	68	*69

All of above readings on General Radio Octave Band Analyzer are sound pressure levels in decibels in re. 0.0002 dyne/cm².

RT right loudspeaker - placed lateral to right ear of dummy head.

LT left loudspeaker - placed lateral to left ear of dummy head.

CT center loudspeaker - placed in front of the dummy head.

Output of Tape 1 on Norelco tape recorder 60 dB SPL.

Output of Tape 2 on Sony tape recorder 60 dB SPL.

Output of Tape 3 on Viking Tape Deck 68 dB SPL.

* Average peak values of 50 words of Peterson-Lehiste CNC word list 6.

b. Harmonic Distortion.

Harmonic distortion percentages of hearing aids #50 and #51 with earphones #52 and #53 were measured through the use of Bruel and Kjaer analyzing equipment, connected to Hewlett-Packard Harmonic Distortion Analyzer Model No. 331 A. The results of such percentage of harmonic distortion in hearing aids #50 and #51 with earphones #52 and #53 are reported in Tables 10 and 11. The V-cord mode using hearing aids #50 and #51 with earphones #52 and #53 was also analyzed for the percentage of harmonic distortion and the results are reported in Table 12.

8. Speech Discrimination Scores, Experiment I.

The speech stimulus used for speech discrimination testing in this study was the revised monosyllabic word lists prepared by Peterson and Lehiste.¹⁵ This list of words resulted from an attempt on the part of Peterson and Lehiste to design a speech discrimination test that would meet the requirements, that the sounds in the words listed be proportional to their presence in English speech and meet phonemic rather than phonetic speech considerations.

¹⁵G.E. Peterson and I. Lehiste, "Revised CNC Lists for Auditory Tests," Journal of Speech and Hearing Disorders, 27 (1962), pp. 62-70.

Table 10. Percentage of harmonic distortion of hearing aid #50 with earphones #52 and #53 using 1000 Hz pure-tone as stimulus, at input level of 68 dB SPL and output level of 105 dB SPL.

<u>Hearing Aid No.</u>	<u>Earphone No.</u>	<u>Frequency</u>	<u>Output</u>	<u>% Distortion</u>
#50	#52	250 Hz	80 dB SPL	4 %
#50	#52	500 Hz	89 dB SPL	2½%
#50	#52	1000 Hz	105 dB SPL	1½%
#50	#52	2000 Hz	104 dB SPL	1%
#50	#52	2500 Hz	107 dB SPL	1%
#50	#52	3000 Hz	89 dB SPL	1½%
#50	#53	250 Hz	79 dB SPL	7%
#50	#53	500 Hz	86 dB SPL	3%
#50	#53	1000 Hz	105 dB SPL	1½%
#50	#53	2000 Hz	100 dB SPL	1½%
#50	#53	2500 Hz	103 dB SPL	1½%
#50	#53	3000 Hz	86 dB SPL	2%

Input 68 dB SPL at 1000 Hz
Output 105 dB SPL at 1000 Hz

Bruel and Kjaer equipment with Hewlett-Packard harmonic distortion analyzer.

Table 11. Percentage of harmonic distortion of hearing aid #51 with earphones #52 and #53 using 1000 Hz pure-tone as stimulus, at input level of 68 dB SPL and output level of 105 dB SPL.

<u>Hearing Aid No.</u>	<u>Earphone No.</u>	<u>Frequency</u>	<u>Output</u>	<u>% Distortion</u>
#51	#52	250 Hz	80 dB	6½%
#51	#52	500 Hz	87 dB	3%
#51	#52	1000 Hz	105 dB	1½%
#51	#52	2000 Hz	107 dB	1%
#51	#52	2500 Hz	111 dB	1%
#51	#52	3000 Hz	94 dB	1½%
#51	#53	250 Hz	78 dB	8%
#51	#53	500 Hz	84 dB	4%
#51	#53	1000 Hz	105 dB	2%
#51	#53	2000 Hz	103 dB	1%
#51	#53	2500 Hz	107 dB	1%
#51	#53	3000 Hz	89 dB	2%

Input 68 dB SPL at 1000 Hz
Output 105 db SPL at 1000 Hz

Bruel and Kjaer equipment with Hewlett-Packard
harmonic distortion analyzer.

Table 12. Percentage of harmonic distortion of hearing aids #50 and #51 with earphones #52 and #53 arranged as V-cord mode of listening using 1000 Hz pure-tone as stimulus, at input level of 68 dB SPL and output level of 105 dB SPL.

<u>Hearing Aid No.</u>	<u>Earphone No.</u>	<u>Frequency</u>	<u>Output</u>	<u>% Distortion</u>
#50 and #51	#52	250 Hz	79 dB SPL	3½%
#50 and #51	#52	500 Hz	90 dB SPL	3%
#50 and #51	#52	1000 Hz	105 dB SPL	1%
#50 and #51	#52	2000 Hz	104 dB SPL	1%
#50 and #51	#52	2500 Hz	110 dB SPL	1%
#50 and #51	#52	3000 Hz	91 dB SPL	1%
#50 and #51	#53	250 Hz	78 dB SPL	6%
#50 and #51	#53	500 Hz	85 dB SPL	4%
#50 and #51	#53	1000 Hz	105 dB SPL	1%
#50 and #51	#53	2000 Hz	102 dB SPL	1%
#50 and #51	#53	2500 Hz	106 dB SPL	1%
#50 and #51	#53	3000 Hz	89 dB SPL	1½%

Input 68 dB SPL at 1000 Hz
Output 105 dB SPL at 1000 Hz

Bruel and Kjaer equipment with Hewlett-Packard harmonic distortion analyzer.

The tape recordings of the Revised Peterson-Lehiste CNC word lists used, were recorded by Chapman¹⁶ of the IBM Data Systems Division.

Only word lists #6, #7, #8, #9, and #10 recorded on the tape prepared by Chapman were utilized in a randomized presentation, for all the speech discrimination tests. Danto¹⁷ in an unpublished Master's thesis found lists #6 through #10 to be reliable and have good interlist exchangeability.

Each subject was seated at a desk in test room 2 and supplied with a sheet of paper numbered 1 through #50, on which he wrote his responses to the monosyllabic words heard, in accordance with the instructions given to each subject as described in Appendix C.

The subject was then given the speech discrimination tests described below, with the Revised Peterson-Lehiste CNC word lists at a constant S/N ratio of +5, wearing the Beyer earphones. Each subject received the speech stimuli at a sensation level of 30 dB above the aided speech reception threshold for the ear under test. The sensation level was attained by means of adjusting the variable T-pads

¹⁶W.D. Chapman, "Tape Recordings of the Peterson-Lehiste CNC Words," Product Development Laboratory of IBM Data Systems Division Manual, (1964), pp. 1-6.

¹⁷J. Danto, "Testing Auditory Discrimination With CNC Words," Unpublished Master's thesis, Brooklyn College, Brooklyn, New York (1967).

so that the sound pressure level at each earphone was 30 dB above the subject's aided SRT, as measured on the General Radio sound level meter, by coupling the Beyer earphone to the meter.¹⁸

a. Monotic Mode.

The high fidelity amplifying system was used with one channel amplification terminating in each Beyer earphone and only one earphone was placed over either the right ear or the left ear of the subject seated in test room 2. The speech stimulus tape was then played through the center loudspeaker at 68 dB SPL, as previously described, and each noise tape was played through a lateral loudspeaker at 60 dB SPL, as described previously. The subject recorded his responses on the sheets provided for him on the desk in test room 2. The ear tested first was alternated among the subjects as shown in the randomization of various modes of listening. (see Appendix D).

b. Monotic V-cord Mode.

The high fidelity amplifying system was used with the output of each Ampex insert microphone fed through the Eico H.E. 85 pre amplifier and then through the McIntosh #225 amplifier, through the T-pads into Mode Control Unit.

¹⁸ Special coupler obtained from Gotham Radio Company, New York, in order to measure sound pressure level output from Beyer earphone with General Radio sound level meter.

The output of each channel was fed into one Beyer earphone (the same earphone used in the monaural monotic test, described in (a. above). This particular test was always performed with the Beyer earphone placed over the ear which showed the better speech discrimination score under the monaural mode of listening. The Beyer earphones were marked right and left, therefore, the same earphone was always placed on the same ear for the various modes of listening.

c. Binaural Mode.

The high fidelity amplifying system was used with the output of each Ampex insert microphone fed through the Eico H.E. 85 pre amplifier and then through the McIntosh #225 amplifier, through the T pads into Mode Control Unit. For this dichotic mode of listening the output of each channel was kept completely independent of the other, from Ampex insert microphones to Beyer earphones. The earphones were placed over the ears of the subject, and the subject recorded his responses on the sheets provided for him on the desk in test room 2.

d. Double V-Cord Mode.

The high fidelity amplifying system was used with the output of each Ampex insert microphone fed through the Eico H.E. 85 pre amplifier and then through the McIntosh #225 amplifier, through the T pads into Mode Control Unit. The output of each channel was then mixed so that the resultant output went into both Beyer earphones. The

Figure 13. Response curve of Beyer Earphone Model No. DT 48 S as measured with 6 cc NBS Coupler, type 9 A, used on right ear of subject in Experiment I.

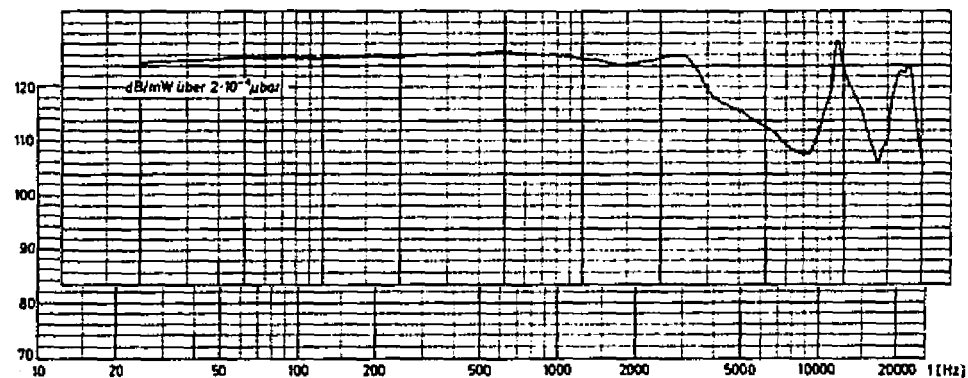
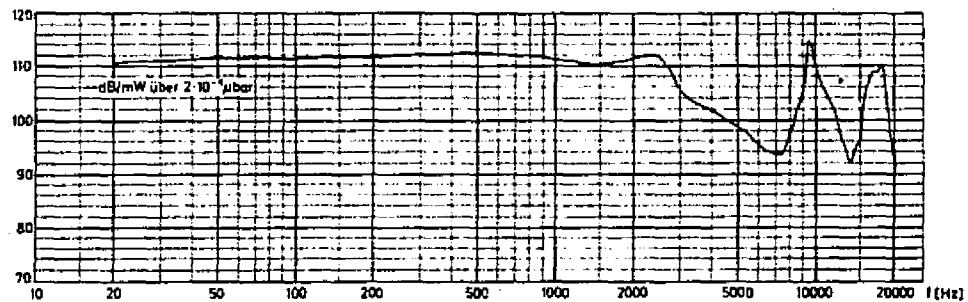


Figure 14. Response curve of Beyer Earphone Model No. DT 48 S as measured with 6 cc NBS Coupler, type 9 A, used on left ear of subject in Experiment I.



earphones were placed over the ears of the subjects, and the subject recorded his responses on the sheets provided for him on the desk in test room 2.

The tests involving the various monotic and dichotic modes of listening were randomized after the monotic test described under (a.) above, had been conducted so that the ear with the better speech discrimination could be ascertained, (see Appendix D - Randomization of modes of listening).

The five Revised Peterson-Lehiste CNC word lists used in this study were also randomized, (see Appendix D Randomization of CNC word lists).

9. Speech Discrimination Scores, Experiment II.

The speech stimulus used for speech discrimination testing was the revised monosyllabic word lists prepared by Peterson and Lehiste as previously described. Each subject was seated at a desk in test room 2 and supplied with a sheet which was numbered 1 through 50, on which he wrote his responses to the monosyllabic words in accordance with the instructions given to him, (see Appendix C).

Each subject was given the tests described below for speech discrimination with the Revised Peterson-Lehiste CNC word lists at a constant S/N ratio of +5. The settings of the main controls of each hearing aid, #50 and #51, with earphones #52 and #53 were fixed, as previously described. The sound was delivered through the particular earphone at a sensation level of 30 dB above the aided speech reception

threshold of the ear into which it was placed. The sensation level was ascertained by means of adjusting the variable T pads so that the sound pressure level at each earphone was 30 dB above the subject's aided SRT, as read on a General Radio sound level meter, by placing each earphone into a 2 cc coupler on the meter.

a. Monotic Mode.

A commercial hearing aid #50 with earphone #52, used as a one channel amplifier, the earphone placed on a custom made earmold was inserted into either the right ear, or the left ear of the subject. The speech stimulus tape was then played through the center loudspeaker at 68 dB SPL, as previously described, and both noise tapes were played through the lateral loudspeakers at 60 dB SPL, as described previously. The subject recorded his responses on the sheets provided for him on the desk in test room 2. The ear tested first was alternated among the subjects as shown in the randomization of various modes of listening. (see Appendix D).

b. Monotic V-Cord Mode.

Hearing aids, #50 and #51, were placed with each aid on one side of the dummy head in test room 1, and the output of the two aids went into an adaptor box (Figure 4). The output of each aid was fed into earphone #52, (the same earphone used in the monaural monotic test, described in (a.) above. This particular test was always performed with the earphone attached to the custom earmold, and inserted

into the subject's ear which showed the better speech discrimination score under the monaural mode (a) of testing.

c. Binaural Mode.

This dichotic mode of listening made use of two commercial hearing aids, #50 and #51, each aid positioned on each side of the dummy head in test room 1, and the earphone of each hearing aid attached to a custom made earmold inserted into each ear of the subject. Earphone #52 used in monotic tests (monaural and monotic V-cord, (a) and (b), described above), was placed on a earmold and inserted into the ear showing the better discrimination score under the monotic test (a). Each hearing aid and each earphone was completely separate and each hearing aid amplification system was completely independent of the other hearing aid and earphone.

d. Double V-Cord Mode.

This dichotic mode of listening made use of commercial hearing aids, #50 and #51. A hearing aid was placed on the dummy head, positioned in test room 1, and the output of the two aids was fed into an adaptor box (Figure 4), in which the output of each aid was mixed so that the resultant output went into each of the earphones #52 and #53. Earphone #52 used in the monotic tests, (a) and (b) described above, was attached to a custom earmold and

inserted into the ear showing the better discrimination score under the monotic test (a). Earphone #53 was attached to a custom earmold and inserted into the other ear.

