A TEST OF BINAURAL HEARING

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CHAPTER I

REVIEW OF THE LITERATURE

The past decade has seen a growing interest in, and an expanding knowledge about evaluation of hearing aids. The introduction of easy-to-wear binaural aids has stimulated much research and discussion about their merits, appropriate use, and effectiveness. It is generally accepted that binaural hearing is superior to any form of monaural hearing, with or without an aid. However, the lack of definitive research to objectively support this concept has, in large measure, been responsible for the failure to develop effective guides for the measurement of the efficiency of these new aids.

A normal hearing person placed in a noisy surrounding will still be able to understand speech and can localize its source, if it is not considerably obliterated by the noise. A comparable situation occurs in a gathering of people when several conversations are in progress simultaneously. A person with normal hearing has no difficulty "filtering out" other conversations and concentrating on the one which interests him. This ability has been dubbed the "cocktail party" effect.

In contrast, a person who must listen monaurally, especially one who wears a monaural hearing aid, usually reports that this "cocktail party" effect has been destroyed. For such a listener in a crowd, voices become a hopeless jumble, and speech in the presence of noise becomes almost unintelligible. When the hearing ability of both ears has been nearly equalized, the hard-of-hearing patient reports that the "cocktail party" effect is present.

In 1950, Hirsh reported findings of the preceding years in the field of binaural hearing. It had been well established that binaural thresholds were usually lower than monaural thresholds. It was also known that differential thresholds (discrimination between frequencies or intensities) are more acute when tested binaurally than when tested monaurally. In view of these findings, it would appear that tonal distinctions are differentiated better, and at lower intensities, when heard binaurally than when heard monaurally.[1] Inasmuch as tone and intensity are two basic components of speech, it follows that speech should be more intelligible when heard binaurally than when heard monaurally.

Worthy of consideration is the effect of masking noise upon threshold and the ability to discriminate speech. The term "masking" refers to noises which are extraneous to the actual listening situation, but which, if sufficiently

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[1]Ira J. Hirsh, "Binaural Hearing Aids: A Review of Some Experiments," Journal of Speech and Hearing Disorders, XV (June, 1950), 115-16.

loud, may obliterate the tone or the speech. In this regard, Hirsh, in an original experiment, found that monaural thresholds were lower than binaural thresholds when masking was used.[2] This, of course, is contrary to common expectation that binaural thresholds are lower than monaural. Using earphones, he presented noise and tone to one ear and only noise in the other ear. He found, however, that this phenomenon occurs only when the interaural phase angles for both the noise and the tone are the same. When they are not, then the binaural threshold is lower than the monaural, as expected.

In support of his findings, Hirsh cited the experiments of Licklider who investigated the influence of different interaural phase relations on the masking of speech by white noise. His results for speech generally coincide with those for pure tones. He measured a condition of interaural phase in which the noises in the two ears came from two separate, independent noise generators. Speech presented binaurally could be either in-phase or out-of-phase while the interaural phase angle changed randomly. The intelligibility of the partially masked speech under this condition lies between the intelligibility in a homophasic

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[2]Hirsh, "Binaural Hearing Aids," pp. 116-19.

and an antiphasic condition.[3]

Similar findings were reported by Koenig in 1950. He conducted a test in which the subject listened through receivers connected to two different systems: (a) both receivers fed from a single microphone; and (b) each receiver fed from a different microphone. The microphones were located in an ordinary room and the listeners in another. A switching system enabled the listener to switch between the two microphone systems without changing receivers. The results of the test indicated that the two-microphone or "binaural" system was much superior to the one-microphone or "monaural" system in coping with the masking effect of the background room noises. No unnatural or objectionable reverberation was noticed from either speech or background noises even at twelve decibels above unity (output equals input) with the binaural system, but reverberation was noticed considerably with the monaural system. The ability to select one sound out of many was present with the binaural system but not the monaural system. With the binaural system, speech discrimination was good even at high masking levels (fifty to sixty decibels). Koenig concluded,

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[3] J. C. R. Licklider, "The Influence of Interaural Phase Relation upon the Masking of Speech by White Noise," <u>Journal of the Acoustical Society of America</u>, XX (1948), 150-59.

therefore, that in binaural listening, the two ears receive acoustic signals which differ somewhat in phase and magnitude, and that each ear differs somewhat in sensitivity and frequency response characteristics. These two different signals are then somehow correlated in the brain. This process is responsible for the ability of the two ears, working together, to localize sounds of interest and to suppress unimportant sounds. In monaural listening, of course, this correlation is impossible, and as a result the ability to localize is absent.[4]

It may be well at this point to consider some principles of binaural hearing with regard to sound localization. Following the same line of experimentation as Koenig, Kock, in 1950, reported on experiments which he had conducted which indicated that the ability of the brain to localize a desired sound in a noisy background can be traced in part to the different times of arrival of the sound at the two ears. It is suggested that the brain inserts a time delay in one of two nerve paths associated with the ears so as to be able to compare and thus concentrate on those sounds arriving at the ears with this particular time of arrival difference. The experiments further suggest that the brain

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[4]W. Koenig, "Subjective Effects in Binaural Hearing," _Journal of the Acoustical Society of America_, XXII (January, 1950), 61-62.

preserves and evaluates these time delays to achieve not only directional localization of sound but also observed discrimination of the localized sound (speech or tone) against reverberation and background noise. When the sound and the noise arrive at the two ears without this relative time delay, discrimination fails. The time delay hypothesis explains how two ears permit a person to decide whether a sound source is in front or behind by a twisting motion of the head.[5]

In his earlier binaural experiments, Koenig had found that the listener was able to perceive directional changes in the localization of the sound source, but that the change was always in the semicircle behind him. When the mechanism was adjusted so that the listener could turn to face the source of the sound, it was found that he always faced in the correct direction. He concluded, therefore, that apparently our directional perception depends partly on our ability to draw conclusions from the manner in which binaurally received sounds are affected by head movements.[6]

In 1950, Hirsh reported on experiments which he had conducted concerning the relationship between localization

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[5]W. E. Kock, "Binaural Localization and Masking," The Journal of the Acoustical Society of America, XXII (November, 1950), 803-06.

