8-1971

Adaptation to the Functional Loss of Pinnae in Sound Localization Ability

Marvin Richard Navarro
Western Michigan University

ADAPTATION TO THE FUNCTIONAL LOSS OF PINNAE IN SOUND LOCALIZATION ABILITY

by

Marvin R. Navarro

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment
of the
Degree of Master of Arts

Western Michigan University
Kalamazoo, Michigan
August, 1971

ACKNOWLEDGMENTS

Rarely is one able to successfully complete a task such as this entirely on his own. Since I am not an exception to this maxim, I would like to take this opportunity to thank everyone who in some way facilitated the completion of this work. My sincere thanks go to Dr. Robert Erickson, Dr. Courtney Stromsta, Mr. William Dawson, and Dr. Harold Bate for their encouragement and technical assistance.

Special acknowledgment must go to Dr. Harold Bate whose patience, prodding, and critical consideration of all aspects of this project guided me to its completion.

Acknowledgment must be paid to Western Michigan University for its financial assistance, both at the graduate and undergraduate levels.

Acknowledgment must also be extended to my wife, Diane, for her patience during the most crucial periods of this endeavor.

Marvin R. Navarro

MASTERS THESIS M-3011

NAVARRO, Marvin Richard
ADAPTATION TO THE FUNCTIONAL LOSS OF PINNAE IN SOUND LOCALIZATION ABILITY.

Western Michigan University, M.A., 1971
Speech Pathology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

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CHAPTER I

INTRODUCTION

Purpose of the Study

The phenomenon known as sound localization has been researched extensively for many years. Rosenweig (1961) describes Venturi's research dating back to the early nineteenth century. Such noted scholars as the German physiologist Ernst Weber and the English physicist John Strutt (Baron Rayleigh) have studied sound localization (Stevens and Warshofsky, 1970). Most of the research has tended to explain localization on the basis of these theories: intensity, phase, or time. Stevens and Davis (1938) attempted to evaluate the various cues provided by various frequencies and to tie together the three main theories of sound localization. They stated that

> when both low and high frequencies are present as components in a sound, the low frequencies provide cues in the form of phase differences and the high frequencies provide cues in the form of intensitive (sic) differences, and the two types of cues render each other mutual support (p. 179).

They also note that when sounds come from behind the listener there is a change in the quality and loudness of the sounds due to attenuation of the high frequencies.

Many researchers have tended to overlook or negate the role of the pinnae (also referred to as auricle or external ear) in sound localization ability. This is so in spite of the fact that Bekesy and Rosenblith (1951) have described research dating back to the second half of the nineteenth century in which it was found that "localization suffers when the shape of the external ear is altered. In particular, it becomes less easy to distinguish noises originating in front from those in back of the head" (p. 1079). Yet, in spite of over one hundred years of research, controversy still clouds a precise explanation of the role of the outer ear in localization. As recently as 1966 O'Neill and Oyer stated that "the auricle appears to serve no function for man, except as an ornamentation" (p. 22). Contrary to this undocumented statement, there is an increasing amount of research indicating that the pinnae play a definite role in sound localization. The most noted work in this area is that done by Batteau (1967). He has utilized the principles of information theory and communication theory to construct an electronic working model to explore the role of the pinnae in localization ability. One must bear in mind, though, that what is demonstrated in a laboratory under ideal conditions is not always true outside the laboratory. Yet, in reviewing the literature, one is hard pressed to find much behavioral research that considers the role of the pinnae. Fisher and Freedman (1968), in a series of behavioral studies, have begun to explore the role of the pinnae in sound localization ability in a sound field. The present study was quite similar to Fisher and Freedman's (1968) initial experiment on the role of the pinnae in auditory localization. Fisher and Freedman concluded that in the absence of head movement, the pinnae are crucial to auditory localization. This study sought to verify their findings and to investigate the ability of the human organism to adapt to the handicap of an absent or deformed pinna.

Review of the Literature

The earliest recorded research considering sound localization was evidently done by the Italian physicist Giovanni Battista Venturi sometime during the late eighteenth and nineteenth centuries. In a relatively simple experiment, Venturi positioned a blindfolded subject in the middle of an unobstructed meadow and circled around him.

> Periodically Venturi sounded a note on a flute or rang a bell. When the sound came from a direction at right angles to 'straight ahead', the listener could easily identify the direction. If he kept his head still, he often confused sounds coming from directly in front of him with sounds coming from behind him. When the source was diagonally in back of him on the same side, the subject frequently was unable to distinguish front from back, but he never had any trouble with right or left. If the test sound was sustained for a few seconds and the listener was allowed to turn his head, he did not make these mistakes....Venturi concluded that a listener uses the relative intensities of the stimuli arriving at his ears to localize sounds (Rosenweig, 1961, p. 132).

In 1846 Weber demonstrated that a listener could localize one of two watches, each with a characteristic tick, using binaural hearing. By placing one watch at the listener's right ear and the other watch at the listener's left ear, the listener was able to tell which watch was at which ear. From this information, Weber decided that the listener was indeed locating sound to the left or right by the use of his ears alone.