The tests involving the various monotic and dichotic modes of listening in Experiment II were randomized after the monotic test described under (a) above had been conducted, so that the ear with the better discrimination could be determined, (see Appendix D).

The five Revised Peterson-Lehiste CNC word lists used in Experiment II in this study were also randomized, (see Appendix D).

Rest periods were interspersed between successive tests to avoid fatigue of subject during these relatively time consuming and tedious tests.

D. Scoring.

1. Scoring, Experiment I.

The subjects wrote their responses to the Revised Peterson-Lehiste CNC word lists as they heard them in test room 2, through earphones (Beyer), for the various modes of listening on five sheets each having a numbered listing, 1 through 50.

a. Discrimination Scores on One-Point-Per-Word-Basis.

Speech discrimination scores were obtained by awarding

one point for each correct word and multiplying the results by two in order to obtain a percentage of words correctly reported by the subject (see Appendix G).

b. Discrimination Scores on a Three-Point-Per-Word-Basis.

Speech discrimination scores were also obtained by a system proposed by Duffy,¹⁹ by giving one point for each phoneme correctly identified by the subject. Each word in the Revised Peterson-Lehiste CNC word lists has three phonemes. The results were multiplied by the fraction of two-thirds in order to obtain a percentage of phonemes correctly identified, based on a maximum percentage of 100 per cent (see Appendix G).

2. Scoring, Experiment II.

The subjects wrote their responses to the Revised Peterson-Lehiste CNC word lists as they heard them in test room 2, through earphones #52 and #53, for the various modes of listening, on five sheets each having a numbered listing of 1 through 50.

a. Discrimination Scores on One-Point-Per-Word-Basis.

Speech discrimination scores were obtained by awarding one point for each word correctly reported by the subject as described for Experiment I (see Appendix G).

¹⁹J.K. Duffy, "Audio-visual Speech Audiometry and a New Audio and Audio-visual Speech Perception Index," Maico Audiological Library Series, Vol. V, Report 9 (1967), pp. 1-3.

b. Discrimination Scores on a Three-Point-Per-Word-Basis.

Speech discrimination scores were also obtained by giving one point for each phoneme correctly identified by the subject, as explained in scoring for Experiment I.

Speech discrimination scores obtained by the scoring systems described, were then entered on each of the subjects data sheets, (see Appendix G).

E. Statistical Treatment of Data.

The decision as to whether or not any of the various modes of listening was superior to the other modes, for speech discrimination, was resolved by means of statistical treatment of the data.

F. Method of Analyzing the Data.

The hypotheses of no significant differences in the mean discrimination scores between the various modes of listening utilizing high fidelity amplifiers and earphones of Experiment I, and using commercial hearing aids of Experiment II, were tested by a two factor analysis of variance for repeated measures (Winer).²⁰ One factor, with four levels, being the modes of listening and the second factor, with two levels, being the methods of amplification (high fidelity equipment and commercial hearing aids). The

²⁰B.J. Winer, Statistical Principles in Experimental Design. (New York: McGraw-Hill Book Company, 1962), pp. 298-307.

two factor analysis of variance was computed separately for each method of scoring (one point per word, and three points per word). The 1% confidence level was used in the test of significance, of difference between the sample means being attributable to random variation.

Comparisons between all possible pairs of treatment means were made by using the Newman Keuls test procedure as described by Winer.²¹ The 1% confidence level was used as criterion for determination of statistical significance in the Newman-Keuls procedure.

G. Summary.

This study consisted of two experiments. In Experiment I, twenty-five subjects with approximately bilateral symmetrical sensory hearing losses, were given speech discrimination tests using high fidelity amplifiers and earphones under four different modes of listening.

In Experiment II, an additional twenty-five subjects with approximately bilateral symmetrical sensory hearing losses, were given the same speech discrimination tests using commercial hearing aids under the same four modes of listening.

Head movements in this study were controlled by the use of a dummy head. Intensity and spectrum differences

²¹Winer, op. cit., pp. 309-312.

at the two ears of the acoustic stimuli presented, normally caused by diffraction of sound waves by the head, were avoided by using three loudspeakers (a center loudspeaker for speech and two lateral loudspeakers for the masking noise).

The speech and noise stimuli were administered at a constant signal-to-noise ratio of +5, for all speech discrimination tests. The speech stimuli, the Revised Peterson-Lehiste CNC word lists, were presented at a sensation level of 30 dB above the aided speech reception thresholds.

The word lists used in the speech discrimination tests and the modes of listening used in both experiments were randomized.

The acceptance or rejection of null hypotheses as to significant differences between treatment means in Experiments I and II were resolved by means of parametric statistical procedures utilizing two factor analysis of variance for repeated measures, and Newman-Kuels procedures for multiple comparisons between treatment means.

CHAPTER IV
RESULTS AND DISCUSSION

In this chapter the data resulting from Experiment I, using high fidelity amplifiers and earphones and from Experiment II, using commercial hearing aids has been tabulated, summarized, and analyzed statistically. The tables prepared show the results of computing speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists for the four modes of listening utilized.

A discussion of the results of this investigation as related to the experimental design of the study completes the chapter.

A. Results.

Table 13 shows a comparison between the means of speech discrimination scores computed by a system of scoring which awarded one point for each word correctly reported, and the means of speech discrimination scores computed by a system of scoring which awarded one point for each phoneme correctly identified when using high fidelity amplifiers and earphones for the four modes of listening. It can be seen that speech perception for the binaural mode was superior to all other modes of listening employed for both systems of scoring. The means of speech discrimination scores were higher for dichotic modes than the means of speech discrimination scores for the monotic modes, for both systems of scoring. The monotic V-cord mode increased speech perception over the monaural mode for both systems of scoring.

Table 13. Comparison of the means, standard deviations of the means, and standard errors of the means of speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects using high fidelity amplifiers and earphones, computed by two methods of scoring in Experiment I (N=25).

SCORED ONE POINT PER WORD BASIS

	<u>MONOTIC MODES</u>		<u>DICHOTIC MODES</u>	
	<u>Monaural Better Ear</u>	<u>V-Cord Better Ear</u>	<u>Binaural</u>	<u>Double V-Cord</u>
Mean	65.92	79.04	85.12	83.92
S.D.	3.82	5.32	3.64	6.62
S.E.	.76	1.06	.73	1.33

SCORED THREE POINTS PER WORD BASIS

Mean	75.13	84.01	89.12	87.84
S.D.	4.62	5.53	2.96	2.64
S.E.	.92	1.01	.59	.53

S.D. = Standard deviation

S.E. = Standard error

An examination of the standard deviations associated with the mean of speech discrimination scores for the four modes of listening in Table 13 shows that the standard deviations for the four modes are relatively homogeneous, the smallest being 3.64 and the largest being 6.62 for scoring on a basis of awarding one point for each word correctly reported and the smallest being 2.64 and the largest being 5.53 for a scoring on a basis of one point per phoneme correctly identified.

Table 14 shows a comparison of the means of speech discrimination scores computed by a system of scoring which awarded one point for each word correctly reported and the means of speech discrimination scores computed by a system of scoring which awarded one point for each phoneme correctly identified when using commercial hearing aids for the four modes of listening. It can be seen that speech perception for the binaural mode was superior to all other modes of listening employed for both systems of scoring. The means of speech discrimination scores were higher for dichotic modes than the means of speech discrimination for the monotic modes when scored on a basis of awarding one point for each word correctly reported. However, the mean of speech discrimination for the monotic V-cord mode is 11% higher than the monaural mean when scored on a basis of awarding one point for each word correctly reported and is 14% higher when scored on a basis of awarding one point for each phoneme correctly identified.

Table 14. Comparison of the means, standard deviations of the means, and standard errors of the means of speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects using commercial hearing aids, computed by two methods of scoring in Experiment II (N=25).

SCORED ONE POINT PER WORD BASIS

<u>MONOTIC MODES</u>		<u>DICHOTIC MODES</u>		
<u>Monaural</u> <u>Better Ear</u>	<u>V-Cord</u> <u>Better Ear</u>	<u>Binaural</u>	<u>Double V-Cord</u>	
Mean	55.12	66.40	70.24	67.92
S.D.	5.32	9.52	5.16	4.92
S.E.	1.06	1.90	1.03	.98

SCORED THREE POINTS PER WORD BASIS

Mean	65.92	79.56	83.66	78.71
S.D.	5.39	4.47	4.21	4.61
S.E.	1.08	.89	.84	.92

S.D. = Standard deviation

S.E. = Standard error

An examination of the standard deviations associated with the mean of speech discrimination scores for the four modes of listening in Table 14 shows that the standard deviations for the four modes are relatively homogeneous, the smallest being 4.92 and the largest being 9.52 for scoring on basis of awarding one point for each word correctly reported and the smallest being 4.21 and the largest being 5.39 for scoring on the basis of awarding one point for each phoneme correctly identified.

Table 15 shows a comparison of the means of speech discrimination scores between subjects using high fidelity amplifiers and earphones, Experiment I, and subjects using commercial hearing aids, Experiment II, for the four modes of listening scored on the basis of awarding one point for each word correctly reported. It can be seen that high fidelity amplifiers and earphones are superior for speech perception to the use of commercial hearing aids for all the modes of listening. The increase of the mean of speech discrimination scores between high fidelity amplifiers and commercial hearing aids is 11% for the monaural mode, 13% for the monotic V-cord mode, 15% for the binaural mode and 16% for double V-cord mode of listening.

Table 16 shows a comparison of the means of speech discrimination scores between subjects using high fidelity amplifiers and earphones, Experiment I, and subjects using commercial hearing aids, Experiment II, for the four modes of listening scored on the basis of awarding one point

Table 15. Comparison of the means, standard deviations of the means, and standard errors of the means of speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects using high fidelity amplifiers and earphones in Experiment I and subjects using commercial hearing aids in Experiment II, computed by a method of scoring awarding one point for each word correctly reported (N=25).

	<u>MONOTIC MODES</u>		<u>DICHOTIC MODES</u>	
	<u>Monaural Better Ear</u>	<u>V-Cord Better Ear</u>	<u>Binaural</u>	<u>Double V-Cord</u>
<u>High Fidelity Amplifiers</u>		<u>Experiment I</u>		
Mean	65.92	79.04	85.12	83.92
S. D.	3.82	5.32	3.64	6.62
S. E.	.76	1.06	.73	1.33
<u>Commercial Hearing Aids</u>		<u>Experiment II</u>		
Mean	55.12	66.40	70.24	67.92
S. D.	5.32	9.52	5.16	4.92
S. E.	1.06	1.90	1.03	.98

S. D. = Standard deviation

S. E. = Standard error

Table 16. Comparison of the means, standard deviations of the means, and standard errors of the means of speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects using high fidelity amplifiers and earphones in Experiment I and subjects using commercial hearing aids in Experiment II, computed by a method of scoring awarding one point for each phoneme correctly identified (N=25).

	<u>MONOTIC MODES</u>		<u>DICHOTIC MODES</u>	
	<u>Monaural Better Ear</u>	<u>V-Cord Better Ear</u>	<u>Binaural</u>	<u>Double V-Cord</u>
<u>High Fidelity Amplifiers</u>		<u>Experiment I</u>		
Mean	75.13	84.01	89.12	87.84
S. D.	4.62	5.53	2.96	2.64
S. E.	.92	1.01	.59	.53
<u>Commercial Hearing Aids</u>		<u>Experiment II</u>		
Mean	65.92	79.56	83.66	78.71
S. D.	5.39	4.47	4.21	4.61
S. E.	1.08	.89	.84	.92

S.D. = Standard deviation

S.E. = Standard error

for each phoneme correctly identified. It can be seen that high fidelity amplifiers and earphones are superior for speech perception to the use of commercial hearing aids for all modes of listening. The increase of the mean of speech discrimination scores between high fidelity amplifiers and the commercial hearing aids is 9% for the monaural mode, 4% for the monotic V-cord mode, 5% for the binaural mode and 9% for the double V-cord mode of listening.

A comparison of the results of Tables 15 and 16 indicates that the differences of the mean of speech discrimination scores for the same mode of listening between subjects using high fidelity amplifiers and earphones in Experiment I and subjects using commercial hearing aids in Experiment II are much larger when scoring on a basis of awarding one point for each word correctly reported than scoring on a basis of awarding one point for each phoneme correctly identified.

Table 17 shows a two factor analysis of variance for repeated measures with factor A, (methods of amplification, two levels). The two levels are (1) high fidelity amplifiers and earphones and (2) commercial hearing aids. Factor B, (modes of listening, four levels). The four levels are (1) monaural mode, (2) monotic V-cord mode, (3) binaural mode, and (4) double V-cord mode of listening. Speech discrimination scores were computed on the basis of awarding one point for each word correctly reported. The analysis of variance indicates that the F for factor A,

methods of amplification, is highly significant at the .01 confidence level. The F for factor B, modes of listening is also highly significant at the .01 confidence level. The interaction effect of factors A x B, methods of amplification with modes of listening, is not significant at the .01 level, the criterion established as the confidence level for statistical significance for this study as described in Chapter III on Procedure. The fact that the interaction is not significant can be seen graphically in Figure 15.

Table 18 shows a two factor analysis of variance for repeated measures with factor A, (methods of amplification, two levels). The two levels are (1) high fidelity amplifiers and earphones, and (2) commercial hearing aids. Factor B, (modes of listening, four levels). The four levels are (1) monaural, (2) monotic V-cord mode, (3) binaural mode, and (4) double V-cord mode of listening. Speech discrimination scores were computed on the basis of awarding one point for each phoneme correctly identified. The analysis of variance indicates that the F for factor A, (methods of amplification), is significant at the .01 level. Factor B, (modes of listening), is highly significant at the .01 confidence level. The interaction of factors A x B, methods of amplification with modes of listening is barely significant at the .01 level; the value computed for F is 5.02 and the table value of $F_{.99}$ is 3.95 indicating that the

Table 17. Two factor analysis of variance for repeated measures of speech discrimination scores with factor A (methods of amplification, two levels representing high fidelity amplifiers and earphones, and commercial hearing aids), and with factor B (modes of listening, four levels representing monaural, monotic V-cord, binaural, and double V-cord modes), computed by a method of scoring awarding one point for each word correctly reported (N=25).

<u>SOURCE OF VARIATION</u>	<u>SUM OF SQUARES</u>	<u>df</u>	<u>MEAN SQUARE</u>	<u>F</u>
<u>Between subjects</u>	3068	<u>49</u>		
A (Methods of Amplification)	2319	1	2319.0	148.65*
Subjects within groups	749	48	15.6	
<u>Within subjects</u>	3196	<u>150</u>		
B (Modes of listening)	2268	3	756	123.9*
A X B	47	3	15.6	2.56
B X Subjects within groups	881	144	6.1	

* Significant at the 1% confidence level.