[6]Koenig, "Subjective Effects in Binaural Hearing," p. 62.

and intelligibility. His experiments showed that the intelligibility of speech in noise is at least partially dependent upon the relative localization of the speech and noise. His findings further indicated that the binaural masked threshold of intelligibility depends clearly upon the interaural phase relations of both the masked and masking signals. When the source of both the speech and noise appears to be in the same place, the threshold of the intelligibility of speech is higher. Precision in localization is best obtained when the observer uses two ears and is free to move his head. Reflected sounds due to reverberation may affect localization.[7]

Part of Hirsh's equipment included two loudspeakers mounted on booms, one for speech and one for noise; and two rooms, one anechoic and one highly reverberative. A dummy head with receivers for "ears" was placed in either of the two rooms and used as the "subject." In the process of the testing, the loudspeakers were rotated to ten different positions around the head. Hirsh's conclusions may be summarized as follows:

1. When two independent sound sources, speech and noise, are changed in position relative to each other, the resulting changes in signal-noise ratio at the ear will

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[7] Ira J. Hirsh, "The Relationship Between Localization and Intelligibility," The Journal of the Acoustical Society of America, XXII (June, 1950), 196.

change the threshold of intelligibility of speech.

2. Actual spatial separations and consequent localizations seem responsible for further changes in the threshold.
3. These changes, which presumably depend upon localization, are greater binaurally than monaurally, and greater in the anechoic chamber than in the reverberative room.

On the basis of these conclusions, Hirsh, therefore, recommended the use of binaural aids.[8]

In 1955, Ettore Bocca reported on another approach to binaural hearing. He, too, found hearing more acute binaurally than monaurally. Using normals, he subjected them to the output of two loudspeakers. He delivered the sound first to only one ear at a time, then both ears at the same time. In one speaker he used distorted sound; in the other, the sound was of good fidelity. Binaural hearing proved to be more satisfactory in discriminating the good fidelity sounds.[9]

In discussing binaural hearing aids, Carhart spoke of binaural hearing in terms similar to those of Koenig but differing from Kock's ideas. Carhart maintained that the sound patterns given to the two microphones of a binaural aid are not identical, therefore the sequence of excitatory

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[8]Hirsh, "The Relationship Between Localization and Intelligibility," p. 199-200.

[9]Ettore Bocca, "Binaural Hearing: Another Approach," Laryngoscope, LXV (December, 1955), 1164-171.

events which reaches one ear is different from that which reached the other ear. This he felt establishes the capacity for spatial localization. Normal ability requires two independent sequences of neural events, one from each inner ear, in order to activate the central nervous system. This allows the person to hold his attention to the most important stimulus. The capacity to localize depends upon the separation of the ears by the head. This achieves auditory triangulation on every sound source. The two ears will receive identical acoustical excitation only when the sound source is in the midline sagitial plane. Any other sound source produces bilaterally dissimilar acoustical excitation because the auditory sound paths are no longer the same.[10]

A clinical evaluation of binaural and monaural hearing aids was conducted by Markle and Aber, in 1958. The subjects were all victims of clinical otosclerosis and had no speech discrimination loss. The equipment consisted of two loudspeakers each of which could deliver a signal only (Auditory Test W-22 and spondee wordlists), or a noise alone (recorded factory noise), or signal and noise together. Each subject was tested with conventional aids, monaural and binaural. The results showed no significant difference

[10]Raymond Carhart, "The Usefulness of the Binaural Hearing Aid," _Journal of Speech and Hearing Disorders_, XXIII (February, 1958), 42.

between the speech reception thresholds obtained with monaural and binaural aids when the signal and noise emanated from the same source. When the signal and noise emanated from different sound sources, however, it was found that at a signal-noise ratio of +10 there was some difference between the speech reception thresholds of binaural and monaural aids, and at 0 and -10, the differences were significant and apparent. Markle and Aber's concluding comment was that when fitted with a true binaural aid, the subject experiences significantly better speech discrimination when exposed to a listening environment which is strongly influenced by competitive background noise, provided the speech and noise are separated in space.[11]

In conclusion, it would be well to list four guides which Carhart believes are needed in order to make specific evaluations and decisions for patients regarding use of binaural aids.

1. Essential criteria must be clarified through research because there is a lack of knowledge for intelligent prejudgment of the patient's prospects for practical benefits from a binaural aid. Codification must be made of those features which distinguish those cases

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[11]Donald M. Markle and William Aber, "A Clinical Evaluation of Monaural and Binaural Hearing Aids," Archives of Otolaryngology, LXVII (May, 1958), 606-08.

who will have difficulty with binaural aids from those who will be benefitted.

2. We must be able to gauge directly the performance of the aid for each patient. Methods for testing a patient's efficiency with an aid must be refined and standardized.

3. The two procedures which are currently used to assess the efficiency of a hearing aid fail to possess the rigor necessary to satisfy the foregoing requirements.

    a. Informal demonstration of the instrument is too casual and is not carried out under true performance conditions.

    b. The formalized sound-field test is administered through equipment with a single output channel. Tests must be more complex than what is now used.

4. The fundamental requisite of a good test is that it explores the patient's capacity to perceive foreground and background relationships in the acoustic environment while wearing a binaural aid.[12]

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[12]Carhart, "The Usefulness of the Binaural Hearing Aid," pp. 47-48.

CHAPTER II

PURPOSE OF THE EXPERIMENT

With the advent of easily wearable binaural aids, there arose the problem of accurately evaluating the efficiency of these aids for the individual user. What sort of test would effectively indicate whether an individual user would significantly benefit from the use of such an aid, as opposed to the use of a monaural aid? Would such an aid, in fact, restore to him the ability to localize? Could he again be able to discriminate speech in the presence of noise or of other voices?

As stated in the previous chapter, Markle and Aber reported in 1958 the results of their experiment to construct such a test. Using a two-speaker situation, the task involved recognizing speech in the presence of recorded factory noise.[1] Up to the present time this has been the most satisfactory method of evaluating binaural hearing. Because many hard-of-hearing people have not had prior actual experience with "factory noise," and are not likely to be actually exposed to such noise, the practicality of this test is questionable.

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[1]Markle and Aber, "A Clinical Evaluation of Monaural and Binaural Hearing Aids," pp. 606-08.

On the other hand, all persons are likely to be exposed to situations where there is need to discriminate speech in the presence of other speech. Since this is so, it may be hypothesized that when evaluating an aid, a situation involving speech masked by speech would provide a more natural situation and probably a more sensitive measuring device than the methods in present use.

The purpose of this experiment is to explore the potential for, and efficiency of, testing with such a procedure.

The proposed method involves listening to speech masked by other speech. Both monaural and binaural hearing is involved in a two-speaker and one-speaker situation. At the outset of the experiment it was hoped that the test would show that the differences found between the two-speaker and one-speaker situations when heard binaurally would not be present when heard monaurally. The proposed procedure would permit measurement of the superiority of binaural listening over monaural listening. Carried over to hearing aid evaluations, it would indicate the degree of superiority of a binaural aid over a monaural aid for a prospective individual user.