English physicist John Strutt (Baron Rayleigh) also explored auditory localization by merely closing his eyes while his assistants circled around him activating tuning forks or speaking. Lord Rayleigh found that he could not identify a sound directly in front of him from one directly in back. He also found it more difficult to locate a low pitched tuning fork than a spoken word or a high pitched tuning fork. On the basis of his findings Lord Rayleigh postulated that a sound coming from one side of the head reaches the nearer ear first; therefore, the sound in that ear is more intense than in the other ear because of the shadow effect produced by the head. Low frequencies provide less shadow because their wavelengths are long enough to wrap around the head thereby eliminating the shadow. High frequencies, having very short wavelengths, are not able to overcome the head shadow but provide intensity differences for clues to binaural localization. Rayleigh called this difference in intensities the "binaural ratio." But Rayleigh wondered why the low frequencies could be localized when he felt that binaural ratios did not exist at low frequencies. In 1907 he "suggested that phase differences as well as intensity, might provide clues for binaural location" (Stevens and Warshofsky, 1970, p. 103). Rayleigh demonstrated this phenomenon using the principle of interference beats. By striking two tuning forks of slightly different frequencies and bringing each to a separate ear of a listener

> the sounds of the beats seemed to pass from left to right and back again. In reality, of course, the sound sources had not moved--but Rayleigh had produced an illusion of movement by phase differences alone (Stevens and Warshofsky, 1970, p. 103).

By the beginning of the twentieth century, then, several theories of localization were beginning to emerge--the intensity theory, the phase theory, and the time theory. In 1938 Stevens and Davis attempted to evaluate the main theories of that day that had been postulated to explain auditory localization. They felt that each of the factors--intensity, phase and time, played a role in localization. They explained the intensity theory in this way, "when two tones differing only in intensity, are led separately to each ear, the listener tends to image the source as located toward the side of greater intensity" (Stevens and Davis, 1938, p. 168). However, this theory in itself cannot explain localization because an actual source of sound would produce differences of phase as well as intensity. Stevens and Davis (1938) also said that:

> When an actual source of sound is situated at the side of an observer, a difference of intensity occurs at the two ears, for one ear finds itself located in the shadow of the head. In a tone the sharpness of this shadow is a function of frequency. Very low tones produce practically no shadows, but when the frequency is greater than 5000 cycles, the difference in loudness-level at the two ears may be as great as 30 dB (p. 169).

A complex sound, such as speech or music, then provides a difference of intensity and a difference of composition between ears as the high frequencies are lost to the ear on the far side of the head.

Stevens and Davis (1938) explained the phase theory by stating that "when two tones, differing only in phase, are led one to each ear, the listener tends to image the source as located toward the side of the leading phase" (p. 171). This is to say that if the crest on one sound wave arrives at the one ear before the crest of the second sound wave arrives at the other ear the sound will appear to be on the side that was stimulated first. However, phase alone can be a very ambiguous and misleading clue. A continuous tone consisting of successive waves may lead the phase of the sound of the other ear by 180° or more. If this is the case, then the first sound can no longer be said to lead the second sound but to lag. They explain that this situation may occur whenever the difference in the length of the path to the two ears is greater than half of the wave-length of the sound. When this occurs, there is a position of the source on both sides of the head which will give the same phase difference at the two ears. With the short wave-length of high frequencies, localization relying on phase differences as a primary clue will break down. The critical frequency above which this break down should occur is that frequency whose wave-length is just twice the distance between the ears. Since the ears are about 21 cm apart, the critical frequency appears to be 800 hertz (Hz). With higher frequencies, there are key positions on either side of the head at which the sound source could produce identical phase differences.

Phase differences may provide clues for continuous or relatively long sounds but, as it was pointed out, these differences are probably nonexistent above 800 Hz. These differences will also not exist with an impulsive stimulus such as a sharp click. In such a case, time of arrival takes precedence. "When two sound impulses differ in time at the two ears by the proper amount, the apparent source tends to shift to the side of the first arrival" (Stevens and Davis, 1938, p. 173). A key phrase in this explanation is "by the proper amount." Stevens and Davis (1938) feel that there is a minimum value below which no lateral displacement occurs. They place this value at .1 msec. An upper value of 2 msec causes the sound to be perceived as two separate stimuli--one at each ear. Evidently in the absence of other cues, time of arrival may be of primary importance in the location of impulsive stimuli.

Stevens and Davis (1938) report Trimble's work in making the following assertion:

> Under the proper conditions, when a difference of intensity is opposed with a temporal difference in the two ears, the two tendencies to lateral localization may cancel one another and leave the apparent source of sound in the median plane (p. 173).

Until recently these theories--either separately or together--have been accepted as the explanation of auditory localization. In the early 1960's, another theory of localization materialized. This is the "pinnae theory." The most noted researcher on this theory is Batteau (1967). He defines the role of the pinnae in localization as a means of introducing,

> ...by means of delay paths, a transformation of the incoming signal which is mentally inverted to provide attention, and that the inverse transform required defines the location of the sound source. It may be further shown that relatively simple systems of delays, attenuations, and signed additions may be used to construct the inverse transformations, and that these could easily be realized in the nervous system. It may further be theorized that the same method of constructing inverse transformations can apply to monaural and binaural localization, sound recognition, and the utilization of reverberation (p. 174).

Since a transformation of the incoming sound front is necessary to localization, Batteau felt it reasonable to assume that the external ear served as the acoustical device to perform the requisite transformation. To test this theory, Batteau has devised an electronic working model of the pinnae. This model consisted of a high fidelity electronic system in which microphones were inserted in casts of human pinnae. Experimentation with this model demonstrated that perception of all locales of a sound position (front, back, up, down, left, right, distance) could be accurately made. Batteau (1967) lists the following as taking part in sound localization:

1) The incoming sound is characteristic of its source, transformed by the environment.

2) The incoming sound is transformed by the pinna and each direction of arrival has a characteristic.

3) The transformations pertinent to the source to which attention is to be paid are inverted for all directions of arrival, giving a set of environmental transformations.

4) Each environmental transformation for the sound to which attention is paid is inverted and the resultant set of elements combined.

5) The same process is accomplished for each channel and the results combined.