Table value of $F_{.99}$ (1, 48 Degrees of freedom) = 7.31

Table value of $F_{.99}$ (3,144 Degrees of freedom) = 3.95

Table 18. Two factor analysis of variance for repeated measures of speech discrimination scores with factor A (methods of amplification, two levels representing high fidelity amplifiers and earphones, and commercial hearing aids), and with factor B (modes of listening, four levels representing monaural, monotic V-cord, binaural, and double V-cord modes), computed by a method of scoring awarding one point for each phoneme correctly identified (N=25).

<u>SOURCE OF VARIATION</u>	<u>SUM OF SQUARES</u>	<u>df</u>	<u>MEAN SQUARE</u>	<u>F</u>
<u>Between subjects</u>	<u>9716</u>	<u>49</u>		
A (Methods of amplification)	4851	1	4851	47.86*
Subjects within groups	4865	48	101.35	
<u>Within subjects</u>	<u>22,671</u>	<u>150</u>		
B (Modes of listening)	18,732	3	6244	252.18*
A X B	373	3	124.3	5.02*
B X Subjects within groups	3,566	144	24.76	

* Significant at the 1% confidence level.

Table value of $F_{.99}$ (1, 48 Degrees of freedom) = 7.31

Table value of $F_{.99}$ (3,144 Degrees of freedom) = 3.95

difference between A_1 and A_2 (high fidelity amplification and commercial hearing aids) is not independent of the levels of B, modes of listening, or equivalently, that the difference between b_1 , b_2 , b_3 , and b_4 (modes of listening) is not independent of the levels of A. In other words, a statement about the factor A effect must be qualified by the particular level of B factor involved or equivalently, a statement about the B factor effect must be qualified by the particular level of A involved. The nature of the interaction can be seen in Figure 16, the graph of the levels of B, (modes of listening) against levels of A, (method of amplification).

Figure 15 shows a graph comparing the means of speech discrimination scores for the four modes of listening between subjects using high fidelity amplifiers and ear-phones in Experiment I, and subjects using commercial hearing aids in Experiment II, scored on the basis of awarding one point for each word correctly reported. The fact that the lines are nearly parallel, within the limits of random sampling, corresponds to the fact that the interaction of methods of amplification and modes of listening is not significant as shown in Table 17.

Figure 16 shows a graph comparing the means of speech discrimination scores for the four modes of listening between subjects using high fidelity amplifiers and ear-phones in Experiment I, and subjects using commercial hearing

aids in Experiment II, scored on the basis of awarding one point for each phoneme correctly identified.

The fact that the lines in Figure 16 are not parallel within the limits of random sampling, corresponds to the fact that the interaction of methods of amplification and modes of listening is significant when speech discrimination scores are computed by a system of scoring which awarded one point for each phoneme correctly reported. By examining the nature of the interaction graphically, it is evident that the difference between the binaural mode and the double V-cord for speech perception is significant when commercial hearing aids are used, though the difference between the means of speech discrimination scores of the two modes is not significant when high fidelity amplifiers and earphones are used, as shown in Table 18.

Table 19 shows the Newman-Keuls procedure for the tests on pairs of the means of speech discrimination scores resulting from Experiment I, using high fidelity amplifiers and earphones, for the four modes of listening, computed by a system of scoring which awarded one point for each word correctly reported. All differences between pairs of means are significant at the .01 level, except the difference between the means of speech discrimination scores for the binaural mode and the double V-cord mode of listening which is not significant.

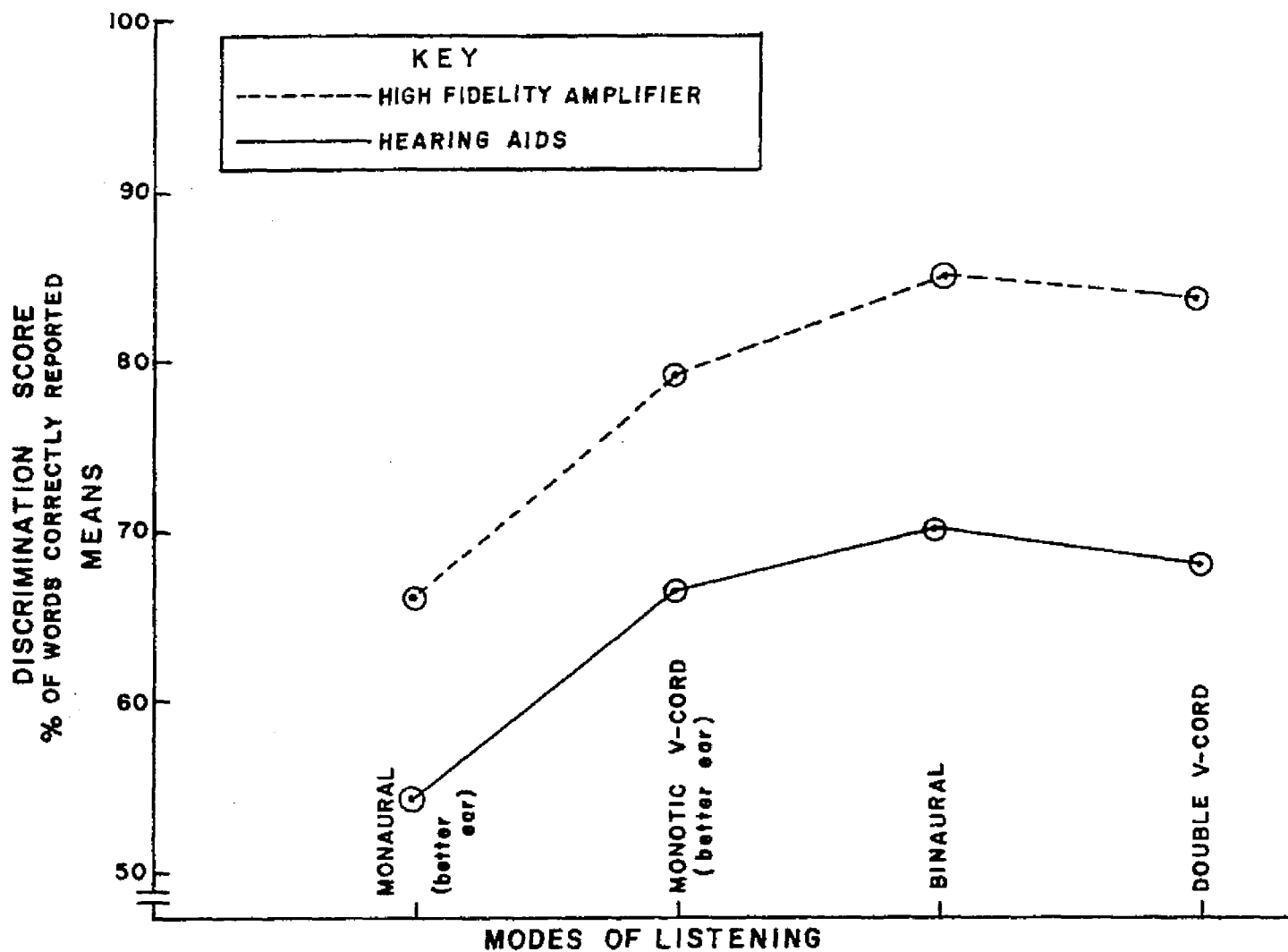


Figure 15. Comparison of mean percentage speech discrimination scores between high fidelity amplifiers and commercial hearing aids, for four modes of listening, scored on a one point per word correctly identified basis. (N=25)

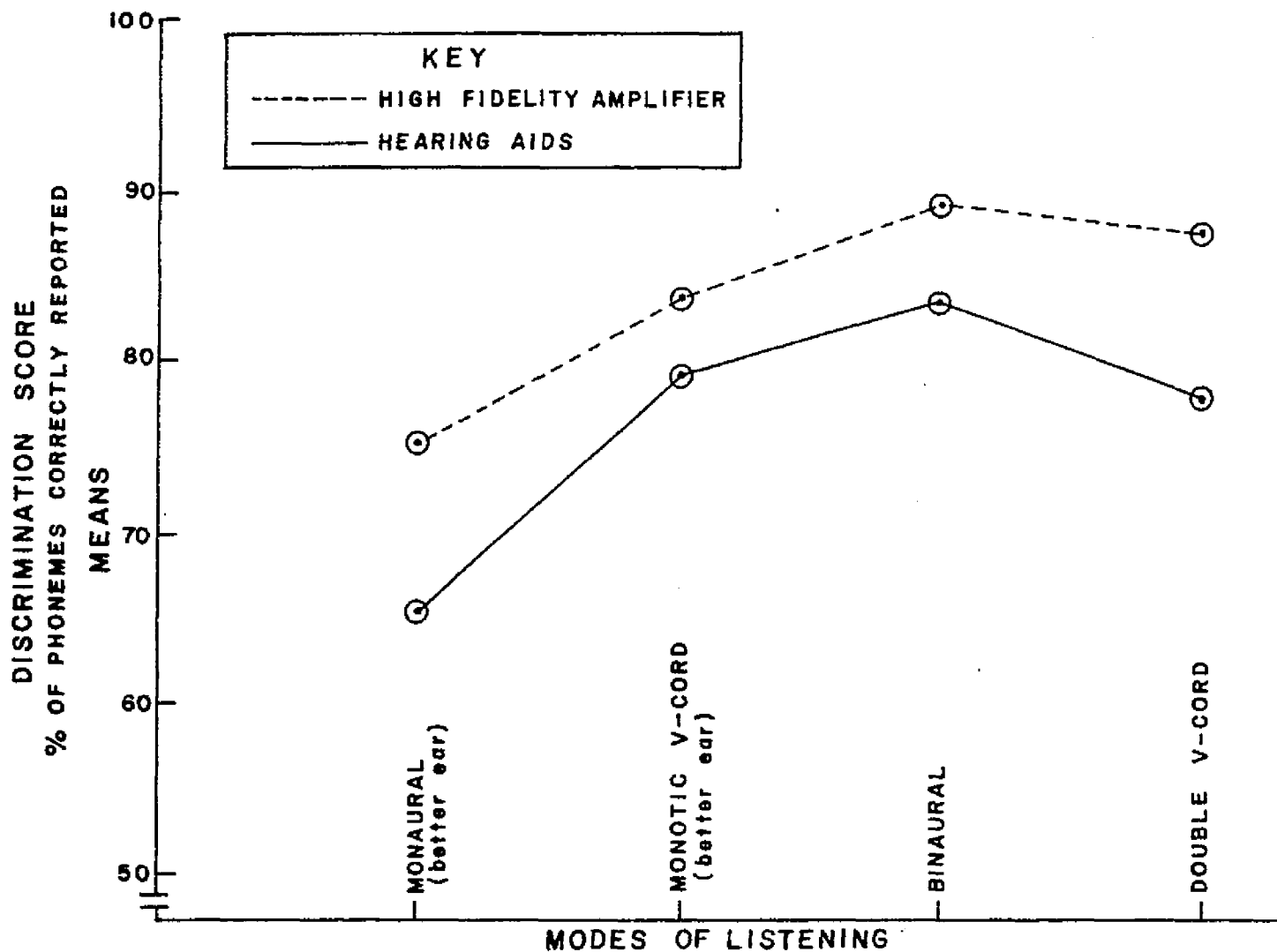


Figure 16. Comparison of mean percentage speech discrimination scores between high fidelity amplifiers and commercial hearing aids, for four modes of listening, scored on a one point per phoneme correctly identified basis. (N=25)

Table 20 shows the Newman-Keuls procedure for the tests on pairs of means of speech discrimination scores resulting from Experiment I, using high fidelity amplifiers and earphones, for the four modes of listening, computed by a system of scoring which awarded one point for each phoneme correctly identified. All differences between pairs of means are significant at the .01 level, except the difference between the means of speech discrimination scores for the binaural mode and the double V-cord mode of listening which is not significant.

Table 21 shows the Newman-Keuls procedure for the tests on pairs of means of speech discrimination scores resulting from Experiment II, using commercial hearing aids, for the four modes of listening, computed by a system of scoring which awarded one point for each word correctly reported. The differences between the pairs of means of speech discrimination scores for the monaural and binaural modes is significant at the .01 level. The difference between the pairs of means of speech discrimination scores for the monotic V-cord and the binaural modes is significant at the .01 level. The difference between the means of speech discrimination scores of the monaural and the monotic V-cord modes is significant at the .01 level. The difference between the means of speech discrimination scores for the monaural and the double V-cord modes is significant at the .01 level. There is no significant difference between

Table 19. Newman-Keuls test for significance on pairs of means of speech discrimination scores, computed by a method of scoring awarding one point for each word correctly reported for subjects using high fidelity amplifiers and earphones.

	b_1	b_2	b_4	b_3
	32.96	39.52	41.96	42.56
b_1		6.56	9.00	9.60
b_2			2.44	3.04
b_4				.60

$$S_B = .349$$

$q_{.99} (r, 144)$	$r=2$	$r=3$	$r=4$
Table values	3.70	4.20	4.50
$S_B q_{.99} (r, 144)$	1.29	1.47	1.57

	b_1	b_2	b_4	b_3
b_1		*	*	*
b_2			*	*
b_4				-

* Significant

- Not significant

b_1 Monaural (Better ear) mode

b_2 Monotic V-cord (BVtter ear) mode

b_3 Binaural mode

b_4 Double V-cord mode

Table 20. Newman-Keuls test for significance on pairs of means of speech discrimination scores, computed by a method of scoring awarding one point for each phoneme correctly identified for subjects using high fidelity amplifiers and earphones.

	b_1	b_2	b_4	b_3
	109.64	125.92	131.64	133.48
b_1		16.28	22.00	23.84
b_2			5.72	7.56
b_4				1.84

$$S_B = .704$$

$q_{.99} (r, 144)$

$r=2$

$r=3$

$r=4$

Table values

3.70

4.20

4.50

$S_B q_{.99} (r, 144)$

2.60

2.96

3.17

	b_1	b_2	b_4	b_3
b_1		*	*	*
b_2			*	*
b_4				-

* Significant

- Not significant

b_1 Monaural (Better ear) mode

b_2 Monotic V-cord (Better ear) mode

b_3 Binaural mode

b_4 Double V-cord mode

the means of speech discrimination scores for the monotic V-cord and the double V-cord modes. There is no significant difference between the pair of means of speech discrimination scores for the double V-cord and the binaural modes of listening.

Table 22 shows the Newman-Keuls procedure for the tests on pairs of the means of speech discrimination scores resulting from Experiment II, using commercial hearing aids, for the four modes of listening, computed by a system of scoring which awarded one point for each phoneme correctly identified. All differences between pairs of means are significant at the .01 level, except the difference between the means of speech discrimination scores for the monotic V-cord mode and the double V-cord mode of listening, which is not significant.

Table 23 shows the results of t-tests and significance levels for the difference between the means of speech discrimination scores for subjects using high fidelity amplifiers and earphones, Experiment I, and subjects using commercial hearing aids, Experiment II, for the four modes of listening, computed by a system of scoring which awarded one point for each word correctly reported. It can be seen that all differences between pairs of means are significant at better than the .01 level.