CHAPTER III

MATERIALS AND SUBJECTS

The Masking Speech

Because of the nature of the thesis experiment, one of the most important procedures was producing the "babble" speech to be used as masking for the test-speech. The effect desired was that of a "cocktail party" type of speech noise. After consideration of several possible alternatives, the following procedure was decided upon and followed.

Six readers, college students, three male and three female, were placed in a sound-proofed room in a circle around a boom microphone.[1] Each was supplied with a different page of typewritten material. Materials were selected at random from published text books (see sample, (Appendix A). The participants were asked to read at a comfortable rate and level of loudness. Before actually beginning the recording session, each reader's voice was monitored with a VU meter, so that all voices would be at approximately the same level and thereby avoid the possibility of one voice being predominant above the rest. Where

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[1]The facilities of the Bowling Green State University radio station, WBGU, were used in making the experimental tape recording. Personal gratitude is expressed to Mr. Robert Greaige.

adjustments were necessary, the reader was moved either closer to or further away from the microphone until the intensity of his voice was at a level equal to the others.

At the start of the recording session, the readers were instructed to read to the bottom of the page and then start over again with as short a pause as possible. They were to continue until given the signal to stop. All read simultaneously for approximately eight minutes. The results were recorded on magnetic tape, and then, in order to be sure of sufficient length during the actual experiments, "dubbed" twice in succession on the final tape used for the thesis experiment. The results of this recording session produced the desired effect of "babble" speech and was most satisfactory throughout the course of the experiments.

Subjects

Thirty-two normal hearing subjects were used. Subjects were screened for this experiment only where there was no evidence of previous audiological evaluation. Only in two cases where there was some doubt about hearing acuity, was any special hearing test made. In both cases, subjects' hearing was normal. The subjects were college students and professors, thirteen male and nineteen female, between the ages of eighteen and forty. The median age was nineteen (all but two subjects were under twenty-one years of age). The group was tested both as normals in a binaural situation and as hard-of-hearing subjects, by inducing a moderate monaural hearing loss (40-50 db).

Inducing Hearing Loss

In order to induce a handicapping hearing loss in normal hearing subjects, equivalent to approximately a 40-50 db monaural hearing loss, the masking device of a Maico D-9 audiometer was used. The machine was situated near the subject. On a signal from the tester, the subject was required to turn the masking output up to full. The dial was visible to the experimenter and instructions were repeated until he complied. The positioning of the earphone was alternated between the left and right ears so that at the conclusion of the experiment, sixteen subjects had worn it on the right ear, and sixteen subjects had worn it on the left ear.

Equipment Used

An Allison Laboratories Two-channel Speech Audiometer was used.[2] The two speakers were arranged so that the output of speaker number one could be either "babble" speech alone or "babble" speech and test speech together, and the output

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[2]Allison Laboratory, LaPuente, California, Audiometer Model 21.

of speaker number two was test speech alone or silence. A switching system allowed the test speech to be presented in either speaker and switched to the other at any time. (Hereafter, test speech will be referred to as "signal", and "babble" speech as noise.")

Room Arrangement

Experiments were conducted in a quiet, acoustically treated room. (See Appendix B.) The two loudspeakers were situated in corners adjacent to one wall. The subjects were seated in the center of the room with their backs to the experimenter, at the point at which the axes of the two loudspeakers intersected. Such seating was arranged because in tests with pilot subjects, they reported that the rather small size of the room made them feel uncomfortably close to the tester when facing her. A mirror was situated on the wall opposite the subject in order that the tester might see the subject's face and thereby avoid possible error in recording the subject's responses on words which sound acoustically alike (such as "fin" and "thin"). The Maico D-9 audiometer was placed on a table to the right of the subject within easy reach.

Test Speech

The standard CID Auditory Test W-22 recorded PB word lists 1A, 1B, 2A, 2B, 3A, 3B, 4A, and 4B, were used.[3] The words were administered in groups of twenty-five for each of the three signal-noise ratio levels in each of four experimental situations. The order in which the words were presented remained constant throughout the course of the experiment and no attempt at rotation of the word lists was made. Because of rotation of situations, however, each list was used in each situation eight times. The order in which they were presented was as shown in Table I.

TABLE I

ORDER OF PRESENTATION OF W-22 PB WORD LISTS

Situations	*S/NR +5	S/NR 0	S/NR -5
First	1A 1-25	1A 26-50	1B 1-25
Second	2A 1-25	2A 26-50	2B 1-25
Third	3A 1-25	3A 26-50	3B 1-25
Fourth	4A 1-25	4A 26-50	4B 1-25

*Signal-noise Ratio

[3]Central Institute for the Deaf. Auditory Test (W-22) Manufactured and distributed by Technisonic Studios, 1201 South Brentwood Blvd., St. Louis 17, Missouri.

CHAPTER IV

PROCEDURES

The subject was seated in the test room, and, to keep his head straight, was instructed to look at the wall facing him. He was then presented with four situations. Two involved binaural (normal) listening, and in two he was subjected to an induced monaural hearing loss by using the masking earphone. Within both the monaural and binaural situations, the subject was presented with two sub-situations: in one the signal and noise both emanated from speaker number one; and in the other the noise was presented in speaker number one and the speech in speaker number two. For ease of reference, the four situations will be referred to as follows: monaural, one-speaker - M1; monaural, two-speaker - M2; binaural one-speaker - B1; binaural two-speaker - B2. In each of the four situations, the noise was kept at a constant intensity level of 50 db above threshold. The signal was presented at intensities 5 db below and above the noise as well as at the same intensity (55db, 50 db, 45 db), thereby providing signal-noise ratios of +5, 0, and -5.

In order to avoid any advantage of one situation over the others because of order of presentation the order was rotated. Each situation was in each of the four positions of presentation (first, second, third, and fourth) eight times. (For rotation schedule see Appendix C.)

Twenty-five words were presented to the subject at each signal-noise ratio level for each of the four situations. He repeated the words he heard. A tally was kept of the number of errors made at each level.

CHAPTER V

RESULTS

In tabulating the data received from the experiment, it was necessary to perform certain statistical analyses. In so doing, one of the first steps was to determine the mean number of errors in each situation at each of the three signal-noise ratio levels. A table of these figures may be seen below.