6) The resultant signal is inverted to the most acute stimulus and interpreted or recognized by the requisite transformation used to accomplish the inverse (p. 168).

It is evident that Batteau has spent a considerable amount of time investigating the role of the pinnae in auditory localization. A review of the literature, however, makes another point evident. Few researchers have conducted behavioral studies of this promising theory. Fisher and Freedman (1968) in a series of behavioral experiments have begun to investigate the pinnae's role in localization. In their study a blindfolded subject sat in an adjustable chair located in an acoustically treated room. A speaker was suspended on a motorized boom which was rotated to allow localization judgments from one of eight selected positions 45° apart. Using a train of three pulses of white noise as stimuli, they asked subjects to locate the position of the sound source under three conditions allowing free head movement and three conditions with restricted head position.

The three conditions were:

1) own pinnae.

2) no pinnae--sound attenuating earmuffs provided a functional loss of the pinnae. Stimuli were routed to the ear canal through a metal tube.

3) artificial pinnae--casts of human pinnae were mounted on tubes.

From their results, two findings are striking:

1) Free head movement appears to "wash out" differences among the three pinnae conditions. 2) When head movement is restricted, auditory localization is better with pinnae, even when these pinnae are artificial.

They concluded from their findings that "the crucial factor in auditory localization in the absence of head movement is the presence of pinnae, even someone else's pinnae" (p. 25). The authors attempted to correlate their results with Batteau's theory of localization. In this regard the authors state "It would appear that the pinna provides a transformation of acoustic stimulation which is adequate for a first approximation of locale at least if the stimulus is a complex sound" (p. 25).

Since the pinnae theory is relatively new, the present study was an attempt to verify the findings of Fisher and Freedman and Batteau and to go beyond their experiments in an attempt to investigate the ability to adapt to the functional loss of pinnae.

Statement of the Problem

The overwhelming amount of literature that has dealt with the phenomenon of localization has tended to concentrate on interaural phase, time, and intensity cues. These theories, however, cannot explain 1) accurate monaural localization as described by Angell and Fite (1901), and Bauer, et al. (1966), or 2) successful localization of elevated sources (Batteau, 1967; Bauer and Blockmer, 1965). Only more recently has anyone seriously considered the role of the pinnae in sound localization. Batteau's model of the pinnae (1967) and the behavioral studies by Fisher and Freedman (1968) are the primary expositors of the "pinnae theory" of sound localization. It is only reasonable to assume that in the light of this research, coupled with the subjective reports described by Bekesy and Rosenblith (1951) and others, that the pinnae serve a more useful function than popularly believed. The present experiment was devised to study this assumption. Its primary purpose was to further assess the role of the pinnae in the phenomenon of sound localization. In essence this study sought to verify the findings of Fisher and Freedman (1968), and Batteau (1967) and to further investigate the question: Can one adapt to the functional loss of pinnae and regain accurate localization ability? To accomplish this task, each subject was asked to localize a series of pulses of white noise presented under two conditions. One condition tested localization with pinnae uncovered and served as the control condition (CC). The second condition tested localization with the pinnae covered by a specially designed earpiece. This condition served as the experimental condition (EC). Subjects were tested at the beginning of an hour (CC_A and EC_A, respectively) and at the end of an hour (CC_B and EC_B, respectively) for a period of five days for each condition. The pertinent questions were stated in the form of the following null hypotheses:

1) There is no significant difference between scores obtained on a discrete localization task under conditions of CC_A and CC_B.

2) There is no significant difference between scores obtained on a discrete localization task under conditions of CC_{A+B} and $EC_{A'+B'}$.

3) There is no significant difference between scores obtained on a discrete localization task under conditions of $EC_{A'}$ and $EC_{B'}$.

CHAPTER II

EXPERIMENTAL DESIGN

Description of Subjects

One male and six female college students majoring in Speech Pathology and Audiology volunteered to serve as subjects. Subjects ranged in age from 21 years to 26 years with a mean age of 22.7 years. All subjects were screened by pure tone audiometry. The hearing for both ears had to be within normal limits (15 dB or better re: ISO 1964) for octave frequencies from 125 hertz (Hz) to 8000 Hz. All subjects were examined to insure that no pinna or meatus was grossly deformed. The subjects had no prior knowledge of the details of the experiment.

Stimuli and Equipment

Stimuli consisted of tape recorded trains of three consecutive pulses of white noise at the rate of one pulse per second. The duration of each pulse was 40 msec with a 5 msec rise/fall time. After each train of three pulses, there was a five sec interval during which no pulses occurred.

The stimuli were presented to the subjects by playing the tape on a tape recorder (Sony, Model TC 5600) which was connected to a speech audiometer (Grason-Stadler, Model 162). The input of the six position switch was plugged into the speech audiometer. Each of the six output leads of the switch led to one of six identical speakers located in a sound treated room (Industrial Acoustics Company, Model No. 1203A). The six identical 5" X 4" speakers were housed separately in 2" X 6" X 10" plastic boxes lined with foam rubber. Each speaker was 40 inches from the midpoint of the subject's head and 45 inches from the floor of the test booth. This height level corresponded to ear level for most subjects. The speakers on each side formed two separate arcs of approximately 100 degrees each. Each speaker on a given side was approximately 50 degrees from the adjacent speaker on that side. No speakers were placed in zero azimuth as several researchers have shown a high percentage of front/back reversals

(Rosenweig, 1961; Hochberg, 1966) which would only confound the present problem. The block diagram in Figure 1 illustrates this equipment.