Table 21. Newman-Keuls test for significance on pairs of means of speech discrimination scores, computed by a method of scoring awarding one point for each word correctly reported for subjects using commercial hearing aids.

	b_1	b_2	b_4	b_3
	27.48	33.20	33.96	35.12
b_1		5.72	6.48	7.64
b_2			.76	1.92
b_4				1.16
$S_B = .349$				
$q_{.99} (r, 144)$			$r=2$	$r=3$ $r=4$
Table values			3.70	4.20 4.50
$S_B q_{.99} (r, 144)$			1.29	1.47 1.57

	b_1	b_2	b_4	b_3
b_1		*	*	*
b_2			-	*
b_4				-

* Significant

- Not significant

b_1 Monaural (Better ear) mode

b_2 Monotic V-cord (Better ear) mode

b_3 Binaural mode

b_4 Double V-cord mode

Table 22. Newman-Keuls test for significance on pairs of means of speech discrimination scores, computed by a method of scoring awarding one point for each phoneme correctly identified for subjects using commercial hearing aids.

	b_1	b_4	b_2	b_3
	98.44	118.04	119.32	125.48
b_1		19.60	20.88	27.04
b_4			1.28	7.44
b_2				6.16
$S_B = .704$				
$q_{.99} (r, 144)$		$r=2$	$r=3$	$r=4$
Table values		3.70	4.20	4.50
$S_B q_{.99} (r, 144)$		2.60	2.96	3.17

	b_1	b_4	b_2	b_3
b_1		*	*	*
b_4			-	*
b_2				*

* Significant

- Not significant

b_1 Monaural (Better ear) mode

b_2 Monotic V-cord (Better ear) mode

b_3 Binaural mode

b_4 Double V-cord mode

Table 23. Values of t and significance levels for the differences between the means of speech discrimination scores of subjects using high fidelity amplifiers and earphones, Experiment I, and of subjects using commercial hearing aids, Experiment II, computed by a method of scoring awarding one point for each word correctly reported.

	<u>MONOTIC MODES</u>		<u>DICHOTIC MODES</u>	
	<u>Monaural Better Ear</u>	<u>V-Cord Better Ear</u>	<u>Binaural</u>	<u>Double V-Cord</u>
<u>High Fidelity Amplifiers</u>		<u>Experiment I</u>		
Mean	65.92	79.04	85.12	83.92
<u>Commercial Hearing Aids</u>		<u>Experiment II</u>		
Mean	55.12	66.40	70.24	67.92
Difference Between Means	10.80	12.64	14.88	16.00
t	8.30	5.82	11.81	9.70

All differences between pairs of means are significant at better than the .01 level.

Table 24. Values of t and significance level for the difference between the means of speech discrimination scores of subjects using high fidelity amplifiers and earphones, Experiment I, and of subjects using commercial hearing aids, Experiment II, computed by a method of scoring awarding one point for each phoneme correctly identified.

	<u>MONOTIC MODES</u>		<u>DICHOTIC MODES</u>	
	<u>Monaural Better Ear</u>	<u>V-Cord Better Ear</u>	<u>Binaural</u>	<u>Double V-Cord</u>
<u>High Fidelity Amplifiers</u>		<u>Experiment I</u>		
Mean	75.13	84.01	89.12	87.84
<u>Commercial Hearing Aids</u>		<u>Experiment II</u>		
Mean	65.92	79.56	83.66	78.71
Difference Between Means	9.21	4.45	5.46	9.13
t	6.49	3.30	5.30	8.61

All differences between pairs of means are significant at better than the .01 level.

Table 24 shows the results of t-tests and significance levels for the difference between the means of speech discrimination scores for subjects using high fidelity amplifiers and earphones, Experiment I, and subjects using commercial hearing aids, Experiment II, for the four modes of listening computed by a system of scoring which awarded one point for each phoneme correctly reported. It can be seen that all differences between pairs of means are significant at better than the .01 level.

Table 25 shows the rank order of means of speech discrimination scores for the four modes of listening for subjects using high fidelity amplifiers and earphones, Experiment I, and for subjects using commercial hearing aids, Experiment II, computed by a system of scoring which awarded one point for each word correctly reported. It can be seen that the binaural mode of listening resulted in the highest intelligibility for both systems of amplification. The significance of differences between the means of speech discrimination scores of modes of listening in adjoining ranks are also shown in Table 25.

Table 26 shows the rank order of means of speech discrimination scores for the four modes of listening for subjects using high fidelity amplifiers and earphones, Experiment I, and for subjects using commercial hearing aids, Experiment II, computed by a system of scoring which awarded one point for each phoneme correctly identified.

Table 25. Rank order of the means of speech discrimination scores of subjects using high fidelity amplifiers and earphones, Experiment I, and of subjects using commercial hearing aids, Experiment II, for the four modes of listening computed by a method of scoring awarding one point for each word correctly reported.

<u>Modes of Listening</u>	<u>HIGH FIDELITY AMPLIFIERS</u>		<u>COMMERCIAL HEARING AIDS</u>	
	<u>Mean</u>	<u>Difference</u>	<u>Mean</u>	<u>Difference</u>
Binaural	85.12		70.04	
		1.20 (-)		2.12 (-)
Double V-Cord	83.92		67.92	
		4.88 (*)		1.52 (-)
Monotic V-Cord Better Ear	79.04		66.40	
		13.12 (*)		11.28 (*)
Monaural Better Ear	65.92		55.12	

• Significant

- Not significant

Table 26. Rank order of the means of speech discrimination scores of subjects using high fidelity amplifiers and earphones, Experiment I, and of subjects using commercial hearing aids, Experiment II, for the four modes of listening computed by a method of scoring awarding one point for each phoneme correctly identified.

	<u>HIGH FIDELITY AMPLIFIERS</u>		<u>COMMERCIAL HEARING AIDS</u>	
	<u>Mean</u>	<u>Difference</u>	<u>Mean</u>	<u>Difference</u>
<u>Modes of Listening</u>			<u>Modes of Listening</u>	
Binaural	89.12		Binaural	83.66
		1.28 (-)		4.10 (*)
Double V-Cord	87.84		Monotic V-Cord Better Ear	79.56
		3.83 (*)		.85 (-)
Monotic V-Cord Better Ear	84.01		Double V-Cord	78.71
		8.88 (*)		12.79 (*)
Monaural Better Ear	75.13		Monaural Better Ear	65.92

* Significant

- Not significant

It can be seen that the binaural mode of listening resulted in the highest intelligibility for both systems of amplification. The significance of differences between the means of speech discrimination scores of modes of listening in adjoining ranks is also shown in Table 26.

Table 27 shows the rank order of means of speech discrimination scores for the four modes of listening for subjects using high fidelity amplifiers and earphones, Experiment I, and the results of a study by Harris¹ for the same modes of listening. Table 27 indicates that the binaural mode resulted in the highest intelligibility for speech in this study, whereas in the study by Harris the double V-cord mode resulted in the highest intelligibility for speech. The table further shows that the difference between the means of discrimination scores of the binaural and double V-cord modes of this study is not significant, whereas it can be seen that in the study by Harris the differences between the means of speech discrimination scores for the various modes of listening are all significant.

Table 28 shows the comparison between differences in the means of speech discrimination scores of subjects using high fidelity amplifiers and earphones, Experiment I, and subjects using commercial hearing aids, Experiment II, for the four modes of listening, computed by a system of

¹Harris, op. cit., p. 440.

scoring which awarded one point for each word correctly reported. Table 28 shows a much greater difference between dichotic and monotic modes of listening with the use of high fidelity amplifiers and earphones, which is 12%, whereas the difference between monotic and dichotic modes of listening with the use of commercial hearing aids is 8%.

Table 29 shows the comparison between differences in the means of speech discrimination scores of subjects using high fidelity amplifiers and earphones, Experiment I, and subjects using commercial hearing aids, Experiment II, for the four modes of listening, computed by a system of scoring which awarded one point for each phoneme correctly identified. Table 29 shows the difference of 9% between dichotic and monotic modes of listening with the use of high fidelity amplifiers and earphones to be approximately the same as the difference of 8% between dichotic and monotic modes of listening with the use of commercial hearing aids.

A comparison of Table 28 with Table 29 indicates that the differences between the means of speech discrimination scores for subjects using different methods of amplification are more readily observed when scoring on a basis of one point per word correctly reported.

Table 30 shows the comparison between differences in the means of speech discrimination scores resulting

Table 27. Rank order of the means of speech discrimination scores of subjects using high fidelity amplifiers and earphones, Experiment I of this study, and the results of a study by Harris.**

	<u>HIGH FIDELITY AMPLIFIERS</u>		<u>HARRIS' STUDY</u>	
	<u>Mean</u>	<u>Difference</u>	<u>Mean</u>	<u>Difference</u>
<u>Modes of Listening</u>			<u>Modes of Listening</u>	
Binaural	85.12		Double V-Cord	63.00
		1.20 (-)		4.40 (*)
Double V-Cord	83.92		Monotic V-Cord Better Ear	58.60
		4.88 (*)		7.20 (*)
Monotic V-Cord Better Ear	79.04		Binaural	51.40
		13.12 (*)		22.30 (*)
Monaural Better Ear	65.92		Monaural Better Ear	29.10

* Significant

- Not significant

** Harris, J.D., Monaural and binaural speech intelligibility and the stereophonic effect based upon temporal cues. Laryngoscope, 1965, 75, p. 437.

Table 28. Comparison of differences between the means of speech discrimination scores for the four modes of listening for subjects using high fidelity amplifiers and earphones, Experiment I, and for subjects using commercial hearing aids, Experiment II, computed by a method of scoring awarding one point for each word correctly reported.

<u>MODES</u>	<u>HIGH FIDELITY AMPLIFIERS AND EARPHONES</u>	<u>COMMERCIAL HEARING AIDS</u>
Percentage Difference Between Monaural and Monotic V Cord	+13.12%	+11.28%
Percentage Difference Between Monaural and Binaural	+19.20%	+14.92%
Percentage Difference Between Monaural and Double V-Cord	+18.00%	+12.80%
Percentage Difference Between Monotic V and Binaural	+6.08%	+3.64%
Percentage Difference Between Binaural and Double V	- 1.20%	-2.12%
Percentage Difference Between Monotic V and Double V	+4.88%	+ 1.52%
Percentage Difference Between Monotic and Dichotic	-12.04%	+8.22%

from the use of high fidelity amplifiers and earphones, Experiment I, and the study by Harris² for the four modes of listening. Table 30 indicates that the difference in the means of speech discrimination scores for subjects using high fidelity amplifiers and earphones, Experiment I, between dichotic and monotic modes of listening in this study is 12%, and the difference between dichotic and monotic modes of listening in the study by Harris is 13%. Table 30 also shows the comparison of the difference between means of speech discrimination scores for all modes of listening utilized in this study and in the study by Harris.

B. Discussion.

Research psychoacousticians and clinical audiologists have generally agreed that an index of significance in the comparison of monotic with dichotic systems of amplification is the improvement in speech discrimination scores. In effect, the research design of this study has been structured to elicit and measure quantitatively any increase of speech perception resulting from either the addition of a system of amplification to the second ear (dichotic mode), or by an additional channel of amplification (V-cord mode arrangement) to the better ear of individuals with sensory dysacusis. As a result of the selection procedures previously described each subject selected had a mild to moderate bilateral approximately symmetrical sensory hearing loss with relatively good speech discrimination.

²Harris, loc. cit.

Table 29. Comparison of differences between the means of speech discrimination scores for the four modes of listening for subjects using high fidelity amplifiers and earphones, Experiment I and for subjects using commercial hearing aids, Experiment II, computed by a method of scoring awarding one point for each phoneme correctly identified.

<u>MODES</u>	<u>HIGH FIDELITY AMPLIFIERS AND EARPHONES</u>	<u>COMMERCIAL HEARING AIDS</u>
Percentage Difference Between Monaural and Monotic V-Cord	+8.88%	+13.64%
Percentage Difference Between Monaural and Binaural	+13.99%	+17.74%
Percentage Difference Between Monaural and Double V-Cord	+13.71%	+12.79%
Percentage Differences Between Monotic V and Binaural	+5.11%	+4.10%
Percentage Difference Between Binaural and Double V	-1.28%	-4.95%
Percentage Difference Between Monotic V and Double V	+3.83%	- .85%
Percentage Difference Between Monotic and Dichotic	+8.91%	+8.45%

Table 30. Comparison of differences between the means of speech discrimination scores for the four modes of listening for subjects using high fidelity amplifiers and earphones, Experiment I of this study, and the results of a study by Harris.*

<u>MODES</u>	<u>HIGH FIDELITY AMPLIFIERS EXPERIMENT I</u>	<u>HARRIS' STUDY</u>	<u>DIFFERENCE</u>
Percentage Difference Between Monaural and Monotic V-Cord	+13.12%	+29.50%	16.38%
Percentage Difference Between Monaural and Binaural	+19.20%	+20.60%	1.40%
Percentage Difference Between Monaural and Double V-Cord	+18.00%	+33.90%	15.90%
Percentage Differences Between Monotic V & Binaural	+6.08%	- 8.90%	14.98%
Percentage Difference Between Binaural and Double V	- 1.20%	+13.30%	14.50%
Percentage Difference Between Monotic V and Double V	+ 4.88%	+ 4.40%	.48%
Percentage Difference Between Monotic and Dichotic	+12.04%	+12.50%	.46%

* Harris, J.D., Monaural and binaural speech intelligibility and the stereophonic effect based upon temporal cues. Laryngoscope, 1965, 75, p. 437.

This procedure was followed in order to insure that any inherent advantage of dichotic over monotic modes of listening, or of two channel over one channel systems of amplification would not be obscured by contamination of the experimental groups with subjects whose hearing loss presented special problems inimical to the successful use of the means of amplification employed in this study. The distribution of speech discrimination scores for the four modes of listening resulting from Experiments I and II, shown in Tables 31, 32, 33, and 34 are not typical of results to be expected in a truly random sample of subjects with sensori-neural hearing loss, bilateral asymmetrical as well as symmetrical hearing involvements. Instead, a purposeful selection procedure designed to assure balanced residual hearing and relatively good speech discrimination ability of the subjects tested, was followed.

The statistical analysis of the data resulting from Experiments I and II of this study suggested that there is a principle of binaural enhancement of speech perception over monaural discrimination, which can be measured when conditions are properly structured for its emergence. Binaural hearing, as shown in Tables 13, 14, 15, and 16, had the highest mean of speech discrimination scores of any mode of listening, both for the high fidelity amplifiers and the commercial hearing aids, under both methods of scoring. The principle of binaural signal-to-noise gain as reported

by Harris³ for normal and 'defective' listeners was found to apply in this study to subjects with sensory hearing losses which are approximately bilaterally symmetrical. His study showed that with an appropriate test, the improvement in intelligibility of dichotic over monotic modes is of the order of +4 to +5 dB signal-to-noise ratio. Harris converted percentage increases in intelligibility between dichotic and monotic modes of listening, to differences in signal-to-noise ratios by assuming a conversion factor of 6% of intelligibility score for one decibel of signal-to-noise ratio, based on articulation curves for the speech stimuli used.