TABLE II

MEAN NUMBER OF ERRORS PER SITUATION

Situations	+5 S/NR	0 S/NR	-5 S/NR
M1	4.56	9.31	15.18
M2	6.25	12.28	17.19
B1	3.38	8.13	13.38
B2	2.06	4.81	7.41

A "t" test was performed on each of the two halves of the test (monaural, one and two-speaker - M1 and M2; binaural, one and two-speaker - B1 and B2) in order to determine if any significant differences existed between the one-speaker and two-speaker situations with regard to errors in distinguishing the test at the various signal-noise ratios.

Involved in the tabulation of these "t" scores was the consideration of the standard deviations and mean differences within the M1-M2 and B1-B2 halves of the test. These figures may be found in Table III.

TABLE III

MEAN, DIFFERENCE IN ERRORS, STANDARD DEVIATIONS, AND "t" SCORES OF THE DIFFERENCES IN THE NUMBER OF ERRORS IN THE BINAURAL AND MONAURAL SITUATIONS

S/NR	M1 - M2 "t"	M1 - M2 Mean	M1 - M2 SD	B1 - B2 "t"	B1 - B2 Mean	B1 - B2 SD
+5	*-2.28	-1.69	4.20	**3.47	1.32	2.16
0	-1.43	-2.97	7.43	**6.51	3.32	2.87
-5	*-2.27	-2.01	8.00	**8.65	5.97	3.94

* Significant at the 1% level of confidence

** Significant at the 5% level of confidence

Interpretation of the "t" scores yielded quite significant information. In order to indicate a significant difference at the 5 per cent level of confidence, results must be above 2.04, and at the 1 per cent level of confidence, results must be above 2.75. From table three it may be seen that results were significant at the 5 per cent level of confidence at all signal-noise ratio levels except at 0 monaurally. At the 1 per cent level of confidence, results were not significant in the monaural situations, yet, in the binaural situations, differences were quite significant and apparent at all three signal-noise ratio levels. Since the nature of the experiment is such that the most stringent levels of confidence must be required in order to insure maximum efficiency, the 5 per cent level will be considered negligible, and attention will be centered solely upon the 1 per cent level of confidence. These results appear to indicate that in the monaural half of the experiment, neither situation provides any advantage over the other in increasing hearing efficiency. In the binaural half, however, there is a very definite increase in hearing efficiency in the two-speaker situation as opposed to the one-speaker situation.

Represented in graphic form, the results are illustrated in percentage of errors in Figure 1.

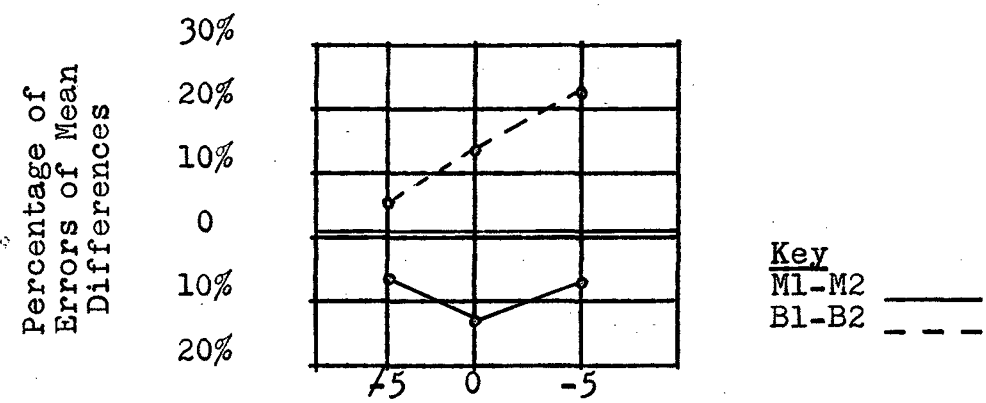

FIGURE 1

MEAN DIFFERENCES WITHIN THE MONAURAL ONE AND TWO-SPEAKER SITUATIONS AND THE BINAURAL ONE AND TWO-SPEAKER SITUATIONS EXPRESSED IN PERCENTAGE OF ERRORS

In the monaural situation, differences appear to indicate an average of two errors or ten per cent fewer errors in the M1 as compared with the M2 situation, or a negative disadvantage of approximately -2 errors or -10 per cent. Variations in the M1-M2 curve may be attributed to chance variation. Although results were not shown to be significant, it is believed that the negative result is the effect of an error in calibration of speaker number two in the two-speaker situation. Had the error not existed, it is believed that the mean differences between the two monaural situations would have been in the area of 0, or only very minor chance variation.[1] In the binaural situations, the differences indicate that as the situation became more difficult, the use of binaural hearing became more helpful. As the signal-noise ratio decreased, the differences between the number of errors made in the one-speaker situation as opposed to those in the two-speaker situation steadily increased. (Had there not been an error in calibration in the two-speaker situation, results would have indicated an curve about 10 per cent higher in favor of the two-speaker

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[1]After completion of the experiment, it was discovered that in the two-speaker situation there was a discrepancy in calibration of speaker number two of 2 db, so that in the two-speaker situation, the actual signal-noise ratios were +3, -2, and -7. The discrepancy is believed to be the result of a shift in positioning of subjects made after preliminary testing of several pilot subjects.

situation.)

A comparison of the two-speaker monaural and binaural situations now appears to be in order. Using the formula (M2-B2)/25, the reduction in the percentage of errors in the binaural as compared with the monaural situation at the three signal-noise ratio levels, and the actual number of errors reduced are represented in graphic form in Figure 2.

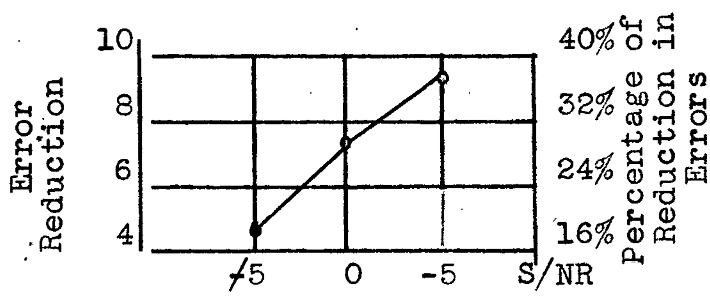

FIGURE 2

REDUCTION IN ERRORS BETWEEN THE MONAURAL AND BINAURAL TWO-SPEAKER SITUATIONS EXPRESSED NUMERICALLY AND IN PERCENTAGES

Analysis of Figure 2 indicates that the reduction in errors between the monaural and binaural two-speaker situations bears out the information garnered from the analyses of the other situations. As the situation becomes increasingly more difficult, the superiority of binaural hearing over monaural hearing provides increasingly efficient recognition of speech when the speech and noise come from sources separated in space as in the two-speaker situations. The curves illustrated in Figure 2 reinforce the conviction of binaural superiority.