The stimulus was prerecorded to allow better control of the stimulus during the actual experiment. Recording the stimulus permitted monitoring of the tape prior to the actual test and facilitated the maintenance of a relatively unvarying stimulus. During a given test session, the tape recorder remained on so that the noise pulses were not subjected to unusual distortion due to the slowing or speeding up of the tape reel. The stimulus was recorded on magnetic tape (Scotch, Type 202), at a constant speed of 7 1/2 inches per second. Figure 2 is a block diagram showing the equipment and how it was used to record the stimuli. The sine random generator (Bruel and Kjaer, Type 1024), used to generate the white noise, was coupled to an electronic switch (Grason-Stadler, Model 829E). The output of the electronic switch was fed to the line input of a tape recorder/reproducer (Sony, Model TC 650). Two pulse generators (Tektronix, Type 161), two

Figure 1.

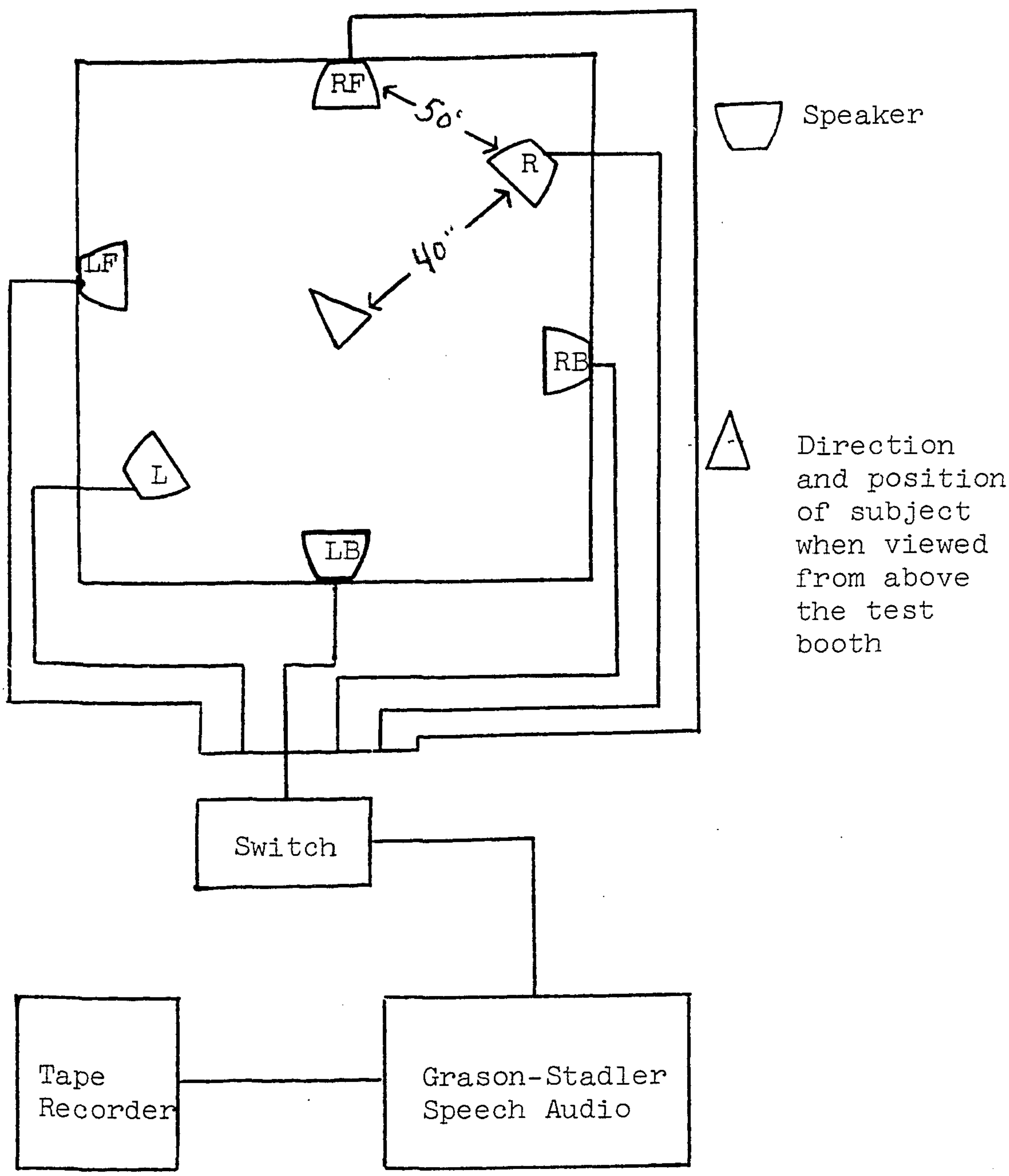
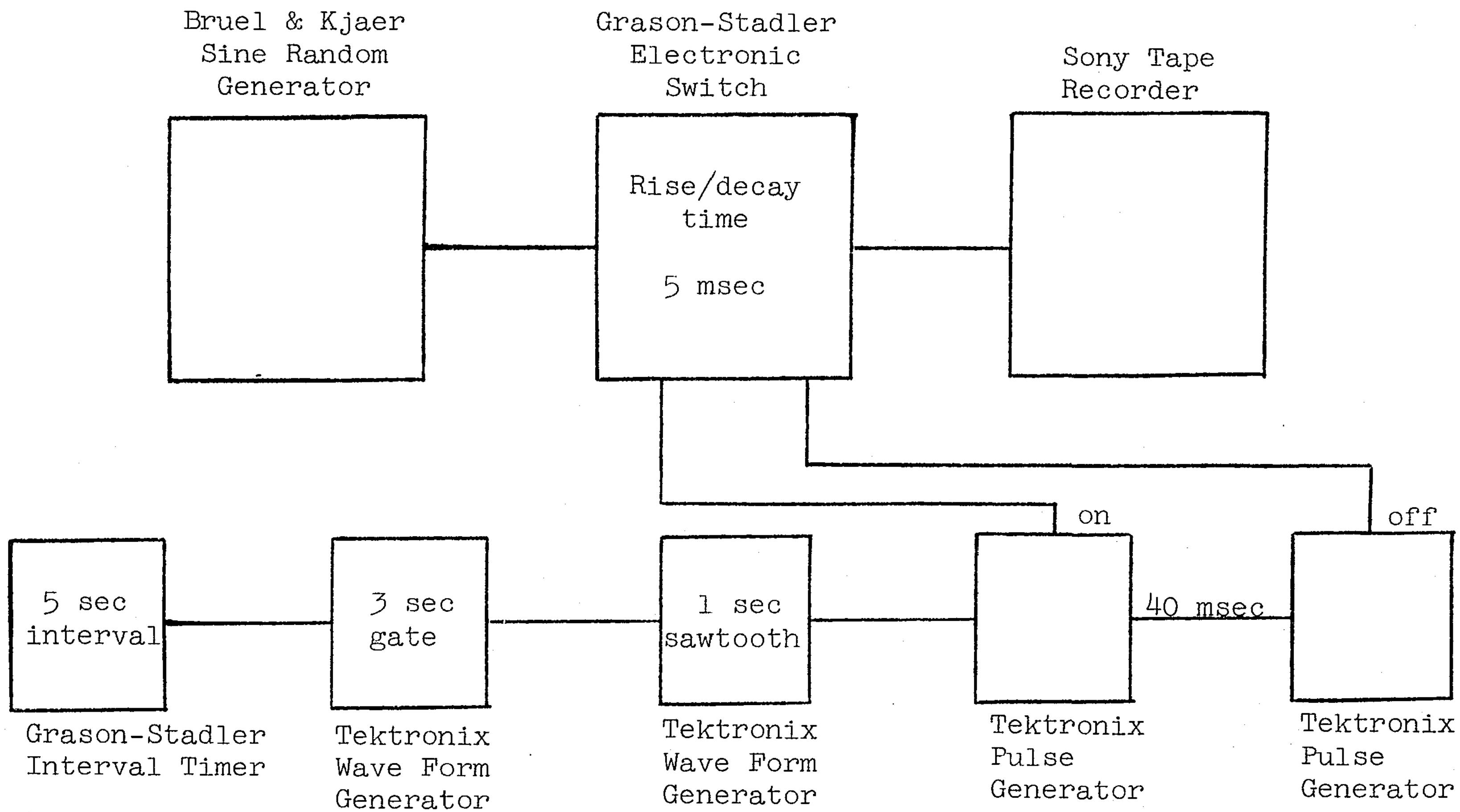