Increased intelligibility for speech through redundancy of the information furnished to the ear has been demonstrated on normal hearing subjects by Bocca and Calearo,⁴ and on normal and 'defective' listeners by Harris.⁵ This principle of redundancy appears to be an appropriate explanation for the gain in speech intelligibility for the V-cord mode (better ear) over the monaural mode (better ear).

³J.D. Harris, "Monaural and Binaural Speech Intelligibility and the Stereophonic Effect Based upon Temporal Cues," Laryngoscope, 75 (1965), p. 436.

⁴E. Bocca and C. Calearo, "Central Hearing Processes." In J. Jerger, (Ed.), Modern Developments in Audiology. (New York: Academic Press, 1963), p. 342.

⁵Harris, op. cit., p. 444.

when using the high fidelity amplifiers and earphones, Experiment I, and the commercial hearing aids, Experiment II, for both methods of scoring. The increased intelligibility of the monotic V-cord mode over the monaural mode was demonstrated in Tables 13, 14, 15, and 16 of this study. It seemed that this principle of redundancy was applicable to hard of hearing individuals suffering from bilateral approximately symmetrical sensory hearing losses.

The speech stimuli (Revised Peterson-Lehiste CNC word lists) were presented in the presence of speech spectrum noise at a constant signal-to-noise ratio of +5 for all speech discrimination tests. This particular signal-to-noise ratio prevented the single aided ear under the conditions of this study, from functioning maximally and achieving as high a discrimination score as would be achieved by both ears under ideal listening conditions. Prior studies evaluating binaural hearing aids under quiet conditions have repeatedly failed to yield significant differences between monaural and binaural discrimination scores (DiCarlo and Brown,⁶ Hedgecock and Sheets).⁷ The

⁶L.M. DiCarlo and W.J. Brown, "The Effectiveness of Binaural Hearing for Adults with Hearing Impairments," Journal of Auditory Research, 1 (1960), pp. 35-76.

⁷L.D. Hedgecock and B.V. Sheets, "A Comparison of Monaural and Binaural Hearing Aids for Listening to Speech," Archives of Otolaryngology, 68 (1958), pp. 624-629.

results of a study by Wright and Carhart⁸ comparing discrimination scores both in quiet and with a competing noise, showed that though not all of the subjects heard better with binaural amplification, some differences appeared in the noise situation which were undetectable under the quiet listening conditions. It appeared that whatever contribution the second ear might make to better intelligibility cannot be expressed through a difference in speech discrimination scores unless the procedures of the investigation measure such contribution in the presence of competing sound for the monotic and dichotic modes of listening. The literature on binaural hearing failed to suggest any other procedure for eliciting differences in speech discrimination between monaural and binaural hearing. It may be, therefore, that where competing noise has been used in prior studies, the signal-to-noise ratio employed in comparing monaural with binaural discrimination scores resulted in such high intelligibility scores for the monaural mode that a binaural improvement could not be demonstrated (Gerber).⁹

⁸H.N. Wright and H. Carhart, "The Efficiency of Binaural Listening Among the Hearing Impaired," Archives of Otolaryngology, 72 (1960), pp. 789-797.

⁹S.E. Gerber, "Phase and Speech Discrimination in Noise; An Expectation and First Look," International Audiology, 6 (1967), pp. 397-400.

The results of this study indicated that speech intelligibility was better when hard of hearing subjects used high fidelity amplification equipment compared to the use of commercial hearing aids. In fact, Tables 23 and 24 showed the difference between mean speech discrimination scores under the two systems of amplification to be statistically significant at .01 confidence level, with the use of t -test statistic for both methods of computing discrimination scores (one point for each word correctly reported); and by one point for each phoneme correctly identified.

The lower speech discrimination scores when using commercial hearing aids may be due to the limited frequency response of the hearing aids. The limited frequency band width of commercial hearing aids might have reduced or eliminated some of the sound cues ordinarily used in the auditory mechanism for detection and understanding of speech. It has been shown by others that band width limitation of systems of amplification affects intelligibility.

In this study, since speech stimulus and masking stimulus were presented simultaneously, the listening situation had to be structured so that localization of side-ness effects would be eliminated. In prior studies when the sources of signal stimuli and noise stimuli were separated in space, additional clues such as interaural intensity differences and differences in signal-to-noise ratios at the

two ears obscured the particular discrimination gain which was the focus of interest in the test. Such obscuring influences were observed by Wright and Carhart¹⁰ who found a sidedness effect related to the intelligibility scores obtained by their subjects. If a study is not designed to eliminate sidedness effects, one cannot separate the contribution to intelligibility due to the second ear from the contribution due to localization. This investigation made use of a dummy head, coated with diluted silicone rubber, placed in test room 1 as previously described. Head movements were therefore, eliminated and contamination of the results by localization effects were avoided.

This report does not suggest that tests for the ability to localize with binaural amplification be abandoned. The principle reason for eliminating localization effects, was for the purpose of measuring the contribution of the second ear to speech intelligibility.

It has been reported that the range of sensation levels yielding the highest discrimination scores for subjects with cochlear involvement is often quite restricted, and levels above these intensities usually

¹⁰H.N. Wright and H. Carhart, "The Efficiency of Binaural Listening Among the Hearing Impaired," Archives of Otolaryngology, 72 (1960), pp. 789-797.

produce a degradation of the articulation scores rather than maintaining a plateau as is seen in the normal ear (Yantis et al).¹¹ It is reasonable to assume, based on the audiological tests administered in this study, that the subjects tested consisted of two homogeneous groups who demonstrated bilateral approximately symmetrical sensory dysacusis. The speech stimuli were presented at a sensation level of 30 dB above the subject's speech reception threshold. It has been reported by DiCarlo and Brown¹² that the level of loudness for maximum speech discrimination scores averaged 29 dB above the speech reception threshold for a group of sensori-neural subjects tested. The experiments in this study were therefore structured so that the amplified stimuli were presented at intensity levels that would approximate the level at which speech discrimination was maximal for each subject tested.

Speech discrimination scores in this study were computed by a method of scoring awarding one point for each phoneme correctly identified in addition to the conventional method of one point for each word correctly reported. The statistical evaluation of the data computed by each method of scoring indicates that the system of scoring one point

¹¹P.A. Yantis, J.P. Millin and I. Shapiro, "Speech Discrimination in Sensori-Neural Hearing Loss: Two Experiments on the Role of Intensity," Journal of Speech and Hearing Research, 9 (1966), pp. 178-193.

¹²DiCarlo and Brown, op. cit., p. 47.

for each phoneme correctly identified resulted in significant differences in the means of speech discrimination scores between modes of listening that were not evident under the traditional method of scoring (see Tables 17 and 18). The difference between the means of speech discrimination scores of the binaural mode and the double V-cord mode was significant for subjects using commercial hearing aids scored on the basis of one point for each phoneme correctly identified (see Table 22), whereas under similar conditions when scoring under the traditional method, there was no significant difference between the two modes of listening (see Table 21). It seems reasonable to assume that the method of awarding partial credit (one point for each phoneme correctly identified) indicated differences in auditory perception between modes of listening, not elicited by the all or none method of scoring (one point for each word correctly reported).

The traditional method of scoring indicated a higher significant difference between methods of amplification (high fidelity amplifiers and earphones, and commercial hearing aids) as shown in Tables 17 and 18. It appears appropriate to assume that when high fidelity amplification was used, the subject tested received such additional information that use of the scoring system on a basis of one point for each phoneme correctly identified was not necessary, in a comparison of the high fidelity with the

low fidelity method of amplification. However, in making comparisons of speech perception between modes of listening, the additional information furnished to the subject by the use of dichotic and two channel modes were not as great, and a finer system of scoring becomes more critical. Therefore, it appeared that a method of scoring awarding one point for each phoneme correctly identified proved superior for differentiating advantages for speech perception between modes of listening, whereas the traditional method of scoring seemed superior for determining differences between methods of amplification.

C. Summary.

The results obtained in this study were analyzed by means of statistical treatment of the data. The differences in the mean of speech discrimination scores between the various modes of listening utilizing high fidelity amplifiers and earphones of Experiment I, and using commercial hearing aids of Experiment II were tested by a two factor analysis of variance for repeated measures. The two factor analysis of variance was computed separately for each method of scoring (awarding one point for each word correctly reported, and by awarding one point for each phoneme correctly identified).

The analysis of variance indicated that there were significant differences between the means of speech discrimination scores for the dichotic modes and the monotic

modes of listening for both methods of scoring.

Comparisons between all possible pairs of treatment means were made by using the Newman-Keuls test procedure. This test indicated that for subjects using high fidelity amplifiers and earphones, the differences between pairs of means of speech discrimination scores were significant at the .01 level except the difference between the means for the binaural mode and the double V-cord mode of listening which was not significant for both methods of scoring. This test further indicated that for subjects using commercial hearing aids the significant differences between pairs of means were dependent on the method of scoring used. The difference between the means of speech discrimination scores for the double V-cord mode and the binaural mode of listening was not significant when using a system of scoring awarding one point for each word correctly reported. However, the difference between the means of discrimination scores for the double V-cord mode and the binaural mode of listening was significant when using a system of scoring awarding one point for each phoneme correctly identified.

The results of t-tests on the differences between the means of speech discrimination scores for subjects using high fidelity amplifiers and earphones, Experiment I, and the commercial hearing aids, Experiment II, were significant at the .01 level for all modes of listening for both systems of scoring.

CHAPTER V
SUMMARY, CONCLUSIONS AND
RECOMMENDATIONS FOR FUTURE RESEARCH

A. Summary.

The purpose of this study was to compare speech perception, using the Revised Peterson-Lehiste CNC word lists, for individuals with bilateral approximately symmetrical sensory hearing losses, utilizing monotic and dichotic modes of listening. The monotic modes consisted of (a) a monaural amplifier to one ear, and (b) an amplifying system of two channels to one ear (monotic V-cord arrangement). Dichotic modes comprised (a) a binaural system of amplification, and (b) a two channel amplifying system to each ear (double V-cord arrangement).

A further aim of this research was to compare speech discrimination between an amplifying system using high fidelity amplifiers and earphones, referred to as Experiment I, to a system of amplification using commercial hearing aids, described as Experiment II.

Each experimental group consisted of 25 adults. The average pure-tone hearing level for the subjects selected varied from 45 dB HL to 70 dB HL, (ISO, 1964), for the three mid-frequencies for speech, with hearing loss not less than 35 dB HL at the best frequency of 500, 1000, and 2000 Hz. Each subject did not reveal more than a 15 dB differential between the pure-tone threshold averages of their two ears for the three mid-frequencies tested. It is reasonable to assume, based on the audiological tests administered, that the subjects tested consisted of two homogeneous groups, who demonstrated bilateral

approximately symmetrical sensory dysacusis.

The study was structured so that head movements were avoided through the use of a dummy head. This artificial head, a plastic mannequin head, had been covered with three layers of diluted silicone rubber in order to give a texture similar to human skin.

The geometric array of the experimental equipment used in test room 1 of this study was designed to eliminate head shadow effects. Three loudspeakers were employed, a center loudspeaker for the speech stimuli and two lateral loudspeakers for the speech spectrum noise. The dummy head was placed equidistant from each of the loudspeakers. Therefore, the investigation dealt only with conditions wherein signal-to-noise ratios were the same at the two ears (S/N +5).

Speech discrimination scores were computed by a system of awarding one point for each phoneme correctly identified in addition to the traditional method of scoring one point for each word correctly reported.

The data resulting from Experiments I and II of this study were analyzed by means of a statistical treatment of the data. The differences in the means of speech discrimination scores between the various modes of listening using high fidelity amplifiers and earphones, Experiment I, and using commercial hearing aids, Experiment II were tested by a two factor analysis of variance for repeated measures. The two factor analysis of variance

was computed separately for each method of scoring on a basis of one point for each word correctly reported, and on a basis of one point for each phoneme correctly identified).

B. Conclusion.

The data from Experiments I and II of this study demonstrated that speech perception can be determined psychoacoustically for monotic and dichotic modes of listening, without the contamination of the results by the troublesome effects of head movements and head shadows.

Results of this study tend to support the following hypotheses for Experiment I, using high fidelity amplifiers and earphones and Experiment II, using commercial hearing aids for subjects with bilateral approximately symmetrical sensory hearing losses:

1. The two channel mode (monotic V-cord system) of amplification to the better ear significantly increased speech perception over the monaural mode (one channel system) of amplification to the same ear for both methods of amplification. The improvement in the mean of speech discrimination scores was of the order of 13% when scored on a basis of one point for each word correctly reported, and 9% when scored on a basis of one point for each phoneme correctly identified for subjects using high fidelity amplifiers and earphones. The improvement in the mean of the speech discrimination scores was of the order of 11% when scored on a basis of one point for each word correctly

reported, and 14% when scored on a basis of one point for each phoneme correctly identified, for subjects using commercial hearing aids.

2. The binaural mode of amplification significantly increased speech perception over the monaural mode of amplification to the better ear for both methods of amplification. The improvement in the mean of the speech discrimination scores was of the order of 19% when scored on a basis of one point for each word correctly reported, and 14% when scored on a basis of one point for each phoneme correctly identified for subjects using high fidelity amplifiers and earphones. The improvement in the mean of the speech discrimination scores was of the order of 15% when scored on a basis of one point for each word correctly reported and 18% when scored on the basis of one point for each phoneme correctly identified for subjects using commercial hearing aids.

3. The two channel mode (double V-cord system) of amplification to each ear significantly increased speech perception over the monaural mode of amplification to the better ear for both methods of amplification. The improvement in the mean of the speech discrimination scores was of the order of 18% when scored on a basis of one point for each word correctly reported, and 13% when scored on a basis of one point for each phoneme correctly identified for subjects using high fidelity amplifiers and

earphones. The improvement in the mean of the speech discrimination scores was of the order of 13% when scored on a basis of one point for each word correctly reported and 13% when scored on a basis of one point for each phoneme correctly identified for subjects using commercial hearing aids.

4. The binaural mode of amplification significantly increased speech perception over the two channel mode (monotic V-cord system) of amplification to the better ear for both methods of amplification. The improvement in the mean of the speech discrimination scores was of the order of 6% when scored on a basis of one point for each word correctly reported, and 5% when scored on a basis of one point for each phoneme correctly identified for subjects using high fidelity amplifiers and earphones. The improvement in the mean of the speech discrimination scores was of the order of 4% when scored on a basis of one point for each word correctly reported, and 4% when scored on a basis of one point for each phoneme correctly identified for subjects using commercial hearing aids.