Another avenue of investigation which may be opened is a discussion of the question, what percentage of the errors recorded in M2 is represented by the errors recorded in B2? The actual number of errors involved in the two situations at the three signal-noise ratio levels were these: in the M2 situation at ≠5 - 6.25, at 0 - 12.28, at -5 - 17.19; in the B2 situation, at ≠5 - 2.06, at 0 - 4.81, and at -5 - 7.41. Using the formula M2-B2/M2, we find that the percentage of errors of M2 represented by the errors recorded in B2 are 67 per cent, 61 percent, and 57 per cent at the three signal-noise ratios respectively. A graphic presentation of this may be seen in Figure 3.

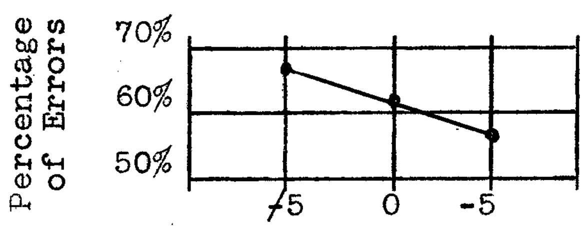

FIGURE 3

PERCENTAGE OF ERRORS OF THE MONAURAL TWO-SPEAKER SITUATION REPRESENTED BY THE BINAURAL TWO-SPEAKER SITUATION

Figure 3 illustrates the fact that the percentage of errors recorded in M2 represented by those recorded in B2 at all three signal-noise ratio levels exceeds 50 per cent. That is, there is a reduction of 50 per cent or more of the errors made in shifting from the monaural to the binaural situation. Since the curve declines, however, a speculation which may be made is that the acuity of binaural hearing is also affected by the more difficult situations, although not sufficiently so to be of much note.

Before any definite conclusion may be drawn from this information, perhaps a look at the results of a similar experiment may be in order. In Markle and Aber's experiment, cited in Chapter I, they stated that they had used recorded factory noise. The percentage of errors which they recorded were as follows: in the two-speaker situation, with a monaural aid at +10 S/NR - 12.0 per cent, at 0 S/NR - 33.6 per cent, and at -10 S/NR - 96.0 per cent; with a binaural aid at +10 S/NR - 7.6 per cent, at 0 S/NR - 22.4 per cent, and at -10 S/NR - 66.2 per cent.[2] Again using the formula M2-B2/M2 the percentage of errors of M2 represented by those recorded in B2 were at +10 - 37 per cent, at 0 - 33 per cent and at -10 - 31 per cent. A graphic presentation of this may be seen in Figure 4.

Inasmuch as Figure 4 appears to bear out what was shown in Figure 3, it would seem that on the basis of these two independent studies, the conclusion to be drawn is that in difficult listening situations, the efficiency of binaural

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[2]Markle and Aber, "A Clinical Evaluation of Monaural and Binaural Hearing Aids," pp. 607-08.

listening as well as monaural listening is affected. However, the deterioration does not appear to be severe enough to be obvious. In any case, binaural hearing still is far superior to any form of monaural listening regardless of the situation. It may be further noted that "babble" speech appears to be a more effective masking device than the noise used by Markle and Aber. The comparison above clearly indicates that the "babble" speech creates more difficulty, and shows more marked binaural effect.

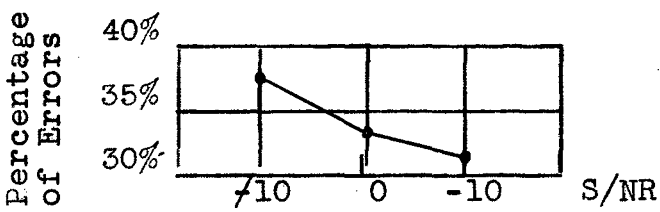

FIGURE 4

PERCENTAGE OF ERRORS OF THE MONAURAL TWO-SPEAKER SITUATION REPRESENTED BY THE BINAURAL TWO-SPEAKER SITUATION - MARKLE AND ABER (Based on Data from Markle and Aber, "A Clinical Evaluation of Monaural and Binaural Hearing Aids".)

The experimental procedure reported in these pages has shown itself to be an effective measurement of binaural hearing when dealing with average results. A basic objective in conducting the experiments was to study the possibilities of using the procedure as a hearing aid evaluation technique. The questions which now arise are these: what are the possibilities of using the procedure in individual cases? Will it give an accurate measure? What percentage of change in the number of errors may be regarded as chance variation? What percentage of change in the number of errors may be considered to be the result of binaural effect?

In order to determine the answers to these questions, an analysis of the differences in errors within the monaural and binaural situations was made. Because it had been established that both monaural situations as well as the one-speaker binaural situation were essentially the same situation, determination of the chance variation of errors to be expected could be accomplished by comparison of any two of the three situations. Comparison of the two one-speaker situations (M1-B1) was made. The greatest difference in percentage among the thirty-two subjects at each of the three signal-noise ratios at +5 it was 20 per cent, at a signal-noise ratio of 0 it was 32 per cent, and at a signal-noise ratio of -5 it was 32 per cent.

In determining the reduction of percentage of error in the binaural two-speaker situation as compared with the monaural two-speaker situation, a similar procedure was followed. Inasmuch as they would be the two situations involved in evaluating binaural as opposed to monaural aids, a comparison was made between the two two-speaker situations. Among the thirty-two subjects, the smallest reduction in percentage of error due to binaural effect at the three signal-noise ratios at a signal-noise ratio of +5 it was 4 per cent, at a signal-noise ratio of 0 it was 4 per cent and at a signal-noise ratio of -5 it was 8 per cent.

Having made these observations, it is now necessary to determine the actual reliability of the testing procedure as a hearing aid evaluation technique. This was done by discovering how many of the scores of thirty-two experimental subjects fell between the maximum chance score and the minimum binaural effect score. In other words, it was necessary to determine how many of the thirty-two subjects had scores which would make difficult the decision as to whether the error reduction between the monaural and binaural situations was due to chance or to actual binaural effect. The results of this tabulation at each of the three signal-noise ratios were at +5, 64 per cent; at 0, 56 per cent; and at -5, 48 per cent. A representation of the preceding data in table form may be seen in Table IV.