Illustration of equipment used to present stimuli

Figure 2.



Block Diagram of Instrumentation
For Recording Stimuli

wave form generators (Tektronix, Type 162), and an interval timer (Grason-Stadler, Model 471-1), were used to control the switching sequence of the electronic switch. The interval timer initiated the sequence by emitting a pulse every eight sec. This pulse was fed to one of the wave form generators that immediately started a 2 1/2 sec gate pulse that fed the gate input of the second wave form generator. This 2 1/2 sec gate caused the second wave form generator to emit the 3 sec sawtooth wave forms that determined the rate at which the on/off pulses were presented. Both pulse generators were controlled by the sawtooth output of the second wave form generator and were set to have a 40 msec difference. One pulse generator was connected to the on terminal of the electronic switch and the other pulse generator was connected to the off terminal. The rise/fall time control, located on the electronic switch, was set for 5 msec and thus eliminated the click transients normally associated with copied switching.

The noise pulses were too short in duration to allow accurate intensity measurements with the equipment used; consequently, a 1000 Hz tone of 60 sec duration was recorded on the beginning of the stimulus tape. For each test session, this tone was calibrated so that it registered at zero Vu on the Vu meter of the speech audiometer. This calibration criterion was maintained throughout the study. The calibration tone was presented at an intensity of 60.3 dB sound pressure level (re: 0.0002 dyne/cm^2) as measured on the linear scale of a sound level meter (Bruel and Kjaer, Cartridge Type 4132). During calibration measurements, the sound level meter was positioned where the subject's head would normally be during the actual test.

For the experimental condition, the subjects wore one of four pairs of specially constructed headsets. These headsets allowed the subjects to hear but limited the use of the pinnae by routing the signal directly to the subject's ear canal. Each headset consisted of a headband, two circumaural cushions (Grason-Stadler, Type 001), and two wooden blocks which were inserted in the cushion as substitutes for the usual earphone transducer.

A 5/16 inch hole was drilled in the middle of each block and a 1/4 inch outside diameter glass tube 3 inches long was inserted through the hole. A 3/16 inch polyethylene tube was inserted through each glass tube. A size 50 cotton thread was introduced through the polyethylene tube to reduce the possibility of standing waves. Rubber ear inserts were then attached to one end of the polyethylene tube and inserted into the subject's ear canal. The outside of the earphone was then covered with foam rubber to minimize reflecting surfaces. This is illustrated in Figure 3.

To insure that each subject's head did not move during a test session and that it was in an identical position on subsequent tests. a head restraining test chair was constructed. The test chair consisted of a straight back wooden chair with a series of braces for the subject's head. One brace projected superiorly from the midline of the back of the chair. A second brace was perpendicular to brace one and projected inferiorly to the second and was perpendicular to it. A third brace had an attachment to fit over the bridge of the subject's nose. All

Figure 3.