5. The two channel mode (double V-cord system) of amplification to each ear significantly increased speech perception over the two channel mode (monotic V-cord system) of amplification to the better ear, for subjects using high fidelity amplifiers and earphones. The improvement in the mean of the speech discrimination scores was of the order of 5%, when scored on a basis of one point

for each word correctly reported, and 4% when scored on a basis of one point for each phoneme correctly identified. There was no significant difference for speech perception between the two channel mode (double V-cord system) of amplification to each ear and the two channel mode (monotic V-cord system) of amplification to the better ear for subjects using commercial hearing aids with either method of scoring.

6. There was no significant difference for speech perception between the two channel mode (double V-cord system) of amplification to each ear and the binaural mode of listening for both methods of amplification when scored on a basis of one point for each word correctly reported. There was no significant difference for speech perception between the two channel mode (double V-cord system) of amplification to each ear and the binaural mode of listening for subjects using high fidelity amplifiers and earphones when scored on a basis of one point for each phoneme correctly identified. However, the binaural mode of amplification to each ear significantly increased speech perception over the two channel mode (double V-cord system) of amplification to each ear for subjects using commercial hearing aids when scored on the basis of one point for each phoneme correctly identified. The improvement in the mean of the speech discrimination scores was of the order of 5%.

A comparison of the results of Experiment I using

high fidelity amplifiers and earphones to the results of Experiment II, using commercial hearing aids tended to support the following hypothesis:

High fidelity amplifiers and earphones were superior for speech perception to the use of commercial hearing aids, for all modes of listening for both systems of scoring.

C. Recommendations for Future Research.

This study has investigated speech perception of subjects with bilateral approximately symmetrical sensory hearing losses using high fidelity and low fidelity systems of amplification, utilizing monotic and dichotic modes of listening. The generalizations made, based on the results of two experiments conducted, have been limited to a population of individuals with sensory dysacusis. The following suggestions for future research are proposed in order that the effects of binaural interaction on populations of different type and severity of hearing dysfunction be determined:

1. A comparison of speech perception as measured by the Revised Peterson-Lehiste CNC word lists, for subjects with bilateral asymmetrical sensory hearing losses, utilizing monotic and dichotic modes of listening, employing;

- (a) high fidelity amplifiers and earphones as the amplifying system, and

- (b) commercial hearing aids as the amplifying system.

2. A comparison of speech perception, as measured with sentences, and competing sentences as masker, for subjects with bilateral approximately symmetrical sensory hearing losses, utilizing monotic and dichotic modes of listening, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

3. A comparison of speech perception, as measured with sentences, and competing sentences as masker, for subjects with bilateral asymmetrical sensory hearing losses, utilizing monotic and dichotic modes of listening, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

4. A comparison of speech perception as measured by the Revised Peterson-Lehiste CNC word lists, for subjects with bilateral symmetrical sensory hearing losses, utilizing monotic and dichotic modes of listening, employing:

(a) high fidelity amplifiers and earphones using filtering system which would attenuate low frequency components of speech, as the amplifying system, and

(b) commercial hearing aids designed for low

frequency attenuation, as the amplifying system.

5. A comparison of speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects with bilateral symmetrical sensory hearing losses, utilizing monotic and dichotic modes of listening, at different signal-to-noise ratios, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

6. A comparison of speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects with mild, moderate, and profound hearing losses, utilizing monotic and dichotic modes of listening, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

7. A comparison of speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects with bilateral symmetrical hearing losses, utilizing monotic and dichotic modes of listening, after a six month period of auditory training with the use of binaural hearing aids, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

8. A comparison of speech perception, as measured by the Duffy Audio-visual Speech Perception Index,¹ for subjects with bilateral symmetrical sensory hearing losses, utilizing monotic and dichotic modes of listening, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

9. A comparison of speech perception, as measured by the Duffy Audio-visual Speech Perception Index, for subjects with bilateral asymmetrical sensory hearing losses, utilizing monotic and dichotic modes of listening, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

10. A comparison of speech perception, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects with bilateral approximately symmetrical sensory

¹J.K. Duffy, "Audio-visual Speech Audiometry and a New Audio and Audio-visual Speech Perception Index," Maico Audiological Library Series, Vol. V, Report 9 (1967), pp. 1-3.

hearing losses who have worn binaural hearing aids for at least one year prior to being tested, utilizing monotic and dichotic modes of listening, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

11. An analysis of phonemes correctly and incorrectly identified as measured by the Revised Peterson-Lehiste CNC word lists, for subjects with bilateral approximately symmetrical sensory hearing losses utilizing monotic and dichotic modes of listening, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

12. A comparison of speech intelligibility (articulation functions) as measured by the Revised Peterson-Lehiste CNC word lists, at sensation levels of 10 dB, 20 dB, 30 dB, and 40 dB above speech reception thresholds for subjects with bilateral approximately symmetrical sensory hearing losses utilizing monotic and dichotic modes of listening, computed by a system of scoring awarding one point for each phoneme correctly identified and by the traditional scoring system of awarding one point for each word correctly reported, employing:

(a) high fidelity amplifiers and earphones as the amplifying system, and

(b) commercial hearing aids as the amplifying system.

APPENDIX A

Definitions of terms used.

Definition of Terms Used.

1. Antiphasic Conditions - This condition exists when the speech stimulus or signal at the two ears is in phase and the noise stimulus at the two ears is out of phase, or when the speech stimulus or signal at the two ears is out of phase and the noise stimulus at the two ears is in phase.
2. Binaural - The stimulus is applied to both ears, it may be dichotic in respect to several dimensions, or in respect to one dimension; for example, dichotic in phase, but diotic in intensity and frequency.
3. Binaural Hearing Aids - Two complete hearing aids, one for each ear.
4. Binaural Intelligibility Level Differences (BILD) - This term is defined as the difference in signal level (in decibels) between two binaural conditions for a given per cent intelligibility.
5. Binaural Masking Level Differences (BMLD) - This term is defined as the difference in signal level (in decibels) for detection between two binaural conditions. A reversal of phase, change of time of arrival, or difference in intensity of target signal or masking signal in one ear may change the binaural threshold significantly.
6. Bi CROS Hearing Aid - One complete hearing aid and custom earmold is placed on the side of moderately impaired ear, connected to an additional microphone placed on side of severely deafened ear.

7. CROS - The Contralateral Routing of Signal, is a condition whereby the microphone of a hearing aid is placed on the side of the affected ear and the amplified sound is routed through an open mold into the better ear.

8. Dichotic - A condition in which different sound stimuli are applied to the two ears; utilizing either one channel, or two channel amplifying systems, two independent hearing aids are presenting sounds to both ears.

9. Difference Limen (DL) - The difference limen is defined as the minimum change in a stimulus needed to produce a first noticeable difference in sensation, either in pitch, loudness, or phase. The DL is a statistical measurement and all prior research reported upon in this study used 50 per cent of observations as criterion.

10. Diotic (Pseudo-binaural, Y-cord) - The same sound stimulus is applied to the two ears, through one amplifying system; one hearing aid utilizing a Y-cord is splitting the output of the hearing aid to the two earphones.

11. Discrimination Score for Speech - The discrimination score for speech is the percentage of a given speech material that a listener repeats correctly, at a level that is sufficiently high so that a further increase in intensity is not accompanied by a further increase in the amount of speech material repeated correctly. The information desired for each listener who takes this test is the maximum percentage of words in a test that can be repeated correctly. This datum is called the maximum discrimination score.

12. Double V-Cord Mode - This condition exists when the output of each of two completely separate hearing aid amplifiers, each amplifier being placed on each side of the head, is fed into two separate earphones and each earphone delivers the sound to each ear.

13. Head Shadow Effect - The effect on high frequency components of a complex acoustic stimulus because of the diffraction properties of the human head. Low frequency sounds are diffracted around the head much better than the high frequency sound with their short wave lengths. There may be as much as 13 dB change of signal-to-noise ratio because of the diffraction effects on speech stimulus depending on the geometry of the source of speech and the source of noise in relation to the head.

14. Heterophasic Conditions - This condition exists when the speech stimulus or signal at the two ears is in phase and the noise comes from two independent sources to each ear. It may also exist when the noise stimulus is in phase at the two ears, and the speech stimulus or signal comes from two independent sources, to each ear.

15. Homophasic Conditions - This condition exists when the speech stimulus or signal at the two ears is in phase, and the noise stimulus at the two ears is in phase. This condition may also exist when the speech stimulus or signal at the two ears is out of phase, and the noise stimulus at the two ears is out of phase.

16. Interaural Intensity Differences (IID) - The difference in sound pressure in decibels measured at each eardrum. The IID will vary with frequency of tone.

17. Interaural Time Difference (ITD) - The difference in time of arrival of the stimulus at the two ears.

18. Interaural Phase Differences - The relationship in terms of lead or lag of a sound wave in one ear, to a corresponding sound wave in the other ear. In order to express this relationship at each ear between a given frequency component of the signal stimulus and a corresponding frequency component of the masker, the term deviation or divergence of phase is used, and the amount of deviation is measured in degrees.

19. Lateralization - The ability to judge the location of an auditory image inside the head; in the medial plane of the head, or right or left of such medial plane.

20. Localization - The ability to judge the location and distance of the sound of an acoustic stimulus in space, external to the human head.

21. Monotic - This condition exists when a speech stimulus or signal is applied only to one ear, utilizing either one channel, or two channel amplifying systems to that ear.

22. Precedence Effect - The tendency of an acoustic stimulus to be heard in the ear first perceiving such stimulus, regardless of time and intensity changes which should cause the auditory sensation to be experienced in the other ear.

23. Threshold for Speech - An individual's threshold for speech has been defined as the level at which the individual can repeat 50 per cent of the test material presented to him. The threshold will vary depending on the type of speech material used.

24. V-Cord Mode - This condition exists when the output of two completely separate hearing aid amplifiers, each placed on each side of the head, are fed into one earphone and that earphone delivers the sound to one ear.

APPENDIX B

Speech discrimination scores as
measured by Revised Peterson-Lehiste
CNC word lists, for four modes of
listening.

Table 31. Speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects using high fidelity amplifiers and earphones, computed by a method of scoring awarding one point for each word correctly reported in Experiment I.

<u>SUBJ.</u>	<u>MONOTIC MODES</u>			<u>DICHOTIC MODES</u>	
	<u>RT EAR</u>	<u>LT EAR</u>	<u>V-Cord</u> (Better Ear)	<u>BINAURAL</u>	<u>DOUBLE</u> <u>V-Cord</u>
1.	68%	64%	76%	82%	78%
2.	72%	74%	78%	84%	84%
3.	62%	58%	78%	76%	72%
4.	64%	60%	70%	80%	82%
5.	60%	56%	72%	78%	80%
6.	68%	62%	80%	84%	80%
7.	62%	64%	82%	84%	86%
8.	60%	64%	78%	84%	88%
9.	68%	62%	80%	88%	88%
10.	64%	58%	76%	86%	84%
11.	58%	56%	76%	82%	86%
12.	68%	64%	78%	88%	88%
13.	62%	66%	74%	90%	86%
14.	60%	62%	84%	82%	78%
15.	64%	62%	72%	86%	88%
16.	63%	66%	76%	88%	86%
17.	66%	70%	88%	90%	84%
18.	58%	62%	70%	86%	82%
19.	70%	66%	84%	88%	84%
20.	62%	64%	86%	90%	84%
21.	66%	62%	88%	86%	86%
22.	58%	64%	86%	84%	82%
23.	70%	64%	76%	88%	86%
24.	68%	72%	82%	88%	88%
25.	64%	68%	84%	86%	88%

Scores were doubled, so that results could be expressed in percentages.

RT Right Ear
LT Left Ear

Table 32. Speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects using high fidelity amplifiers and earphones, computed by a method of scoring awarding one point for each phoneme correctly identified in Experiment I.

<u>SUBJ.</u>	<u>MONOTIC MODES</u>			<u>DICHOTIC MODES</u>	
	<u>RT EAR</u>	<u>LT EAR</u>	<u>V-CORD</u> (Better Ear)	<u>BINAURAL</u>	<u>DOUBLE</u> <u>V-Cord</u>
1.	78.7%	75.3%	91.3%	93.3%	90.0%
2.	78.7%	80.7%	84.0%	88.0%	86.0%
3.	72.7%	68.0%	78.7%	84.7%	84.7%
4.	66.0%	68.0%	74.0%	80.7%	86.0%
5.	66.0%	62.7%	80.7%	88.0%	86.0%
6.	76.0%	72.7%	84.0%	91.3%	88.0%
7.	72.7%	74.9%	88.0%	86.0%	88.0%
8.	72.7%	76.0%	84.0%	92.0%	91.3%
9.	72.7%	66.0%	84.7%	88.0%	86.0%
10.	68.0%	62.7%	80.7%	92.0%	88.0%
11.	60.0%	58.7%	74.0%	86.0%	88.0%
12.	76.0%	72.7%	91.3%	90.0%	86.0%
13.	66.0%	72.7%	80.7%	91.3%	90.0%
14.	68.0%	72.0%	88.0%	84.0%	80.7%
15.	74.9%	66.0%	78.7%	90.0%	92.0%
16.	76.0%	72.7%	80.7%	92.0%	91.3%
17.	72.7%	76.0%	92.0%	91.3%	88.0%
18.	62.7%	68.0%	74.0%	90.0%	84.7%
19.	78.7%	72.7%	86.0%	92.0%	88.0%
20.	72.0%	72.7%	88.0%	91.3%	86.0%
21.	72.7%	68.0%	92.0%	88.0%	86.0%
22.	62.7%	68.0%	90.0%	88.0%	88.0%
23.	76.0%	66.0%	80.7%	92.0%	90.0%
24.	74.9%	76.0%	86.0%	90.0%	91.3%
25.	72.7%	74.9%	88.0%	88.0%	92.0%

Scores were doubled and then divided by three, so that results could be expressed in percentages.

RT Right Ear
LT Left Ear

Table 33. Speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects using commercial hearing aids, computed by a method of scoring awarding one point for each word correctly reported in Experiment II.