TABLE IV

SUMMARY OF DATA TO DETERMINE USAGE OF PROCEDURE FOR HEARING AID EVALUATION

S/NR	Maximum Difference of chance error in M1-B1		Minimum Difference caused by binaural effect in M2-B2		Number of "uncertain" cases	
	No.	Per cent	No.	Per cent	No.	Per cent
+5	5	20	1	4	16	64
0	8	32	1	4	14	56
-5	8	32	2	8	12	48

Since the percentage of subjects falling into the area of uncertainty appears to have diminished as the situation became more difficult, perhaps the most difficult listening situation (-5 signal-noise ratio level) would provide finer distinctions. Use of this situation might thereby allow for more reliable evaluation of binaural aid efficiency for the individual user. It now remained to find that percentage level of errors at which the fewest number of patients would fall into one of two categories. Through chance variation it might be possible for some patients to (1) indicate that they would profit from binaural aids when in reality they did not, or (2) indicate that they would not profit from use of a binaural aid when in reality they would.

Since the test at -5 signal-noise ratio appears to have been the most discriminating, evaluation of shift in errors was made at that level. The percentage level judged to be the most efficient was 20 per cent. This level was believed to be that percentage of errors at which the number of subjects would be minimal in determining (1) the maximum percentage level at which differences in monaural errors M1-B1 may be regarded as the result of chance variation, and (2) the minimum percentage level at which differences in binaural errors (M2-B2) could be regarded as the direct result of binaural effect. At this level it was found that ten subjects (31 per cent) of the subjects fell into the "doubtful" category. Of the ten, four were above the percentage mark within the two monaural one-speaker situations. The remaining six were within the monaural to binaural shift, and well below the percentage level. In view of the high percentage of subjects which fall into the "doubtful" category, the conclusion which seems apparent is that the reliability of the procedure reported in this thesis is, at best, only fair with regard to its use as a technique for hearing aid evaluation. Unfortunately, the margin of error involved is too great in making decisions for patients for or against the use of a binaural aid.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A test of binaural hearing was devised and tried experimentally in the hope that the proposed procedure may provide a more sensitive measure of binaural hearing efficiency than the methods now in use.

A group of six readers, each reading a different selection, was recorded while reading simultaneously. The intensity level of the "babble" speech was monitored for consistency.

Thirty-two normal hearing subjects were tested under normal conditions. Using the masking noise and earphone of a Maico D-9 audiometer at its highest level of intensity, the subjects were also tested with an induced monaural hearing loss.

Experiments were conducted in an acoustically treated room using two speakers. The apparatus was arranged so that the output of the speakers was channeled in one of two ways: (1) disk recorded test speech in one speaker and tape recorded masking speech in the other; or (2) both test speech and masking speech in one loudspeaker. (An Allison Laboratories speech audiometer was used to perform these functions.)

Each subject was tested for speech discrimination under both situations described above, monaurally and binaurally, for a total of four testing situations. The differences in numbers of errors were then measured between the two-speaker and one-speaker situations for both the "monaural" and "binaural" listeners. A statistical analysis of the data was also made.

At the outset it was hoped that the results of the test would show that differences between the two-speaker and one-speaker systems heard binaurally would not be present when heard monaurally. This would permit measurement of the superiority of binaural listening over monaural listening with the proposed procedure. Carried over to the field of hearing aid evaluation, it would indicate the possible superiority of a binaural aid over a monaural aid for the individual user. Here again it was hoped that the test would provide more sensitive measurement of the instruments.

Results of the experiment clearly indicate the superiority of binaural hearing, and most especially in extremely difficult situations (where speech is masked considerably by noise) as witnessed by the sharp reduction of errors in the two-speaker binaural situation over the other three situations. Because of the insignificant differences recorded among the two monaural situations and the one-speaker binaural situation, it may be concluded that these three situations are essentially the same.

Because the percentage of errors in the monaural two-speaker situation eliminated by binaural listening was greater in this experiment than in that reported by Markle and Aber, it appears that the use of "babble" speech to mask speech provides a more difficult test of binaural hearing and a finer measure of the efficiency of binaural hearing than "noise" masking. It more obviously demonstrates the improvement shown by the binaural effect.

A final comment which may be made is that although the experimental procedure discussed provides sensitive measurement of binaural hearing as opposed to monaural hearing, the reliability of the procedure for the individual subject is only fair. As an evaluation technique for binaural hearing aids, in its present form the procedure cannot be considered an accurate predictor of success with these aids. It is suggested that the possibility is strong that if signal-noise ratios were set at more difficult levels than those used in the experiment (+5, 0, -5), it might reduce the number of subjects for whom prediction of aid success is now difficult.

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APPENDICES

APPENDIX A

READING MATERIAL

The following material in this appendix was read by the readers in producing the "babble" speech (see page 14 of this thesis). The selections were chosen at random from the text and given at random to the readers. It is believed that any similar material would be suitable for the purpose.

> The aspects of the stuttering youngster's problem that are of chief interest to the classroom teacher are those having to do with his adjustment to school, first of all, and his adjustment to others. She will be concerned so far as she can be with his adjustment to home and family. There is much that is fundamental that she can do also about the speech aspects of his problem aside from his stuttering, although she can be most effective along this line if she coordinates what she does with what is being done by the speech correctionist. If there is no speech correctionist, the classroom teacher should work on the child's speech, to the extent that she does, with due appreciation of the influence that his stuttering has on the other aspects of his speech behavior. She can do her best to see to it that he receives any medical attention that he may require for whatever reason, and that he not be encouraged to worry about his health needlessly. If there is a speech correctionist in the school, the classroom teacher can do much to contribute to the stutterer's adjustment to the remedial program which the speech correctionist is attempting to carry forward with him. What she can do so far as the stuttering aspect of the total problem is concerned, she can best accomplish for the most part through the good effects of her efforts along these other dimensions of improvement, although she can do some things directly.
>
> Encourage the child to talk more. In a very basic sense this is the single most important type of improvement for a stutterer to achieve, because his speaking

time is his working time. Practically any speech improvement of whatever sort that he is going to accomplish he will have to achieve while speaking and through the act of speaking.[1]

The same result may be attained through various exercises of articulation. Although the value of various tongue, lip, and jaw exercises has been questioned and denied by many workers in the field of speech correction, they can be said to be useful in teaching the student to manipulate his articulatory apparatus in many new and unaccustomed ways. Too many articulation cases have only one or two stereotyped tongue movements in their speech repertoire, although they may have many more in their functions of swallowing, laughing, chewing, or sneezing. They need to learn how adaptable the tongue really is. Whenever possible, the articulatory exercises given should proceed out of the movements used in the biological functions or in babbling. The old, formal tongue exercises are of much less value.