Photograph of specially constructed headset used in experimental condition.

braces were adjustable and were marked off in 1/2 inch increments to allow for individual settings for each subject. A headrest similar to ones used in dental chairs was provided to support the back of the subject's head. These braces prevented rotational head movement. Figures 4 and 5 illustrate this chair.

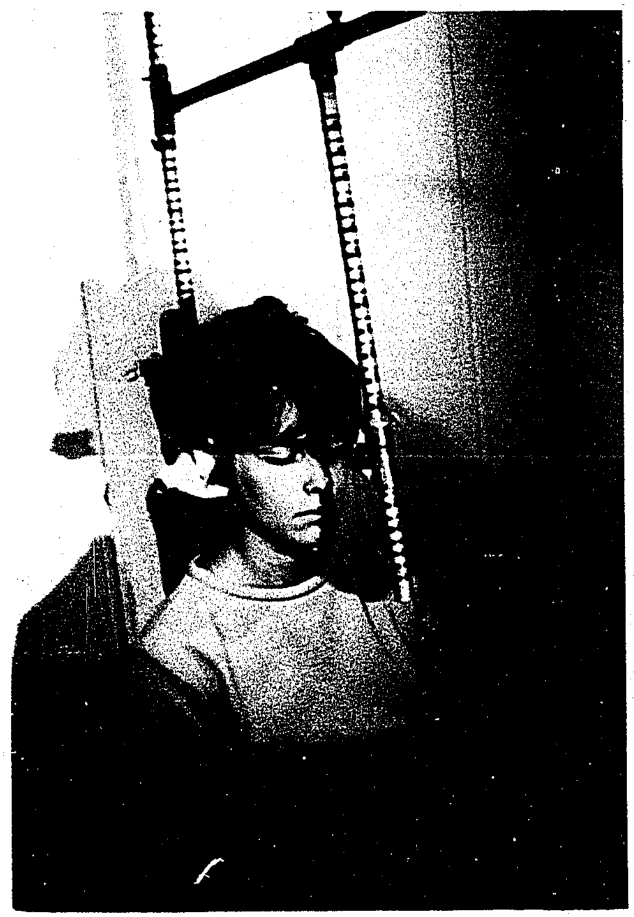
Experimental Procedures

There were two test conditions in the study. Each subject was tested under both conditions. One condition served as the control condition (CC) and involved testing localization ability in the sound field with the pinnae uncovered. The second condition served as the experimental condition (EC) and tested localization ability in the sound field with the pinnae covered by the specially constructed headset described earlier. For each condition each subject was tested at the beginning of an hour (CC_A and EC_A, respectively) and again at the end of the test hour (CC_B and EC_B, respectively). To insure that each subject of the EC had an opportunity for listening experiences during the hour interim between each of the two daily tests, the subjects were required

Figure 4.

Photograph of test chair used to restrict head movement during all testing.

Figure 5.



Photograph of test chair used to restrict head movement during all testing.

to stay in a specified waiting room. Listening experience was provided by a standard AM radio which alternately broadcasted popular music, news, and advertisements. It was felt that even if the subject was not intentionally listening to the radio, the presence of the sound would force the auditory scanning mechanism (Myklebust, 1964) to remain functioning at a high level. The entire testing period for both conditions was ten days. Each five day block was separated by a two day interim during which no testing occurred. Subjects were assigned to one of two groups--Group I or Group II, in a randomized fashion. Originally there were an equal number of subjects in each group. However, two subjects dropped out of the study. Consequently, there were two subjects in Group I and four subjects in Group II. Group I received the control condition first and Group II received the experimental condition first.

The specific test procedure used in this study follows. After the subject was audiometrically and otoscopically examined, he was seated in the test chair. The following directions were read to him.

Your head will be secured in this brace. It will contribute greatly to the scientific technique of this study if your head does not move during today's test and that it be in an identical position for future tests. This brace will serve as a reminder not to move your head and as a guide for me for future tests. Your utmost cooperation will be appreciated. This brace must be tight but should not be so tight as to cause discomfort. The test will consist of a series of three very short pulses of noise similar to a loud /sh/. There are five seconds between one set of three pulses and the next set of three pulses. Your task is to point to and verbalize which one of these white speakers is producing the sound. Tell me what speaker the sound is coming from by saying right front if the sound is coming from the speaker on the right but slightly in front. Left front if from the speaker on your left but in front of you. Left and right are on your immediate left or right. Left back and right back are on your left or right, as the case may be, but behind you. The sounds will be short so remember to listen carefully. Do not respond until you hear all three pulses. Also, remember that you have only five seconds to respond so do not spend an undue amount of time deciding which speaker it is. Try to be as accurate as possible but do not hesitate to guess.

So, whenever you hear the sounds, point to the correct speaker and tell me either right front, right, right back, or left front, left, left back. Do not move your head. Do you have any questions before we begin?

The subject's head was then braced and the brace setting was appropriately recorded on the Score Sheet. These settings were maintained throughout the experiment. The Pretest stimuli consisting of one train of three pulses from each speaker were then presented to insure that the subject understood how he was to respond. If the subject responded appropriately, the test was immediately begun. If the subject did not respond appropriately, he was reinstructed and given the Pretest again. One subject required reinstruction. Upon completion of the test the subject was removed from the brace and instructed to return for the next test in the following manner.

> Thank you for helping today. Please do not discuss any part of this test with anyone. During the next hour, you may study or talk to another person (but you must stay in the waiting room).[1] I will see you in an hour for the second part of today's test. (Or--I will see you tomorrow at the same time).

When the subject returned for the next test session, this explanation was provided.

> This task is the same as the one before--just listen carefully.

[1]This phrase was read only for EC.