<u>SUBJ.</u>	<u>MONOTIC MODES</u>			<u>DICHOTIC MODES</u>	
	<u>RT EAR</u>	<u>LT EAR</u>	<u>V-Cord</u> (Better Ear)	<u>BINAURAL</u>	<u>DOUBLE</u> <u>V-Cord</u>
1.	52%	56%	68%	74%	70%
2.	54%	54%	68%	68%	72%
3.	48%	46%	62%	70%	64%
4.	46%	44%	58%	60%	62%
5.	48%	52%	58%	66%	60%
6.	52%	58%	70%	72%	72%
7.	54%	60%	68%	70%	72%
8.	60%	56%	70%	76%	70%
9.	46%	50%	62%	66%	62%
10.	54%	52%	64%	68%	68%
11.	64%	60%	72%	76%	68%
12.	62%	58%	74%	78%	70%
13.	54%	60%	76%	76%	78%
14.	52%	56%	68%	74%	72%
15.	52%	48%	64%	68%	62%
16.	48%	52%	66%	70%	64%
17.	46%	50%	62%	66%	62%
18.	54%	48%	62%	70%	62%
19.	58%	62%	70%	76%	76%
20.	58%	54%	68%	72%	68%
21.	56%	50%	68%	74%	72%
22.	50%	54%	76%	76%	74%
23.	54%	46%	60%	58%	64%
24.	54%	50%	62%	64%	66%
25.	52%	48%	64%	68%	68%

Scores were doubled, so that results could be expressed in percentages.

RT Right Ear
LT Left Ear

Table 34. Speech discrimination scores, as measured by the Revised Peterson-Lehiste CNC word lists, for subjects using commercial hearing aids, computed by a method of scoring awarding one point for each phoneme correctly identified in Experiment II.

<u>SUBJ.</u>	<u>MONOTIC MODES</u>			<u>DICHOTIC MODES</u>	
	<u>RT EAR</u>	<u>LT EAR</u>	<u>V-CORD</u> (Better Ear)	<u>BINAURAL</u>	<u>DOUBLE</u> <u>V-Cord</u>
1.	62.7%	68.0%	78.7%	88.0%	78.7%
2.	66.0%	66.0%	80.7%	84.0%	84.0%
3.	60.0%	56.7%	76.0%	78.7%	76.0%
4.	58.7%	56.7%	74.0%	76.0%	72.7%
5.	58.7%	64.0%	72.7%	80.7%	74.0%
6.	62.7%	68.0%	84.0%	84.0%	78.7%
7.	64.0%	72.0%	80.7%	88.0%	78.7%
8.	74.9%	64.0%	88.0%	92.0%	86.0%
9.	56.7%	58.7%	72.7%	80.7%	74.0%
10.	64.0%	58.7%	78.7%	84.0%	76.0%
11.	76.0%	72.0%	84.0%	88.0%	80.7%
12.	72.7%	68.0%	88.0%	84.0%	80.7%
13.	64.0%	72.0%	86.0%	80.7%	88.0%
14.	62.7%	64.0%	80.7%	86.0%	80.7%
15.	62.7%	58.7%	76.0%	84.0%	76.0%
16.	60.0%	62.7%	80.7%	84.0%	78.7%
17.	56.7%	64.0%	74.0%	80.7%	72.0%
18.	62.7%	60.0%	76.0%	84.0%	72.0%
19.	64.0%	72.7%	84.0%	88.0%	80.7%
20.	62.7%	58.7%	80.7%	84.7%	74.0%
21.	62.7%	58.7%	78.7%	88.0%	78.7%
22.	56.7%	64.0%	80.7%	80.7%	86.0%
23.	64.0%	58.7%	74.0%	72.7%	76.0%
24.	62.7%	56.7%	80.7%	86.0%	86.0%
25.	68.0%	64.0%	78.7%	84.0%	78.7%

Scores were doubled and then divided by three, so that results could be expressed in percentages.

RT Right Ear
LT Left Ear

APPENDIX C

Instructions to subjects tested.

Instructions to subjects.

There are three phases to this procedure. The first consists of "pure-tone" or "beeps". The second of two-syllable words such as "airplane" or "cowboy". The third is made up of lists of one-syllable words such as "wet" or "road".

The purpose of the first portion is to ascertain the lowest level at which you can hear the tones or beeps. Raise your hand as soon as you hear the tone and lower your hand when you no longer hear the tone. This test will be conducted with the earphones I am placing on your head. (Pure-tone air conduction thresholds were then determined, a bone oscillator was then applied on the mastoid process of the subject, the same instructions given, and bone conduction thresholds were then determined, with the subject in test room 1).

The purpose of the second portion of this test is to determine the lowest level at which you can repeat any of the two-syllable words. You will hear a man ask you to "Say the word... "blackboard". You will repeat only the word asked for. It is not necessary to repeat the initial phrase "Say the word... For example, if the man said "Say the word..."blackboard," you should say "blackboard". The words will become very faint, but please continue to repeat the words as best you can. It is important that you guess, if you are uncertain of a word. (Earphones were then placed on the subject, and speech reception threshold was then

determined, with the subject in test room 1).

The subject was then seated at a desk in test room 2 and informed that the next section of the test is similar to the prior test except you will now hear the two-syllable words through an earphone that will be placed in your ear with a mold that has been prepared for your ear, and you will respond as you did in the prior test. (Speech reception thresholds were then determined through the use of hearing aid #50 and earphone #52 as described in the procedure of this study).

The third section of the test is similar to the second except, you will hear only one-syllable words. Some of these words will be preceded by the phrase "Number one...". As in the second portion of the test you need only write the word, not the introductory phrase, on the sheets presented to you, and having a listing for the words of 1-50. (All speech discrimination tests were then presented to the subject utilizing hearing aids #50 and #51 and earphones #52 and #53 as described in the procedure of this study).

APPENDIX D

Randomization of revised Peterson-Lehiste CNC word lists and modes of listening.

1. Randomization order in which Peterson-Lehiste CNC word lists were presented to subjects tested.
2. Randomization order in which monotic and dichotic modes of listening were presented to the subjects tested.

Randomization order in which Peterson-Lehiste CNC word lists were presented.

<u>SUBJECT</u>	<u>RT EAR</u>	<u>LT EAR</u>	<u>MONOTIC V-Cord</u>	<u>BINAURAL</u>	<u>DOUBLE V-Cord</u>
1. 11,21	#6	#7	#8	#9	#10
2. 12,22	#7	#8	#9	#10	#6
3. 13,23	#8	#9	#10	#6	#7
4. 14,24	#9	#10	#6	#7	#8
5. 15,25	#10	#6	#7	#8	#9
6. 16	#6	#8	#9	#10	#7
7. 17	#8	#9	#10	#7	#6
8. 18	#10	#7	#8	#6	#9
9. 19	#9	#6	#7	#8	#10
10. 20	#7	#10	#6	#9	#8

#6 - Word list 6 as recorded by Chapman designated #162823.

#7 - Word list 7 as recorded by Chapman designated #873120.

#8 - Word list 8 as recorded by Chapman designated #184329.

#9 - Word list 9 as recorded by Chapman designated #192326.

#10- Word list 10 as recorded by Chapman designated #207823.

RT - right ear

LT - left ear

Randomization order in which monotic and dichotic modes of listening were presented to subjects.

<u>SUBJECT</u>	<u>FIRST TEST</u>	<u>SECOND TEST</u>	<u>THIRD TEST</u>	<u>FOURTH TEST</u>	<u>FIFTH TEST</u>
1. 11,21	R	L	MV	B	DV
2. 12,22	L	R	B	DV	MV
3. 13,23	R	L	DV	MV	B
4. 14,24	L	R	B	MV	DV
5. 15,25	R	L	MV	DV	B
6. 16	L	R	DV	B	MV
7. 17	R	L	MV	DV	B
8. 18	L	R	B	DV	MV
9. 19	R	L	DV	MV	B
10. 20	L	R	MV	B	DV

R-Monaural - One channel hearing aid #50 with earphone #52 to the right ear.

L-Monaural - One channel hearing aid #50 with earphone #52 to the left ear.

MV-Monotic V-Cord Mode - To the ear showing better discrimination score under first and second tests above, with hearing aid #50 and earphone #52.

B-Binaural - Hearing aids #50 and #51, hearing aid #50 with earphone #52 to the ear showing better discrimination score under first and second tests above and hearing aid #51 earphone #52 to the ear showing poorer discrimination.

DV-Double V-Cord Mode - With earphone #52 in ear showing better discrimination and earphone #53 in ear showing poorer discrimination.

APPENDIX E

Spondee auditory C.I.D. W-1 word lists for speech
reception threshold tests.

1. List C Alphabetized
2. List C As recorded by C.I.D.
3. List D Alphabetized
4. List D As recorded by C.I.D.

List C. Alphabetized word list from CID, auxiliary test W-1.

- | | |
|---------------|----------------|
| 1. airplane | 19. iceberg |
| 2. armchair | 20. inkwell |
| 3. baseball | 21. mousetrap |
| 4. birthday | 22. mushroom |
| 5. cowboy | 23. northwest |
| 6. daybreak | 24. oatmeal |
| 7. doormat | 25. padlock |
| 8. drawbridge | 26. pancake |
| 9. duckpond | 27. playground |
| 10. eardrum | 28. railroad |
| 11. farewell | 29. schoolboy |
| 12. grandson | 30. sidewalk |
| 13. greyhound | 31. stairway |
| 14. hardware | 32. sunset |
| 15. headlight | 33. toothbrush |
| 16. horseshoe | 34. whitewash |
| 17. hotdog | 35. woodwork |
| 18. hothouse | 36. workshop |

This list was used for familiarizing the subjects with the words before determination of unaided speech reception thresholds.

List C. Word list as recorded from C.I.D. auditory test W-1.

- | | |
|---------------|----------------|
| 1. birthday | 19. farewell |
| 2. hothouse | 20. mousetrap |
| 3. toothbrush | 21. armchair |
| 4. horseshoe | 22. drawbridge |
| 5. airplane | 23. mushroom |
| 6. northwest | 24. baseball |
| 7. whitewash | 25. grandson |
| 8. hotdog | 26. padlock |
| 9. hardware | 27. greyhound |
| 10. woodwork | 28. sunset |
| 11. stairway | 29. cowboy |
| 12. daybreak | 30. duckpond |
| 13. sidewalk | 31. playground |
| 14. railroad | 32. inkwell |
| 15. oatmeal | 33. eardrum |
| 16. headlight | 34. workshop |
| 17. pancake | 35. schoolboy |
| 18. doormat | 36. iceberg |

This list was used in the determination of unaided speech reception thresholds.

List D. Alphabetized word list from C.I.D. auditory test W-1.

- | | |
|---------------|----------------|
| 1. airplane | 19. iceberg |
| 2. armchair | 20. inkwell |
| 3. baseball | 21. mousetrap |
| 4. birthday | 22. mushroom |
| 5. cowboy | 23. northwest |
| 6. daybreak | 24. oatmeal |
| 7. doormat | 25. padlock |
| 8. drawbridge | 26. pancake |
| 9. duckpond | 27. playground |
| 10. eardrum | 28. railroad |
| 11. farewell | 29. schoolboy |
| 12. grandson | 30. sidewalk |
| 13. greyhound | 31. stairway |
| 14. hardware | 32. sunset |
| 15. headlight | 33. toothbrush |
| 16. horseshoe | 34. whitewash |
| 17. hotdog | 35. woodwork |
| 18. hothouse | 36. workshop |

This list was used for familiarizing the subjects with the words before determination of aided speech reception thresholds.

List D. Word list as recorded from C.I.D. auditory test W-1.

- | | |
|----------------|----------------|
| 1. hothouse | 19. playground |
| 2. padlock | 20. oatmeal |
| 3. eardrum | 21. northwest |
| 4. sidewalk | 22. woodwork |
| 5. cowboy | 23. stairway |
| 6. mushroom | 24. hotdog |
| 7. farewell | 25. headlight |
| 8. horseshoe | 26. pancake |
| 9. workshop | 27. birthday |
| 10. duckpond | 28. greyhound |
| 11. baseball | 29. mousetrap |
| 12. railroad | 30. schoolboy |
| 13. hardware | 31. whitewash |
| 14. toothbrush | 32. inkwell |
| 15. airplane | 33. doormat |
| 16. iceberg | 34. daybreak |
| 17. armchair | 35. drawbridge |
| 18. grandson | 36. sunset |

This list was used in the determination of aided speech reception thresholds.

APPENDIX F

Revised Peterson-Lehiste CNC word lists #6 through #10 used in this study to measure speech discrimination.

List 6. Revised Peterson-Lehiste CNC word lists used to measure speech discrimination.

- | | |
|-----------|------------|
| 1. mode | 26. dig |
| 2. search | 27. cool |
| 3. rush | 28. bad |
| 4. bud | 29. live |
| 5. birth | 30. night |
| 6. wing | 31. whip |
| 7. cage | 32. dull |
| 8. wife | 33. chain |
| 9. lawn | 34. jam |
| 10. gone | 35. sit |
| 11. howl | 36. rug |
| 12. tube | 37. hiss |
| 13. fan | 38. raise |
| 14. pole | 39. chesse |
| 15. pace | 40. knock |
| 16. map | 41. veal |
| 17. hike | 42. team |
| 18. shock | 43. get |
| 19. sour | 44. fire |
| 20. bed | 45. niece |
| 21. pope | 46. jot |
| 22. cat | 47. door |
| 23. move | 48. calf |
| 24. look | 49. shone |
| 25. web | 50. turn |

List 6 - second randomization -
identified #162823, from tape
prepared by William D. Chapman.

List 7. Revised Peterson-Lehiste CNC word lists used to measure speech discrimination.

- | | |
|------------|-----------|
| 1. call | 26. vague |
| 2. pine | 27. save |
| 3. gun | 28. such |
| 4. rib | 29. reach |
| 5. loot | 30. did |
| 6. coke | 31. top |
| 7. doom | 32. note |
| 8. bun | 33. wit |
| 9. mouth | 34. tape |
| 10. heat | 35. pearl |
| 11. lose | 36. was |
| 12. shall | 37. join |
| 13. geese | 38. dumb |
| 14. laugh | 39. neck |
| 15. have | 40. sack |
| 16. pass | 41. bet |
| 17. ridge | 42. mole |
| 18. sure | 43. tar |
| 19. cheek | 44. big |
| 20. side | 45. nap |
| 21. caught | 46. fish |
| 22. far | 47. young |
| 23. hole | 48. face |
| 24. led | 49. third |
| 25. gem | 50. mine |

List 7 - second randomization -
identified #873120, from tape
prepared by William D. Chapman.

List 8. Revised Peterson-Lehiste CNC word lists used to measure speech discrimination.

- | | |
|------------|-----------|
| 1. foam | 26. shoot |
| 2. guide | 27. cub |
| 3. noose | 28. near |
| 4. pose | 29. gear |
| 5. rot | 30. some |
| 6. hurl | 31. moss |
| 7. jerk | 32. tin |
| 8. fuss | 33. thing |
| 9. week | 34. vowel |
| 10. wheat | 35. bag |
| 11. rain | 36. gag |
| 12. bite | 37. seek |
| 13. calm | 38. tip |
| 14. cheap | 39. gin |
| 15. wake | 40. dive |
| 16. muff | 41. poor |
| 17. road | 42. sad |
| 18. wet | 43. lash |
| 19. learn | 44. hail |
| 20. hoop | 45. touch |
| 21. daze | 46. page |
| 22. loathe | 47. real |
| 23. lock | 48. there |
| 24. den | 49. cough |
| 25. bath | 50. shawl |

List 8 - second randomization -
identified #184329, from tape
prepared by William D. Chapman.