When the correct sound has been produced [and frequently a lot of trial and error must be resorted to before it appears], the speech defective should hold it, increasing its intensity, repeating it, whispering it, exaggerating it, and varying it in as many ways as possible without losing its identity. He should focus his attention on the "feel" of its position in terms of tongue, palate, lips, jaws, and throat. He should listen to the sound produced. Then he should be asked to leave the position intact but to cease speech attempt, resuming it after a long interval. Finally he should let the tongue assume a neutral position on the floor of the mouth and then attempt to regain the desired position. Sounds produced by phonetic placement are very unstable and must be treated very carefully or they will be lost. Strengthen them as soon as possible and keep out distractions. After a successful attempt, one should insist

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[1]Wendell Johnson, Spencer F. Brown, James F. Curtis, Clarence Edney, Jacqueline Reaster, Speech Handicapped School Children. (New York: Harper and Brothers, 1956), pp. 271-72.

that a student remain for a time before taking part in conversation. This will permit maturation to become effective.[2]

Aptitude for learning must be distinguished from achievement, or the actual learning accomplished. However, in order to measure aptitude for learning, which is commonly identified with intelligence, the designer of intelligence tests must use the indirect approach which involves learning or achievement. Intelligence cannot be measured directly but must be inferred from its products or its application to various types of materials. Hence, in order to accomplish his purpose, the maker of intelligence tests attempts to discover what the individual has learned in situations experienced by a vast majority of persons. Thus he presumes that all persons have had opportunities to learn in these areas and that, in the majority of instances, differences in test scores reflect differences in aptitude rather than in opportunity for learning. Another possibility open to the test-maker is to develop situations that are so completely novel that very few persons are likely to have prior experiences in the area being tested. Hence, mental tests assess the individual's capacity or aptitude only by inference from his achievements with respect to very commonplace or very novel materials and situations. In other words, the mental test is ordinarily a measure of a very general type of achievement.

Customarily, the scholastic-achievement test differs from the general-aptitude test in that results of scholastic tests are considered to be dependent upon the acquisition of specialized skills and knowledges, usually as a result of special training. For example, the individual is provided with opportunities to learn in such fields as reading, writing, spelling, music, and arithmetic, and his achievement-test results reflect his attainment in these areas. Basic to the consideration of

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[2]Charles Van Riper, Speech Correction Principles and Methods (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1954), pp. 238-39.

achievement are the ideas of opportunity to learn and attainment of skill or knowledge as a result of learning.[3]

Before the days of electronic audiometers, the problem of testing hearing was relatively simple. The otologist used a tuning fork, watch tick or his whispered voice as the reference standard. What he could hear, he believed his patient should hear. However, physicians were no more immune to hearing loss than their patients, the intensity of sound emanating from the tuning fork or watch tick varied greatly, and environmental sounds were not taken into account, so that altogether these early measures of sound were highly inaccurate.

The pure-tone audiometer, an electron instrument for measuring the acuity and range of hearing, provided a major part of the solution to the problem of identifying children with hearing loss. The results of audiometric tests also gave a valid basis for referring children with loss for medical evaluation and possible educational care. The pure-tone audiometer is a vacuum-tube audio-oscillator equipped to produce tone of fixed frequencies at measurable intensity levels. The frequencies range from approximately 100 cycles per second to 12,000 cycles per second at octave or half octave intervals. The tones generated by the audiometer and delivered to the listener by a receiver are of calibrated intensity and measured in decibels, the decibel being defined as the minimum change in intensity which the normal ear can detect in either increasing or decreasing loudness.

The audiometer has two principal controls, the hearing loss dial and the frequency control. The hearing loss dial regulates the intensity of each test tone in a range of decibel reference levels from normal hearing to maximum loudness. Readings from this dial are in five decibel steps. In addition to these two controls, the off-on switch, the earphone switch, tone interrupter and air-conduction-bone conduction switch are also found on the panel.[4]

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[3]Denis Baron and Harold W. Bennhard, Evaluation Techniques for Classroom Teachers (New York: McGraw-Hill Book Company, Inc., 1958), pp. 87-88.

[4]Alice Strong, Waring J. Fitch, LeRoy D. Hedgecock, James W. Phillips, James A. Cannell, Hearing Therapy for Children (New York: Grune and Stratton, 1958), pp. 56-57.

In this discussion of the value of the pure-tone audiogram in determining rehabilitative needs so far we have considered the extent of loss only. As was mentioned previously, the shape of the audiogram curve is also important. The shape of the curve determines to a considerable extent the ability of the patient to benefit from the amplification that an individual, wearable hearing aid would provide. The ideal patient, from a rehabilitation standpoint, would have a "flat" loss, that is, a loss which would be approximately equal at all frequencies. We are speaking now only of the air-conduction curve; the shape of the bone conduction curve alone is of little importance. The patient who would present the most difficult problems in rehabilitation would have a loss characterized by a steeply sloping audiogram curve, with better hearing in the low frequencies. The flatness or slope of the curve is important primarily in the area of the speech frequencies.

Speech discrimination ability, that is, the ability to understand what one hears, is related directly to the shape of the air-conduction curve in the area of the speech frequencies. If the losses at 1,000 and 2,000 cps are markedly greater than at 500 cps, the patient may confuse many consonants whose distinguishing characteristics are primarily in the higher frequencies. These consonants are generally the voiceless ones.

The patient who has a flat loss throughout the speech frequencies can usually make good use of amplification, because all speech sounds will be amplified equally. His handicap lies only in his inability to hear speech well. As speech is made louder through amplification, his handicap is diminished for he can understand well what he hears.[5]

There are two major ways in which psychological tests may be properly described as objective. The determination of the difficulty level of an item or of a whole test, and the measurement of test reliability and validity, are based upon objective, empirical procedures.

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[5]Hayes A. Newby, Audiology Principles and Practice (New York: Appleton-Century-Crofts, Inc., 1958), p. 104.

The concepts of reliability and validity will be discussed in subsequent chapters. We shall turn our attention first to the concept of difficulty.

When Binet and Simon prepared their original 1905 Scale for the measurement of intelligence, they arranged the thirty items of the scale in increasing order of difficulty. Such difficulty, it will be recalled, was determined by trying out the items on 50 normal and a few retarded and feebleminded children. The items correctly solved by the largest portion of subject were, ipso facto, taken to be the easiest; those passed by relatively few subject were regarded as more difficult items. By such a procedure an empirical order of difficulty was established. The early example typifies the object measurement of difficulty level, which is now commonplace practice in psychological test construction.