> Point to the speaker from which the sound is coming and say if it is coming from the right front, right, right back or left front, left, left back. Do not move your head and try to be as accurate as possible. Do you have any questions?

This procedure of explaining the task and then testing continued until the data for both conditions were gathered.

Scoring

Each response was appropriately scored on the Score Sheet (Appendix A) by the examiner during the five sec interval when no stimuli were presented. The Score Sheet served as a randomized order of testing. The speakers were numbered and these numbers were then located in a table of random numbers. In determining the randomization of the testing order these criteria were followed.

1) No more than one repeat of any given number was allowed within one series of six stimulus presentations. This was done because it was felt that some repeats were necessary to discourage the subject from ruling out any given speaker as a possible choice.

2) No consecutive repeats were permitted in order to discourage the learning of any possible qualitative cues or other cues that may be present which might become evident to the subject through repetitive stimulation of one speaker at one sitting.

3) No more than one set of repeats per testing order was allowed because of the small number of test presentations (six) for a given testing session.

The speaker designated by the subject was recorded on the Score Sheet. This was done by writing the letters of the selected speakers over the letters of the actual speakers. This information was later transferred to a histogram for a graphic illustration of subjects' judgments. No subject received any feedback as to the accuracy of his judgments.

Statistical Treatment

The following raw scores were obtained for each subject.

Control Condition	A	X1	B	X2
Experimental Condition	A'	X1	B'	X2

Each respective X indicates the total number of correct judgments for that subject under that condition for all test days of that condition. For example subject 1 made the following number of correct judgments for each test day.

	Control Condition		Experimental Condition	
Test Day	A	B	A'	B'
1	6	6	3	1
2	6	6	1	3
3	6	6	0	2
4	6	6	4	3
5	6	6	3	5
	AX 30	BX 30	A'X 11	B'X 14

These total raw scores for each condition for all subjects as a group were used to compute a correlation coefficient using the following raw score correlation formula (Pophams, 1966, p. 89).

$$\underline{r} = \frac{\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{n}}{\sqrt{\left(\Sigma X^2 - \frac{(\Sigma X)^2}{n}\right)\left(\Sigma Y^2 - \frac{(\Sigma Y)^2}{n}\right)}}$$

This $\underline{r}$ was used in the computation of a $\underline{t}$ test to determine just how great the difference between two means had to be in order for it to be judged significant. These same total raw scores for each condition for all subjects as a group were again added together and a mean computed.

	Control Condition		Experimental Condition	
Subject	A	B	A'	B'
1	X1	X2	X3	X4
2	X1	X2	X3	X4
3	X1	X2	X3	X4
4	X1	X2	X3	X4
5	X1	X2	X3	X4
6	X1	X2	X3	X4
Total	ΣA	ΣB	$\Sigma A'$	$\Sigma B'$

$\Sigma A + \Sigma B = D$ $\qquad$ $\Sigma A' + \Sigma B' = D'$

$D \div 6 = \bar{X}$ $\qquad$ $D' \div 6 = \bar{X}$

These means were then used to complete a $\underline{t}$ test using the following formula (Pophams, 1966, p. 152).

$$\underline{t} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2} - 2r\left(\frac{S_1}{\sqrt{n_1}}\right)\left(\frac{S_2}{\sqrt{n_2}}\right)}}$$

This analysis was made to determine if a statistically significant difference existed between the two conditions investigated--pinnae/no pinnae. A t analysis was also made to test the significance of the observed differences between the $EC_{A'}$ and the $EC_{B'}$. This analysis was used to evaluate adaptation to the functional loss of pinnae.

Experimental Condition	A'	B'
Subject 1	X3	X4
Subject 2	X3	X4
Subject 3	X3	X4
Subject 4	X3	X4
Subject 5	X3	X4
Subject 6	X3	X4
Total	$\Sigma A'$	$\Sigma B'$
	$\Sigma A' \div 6 = A'\bar{X}$	$\Sigma B' \div 6 = B'\bar{X}$

The t formula for testing the significance of the observed differences between correlated means described earlier was also used for this analysis.

CHAPTER III

RESULTS AND DISCUSSION

Results

This chapter includes a presentation of the statistical analysis of the data and a discussion of the results.

Four total raw scores were obtained for each of the six subjects--two (A and B) for the normal pinnae condition (CC) and two (A' and B') for the altered pinnae condition (EC).

The scores under test session CC_A, as shown in Table 1, ranged from 28 to 30 with a mean of 29.5. All subjects obtained scores of 30 under test session CC_B. For the normal pinnae condition, then, combined A+B scores ranged from 58 to 60 with a mean of 59.5. The scores obtained under $EC_{A'}$ ranged from 11 to 19 with a mean of 13.83. Under $EC_{B'}$ the obtained scores ranged from 13 to 18 with a mean of 14.83. For the altered pinnae condition combined A+B scores ranged from 25 to 37 with a mean of 28.67.

Table 1.--Summary of total number correct judgments for each condition over the entire test period.

Subject Number	CC A	CC B	CC A B	EC A'	EC B'	EC A' B'
1**	30	30	60	12	13	25
2**	29	30	59	16	13	29
3**	30	30	60	12	15	27
4**	30	30	60	11	14	25
5*	28	30	58	19	18	37
6*	30	30	60	13	16	29
Total	117	180	357	83	89	172
Mean	29.5	30	59.5	13.83	14.83	28.67

* - Group I received CC first
** - Group II received EC first

The difference between the mean A score and the mean B score clearly was of inconsequential magnitude, hence these means were treated together as a CC score. The difference of 6 judgments between A' and B' was tested statistically through the use of a t test (Pophams, 1966). The resultant t of .975 (df 5) did not approach the value of 2.015 required for significance at the .05 level of confidence. This nonsignificant t indicates that subjects did not adapt demonstrably to the altered pinnae condition and permitted the grouping of A' and B' scores together for purposes of analyzing the difference between CC and EC.