List 9. Revised Peterson-Lehiste CNC word lists used to measure speech discrimination.

- | | |
|-----------|-----------|
| 1. soap | 26. wrong |
| 2. tool | 27. feet |
| 3. need | 28. lack |
| 4. curve | 29. got |
| 5. pun | 30. word |
| 6. loaf | 31. fudge |
| 7. mire | 32. dog |
| 8. ham | 33. cut |
| 9. watch | 34. ball |
| 10. dish | 35. yet |
| 11. both | 36. shade |
| 12. lathe | 37. mud |
| 13. reap | 38. voice |
| 14. catch | 39. sin |
| 15. shout | 40. chair |
| 16. time | 41. roof |
| 17. white | 42. jazz |
| 18. book | 43. rag |
| 19. nail | 44. hen |
| 20. tick | 45. sane |
| 21. beat | 46. thine |
| 22. mob | 47. pill |
| 23. lip | 48. cheer |
| 24. girl | 49. haze |
| 25. power | 50. deck |

List 9 - second randomization -
identified #192326, from tape
prepared by William D. Chapman.

List 10. Revised Peterson-Lehiste CNC word lists used to measure speech discrimination.

- | | |
|------------|-----------|
| 1. gore | 26. bake |
| 2. fine | 27. judge |
| 3. rob | 28. pile |
| 4. run | 29. loose |
| 5. chat | 30. hair |
| 6. burn | 31. rope |
| 7. mood | 32. meek |
| 8. path | 33. deep |
| 9. wash | 34. coin |
| 10. thatch | 35. sell |
| 11. towel | 36. cone |
| 12. death | 37. safe |
| 13. din | 38. chill |
| 14. hit | 39. neat |
| 15. cause | 40. term |
| 16. sag | 41. hurt |
| 17. sub | 42. jade |
| 18. witch | 43. ride |
| 19. cave | 44. shack |
| 20. palm | 45. nick |
| 21. lot | 46. mouse |
| 22. load | 47. peak |
| 23. lung | 48. while |
| 24. fool | 49. your |
| 25. bit | 50. guess |

List 10 - second randomization -
identified #207823, from tape
prepared by William D. Chapman.

APPENDIX G

Data sheet and sample subject response sheet.

1. Subjects data sheet.
2. Sample sheet for subject to record his response to the Revised Peterson-Lehiste CNC word lists.

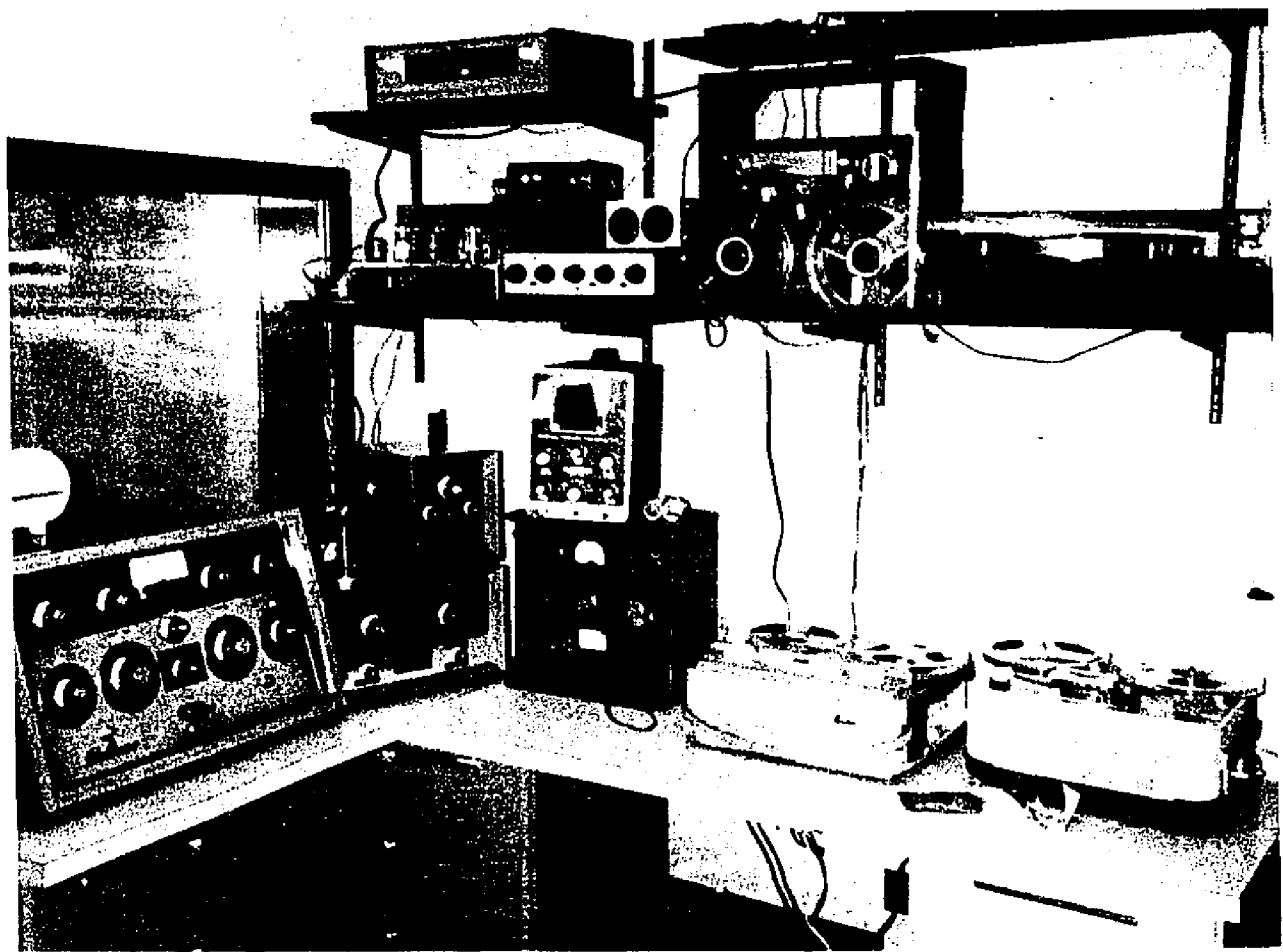
List 6. Responses to Revised Peterson-Lehiste CNC
word list.

1.	26.
2.	27.
3.	28.
4.	29.
5.	30.
6.	31.
7.	32.
8.	33.
9.	34.
10.	35.
11.	36.
12.	37.
13.	38.
14.	39.
15.	40.
16.	41.
17.	42.
18.	43.
19.	44.
20.	45.
21.	46.
22.	47.
23.	48.
24.	49.
25.	50.

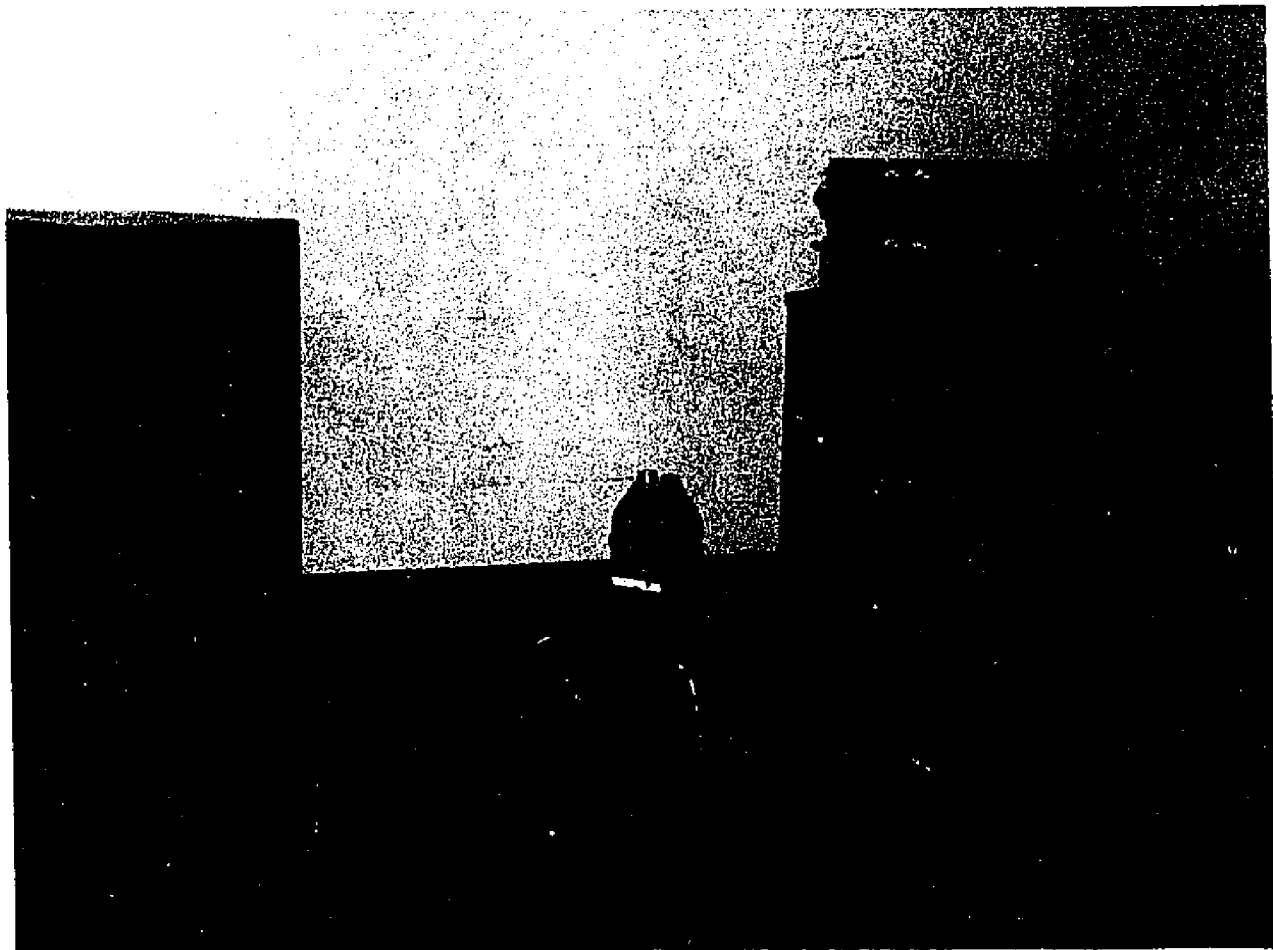
APPENDIX H

Photographs of experimental
equipment used in this study.

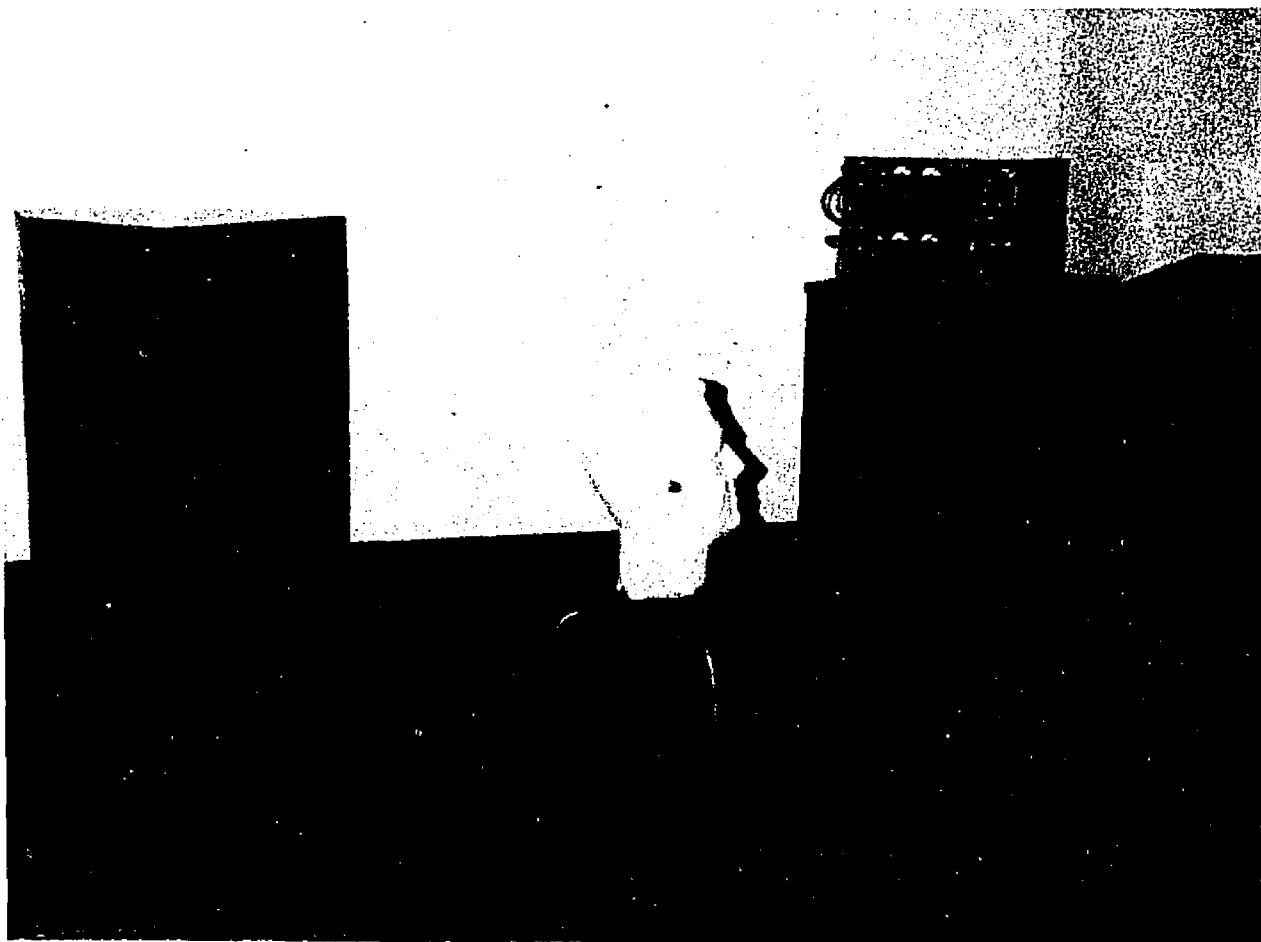
Photograph of experimental equipment in control room.



Photograph of General Radio sound level meter in position of the dummy head in Test Room 1 for measuring sound pressure levels.



Photograph of dummy head with Ampex insert microphones positioned equidistant from the three loudspeakers in Test Room 1.



Photograph of dummy head with hearing aids #50 and #51 positioned equidistant from the three loudspeakers in Test Room 1.



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