Not only the arrangement but also the selection of items for inclusion in a test can be determined by the proportion of subjects in the trial samples who pass each item. Thus, if there is a bunching of items at the easy or difficult end of the scale, some items can be discarded. Similarly if some items are sparse in certain portions of the difficulty range, new items can be added to fill in the gaps.

Frequency of correct response is also employed in constructing age scales, such as the later revisions of the Binet scales. In such a case, the proportion of children at each age level who pass each item is determined. The item is then assigned to that age level at which a certain proportion passed it.[6]

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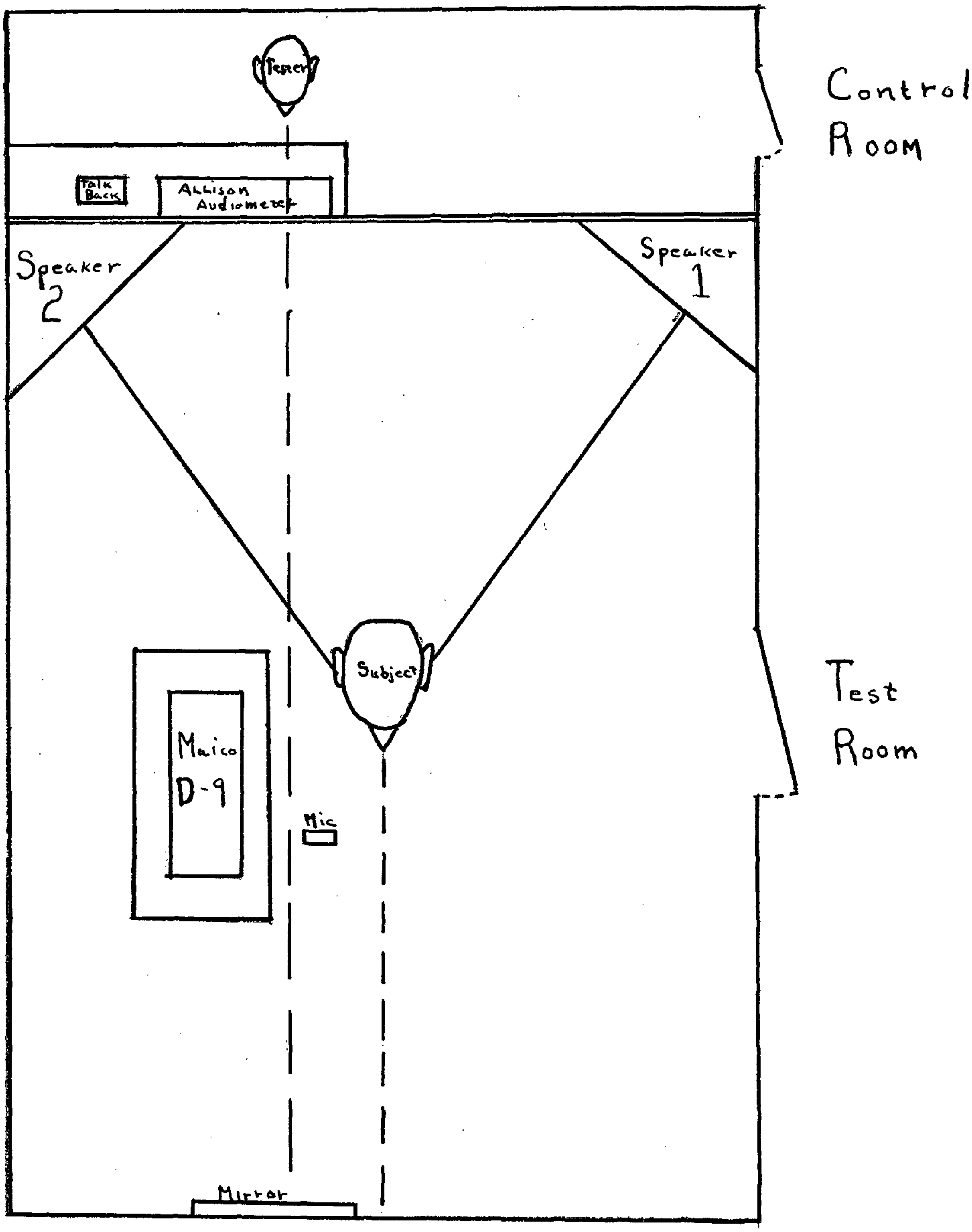
[6]Anne Anastasi, Psychological Testing (New York: The Macmillan Company, 1954), p. 167.

APPENDIX B

ROOM ARRANGEMENT



APPENDIX C

TABLE V

SCHEDULE OF ROTATION OF SITUATIONS

Word List	1A,1B	2A,2B	3A,3B	4A,4B
Order of Situations				
1	M1	M2	B1	B2
2	M2	M1	B2	B1
3	B1	B2	M1	M2
4	B2	B1	M2	M1

Key

M1 - Monaural one-speaker

M2 - Monaural two-speaker

B1 - Binaural one-speaker

B2 - Binaural two-speaker

The presentational order of the four situations was restricted to the four orders in the table above. Each time one of the orders was used, a notation was made and a record kept of the number of times each order was used until each presentational order was used eight times.

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An Abstract of

A TEST OF BINAURAL HEARING

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DE FRANCIS, PATRICIA, M.S. in Ed., August, 1960. Speech and Hearing Therapy.

A Test of Binaural Hearing. (47 pp.) No.

Faculty Adviser: George Herman

This experiment attempted to develop a more sensitive method than currently used to evaluate the efficiency of binaural hearing.

"Babble-type" speech masking was prepared by recording the simultaneous reading of six different talkers.

Thirty-two normal hearing persons listened first binaurally and then with monaural hearing loss simulated by masking with a complex tone.

Two situations were employed: (1) Disk recorded PB words (C.I.D. Test W-22) channeled through one loudspeaker and tape recorded "babble" masking through a second; and (2) both test speech and "babble" masking from a single loudspeaker.

Each subject was tested for speech discrimination, monaurally and binaurally, under the two test situations.

Results clearly indicated the superiority of binaural hearing in situations where speech is masked by noise. It appears that "babble" speech masking provides a more discriminating test of binaural hearing efficiency than "noise" masking, as judged by comparison of the results of this study with previously published reports.

Although the procedure discussed does reveal the superiority of binaural hearing, its application to individual subjects as a clinical test is only fair. Several subjects failed to show marked gains in discrimination when using both ears, so that the test has not been shown an accurate predictor of success in the use of binaural hearing aids.