The difference of 30.83 between the mean of CC and the mean of EC scores gave rise to a t of 20.36 which far exceeds the value of 6.859 required for significance at the .001 level of confidence. The accuracy with which subjects performed the sound localization task under the normal pinnae condition, then, was seen to have been significantly reduced when pinnae alteration occurred.

It is of interest to note, nevertheless, that a relatively direct relationship existed between scores under CC and those under EC for these subjects. A raw score *r* correlation coefficient of .912 was obtained (using A+B scores versus A'+B' scores). This *r* exceeds the value of .874 required for significance at the .01 level of confidence and indicates strongly the existence of more than a chance relationship between the two sets of scores. Whatever the effects of pinnae alteration, then, there would appear to be factors unaltered by this experimental condition which play a significant--but not exclusive--role in sound localization ability.

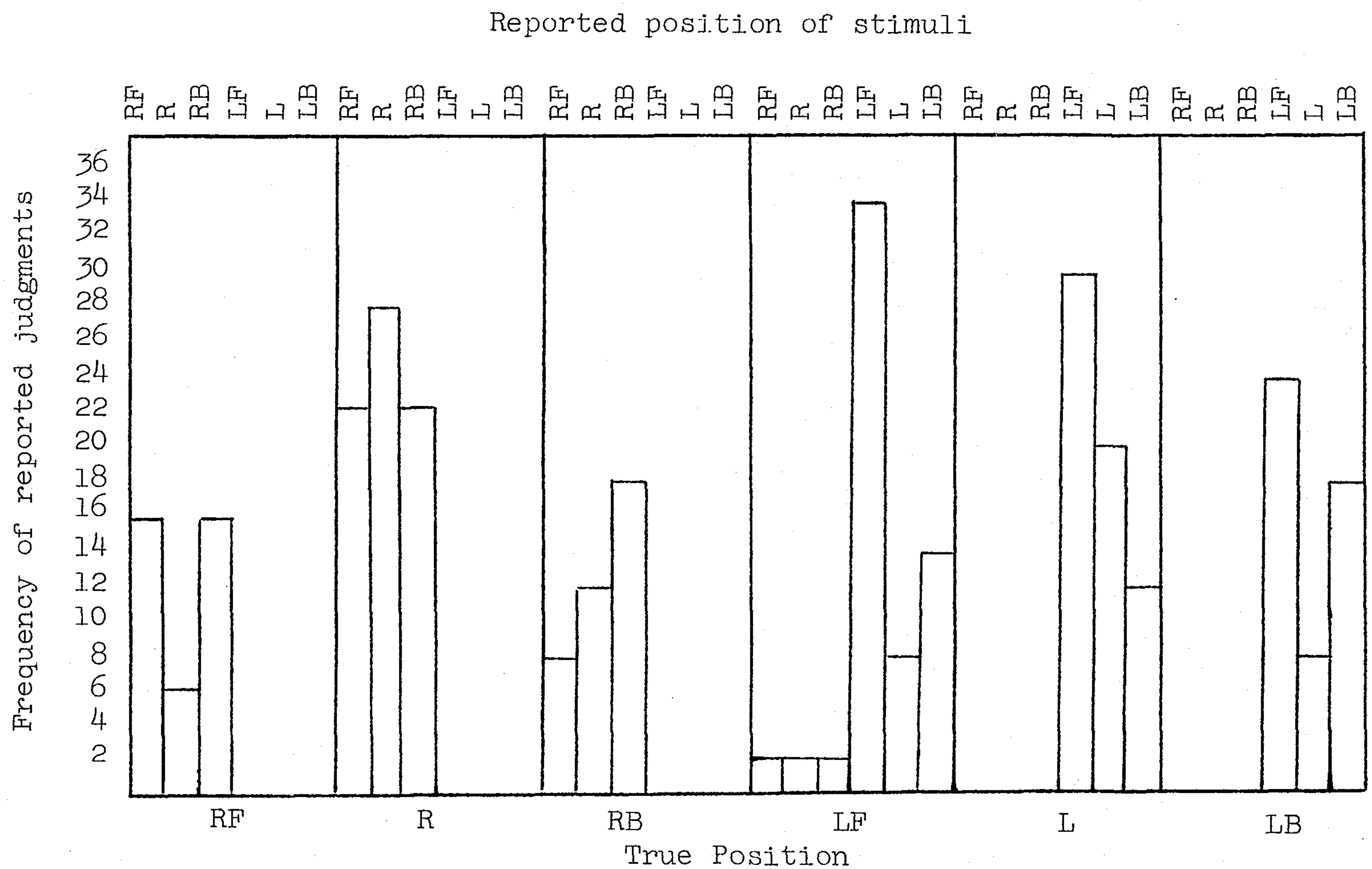
Discussion

An inspection of the results shows that under the conditions of this study the functional loss of pinnae had a marked negative effect on sound localization ability. This would tend to verify the findings of Fisher and Freedman (1968) and Batteau (1967) that the pinnae play a definite role in localization. It is interesting that this disruption of localization ability was not overcome by either the practice in localizing provided by continued testing or sub-conscious adaptative phenomenon. It seems reasonable to assume that successful localization is evidently a function of more than phase, intensity, and time cues as previously believed by many researchers.

An inspection of the data listed in Table 1 shows that the two subjects of Group 1 did perform better than most of the subjects of Group 2 in the experimental condition. Only one subject of Group 2 (subject 2) received a total score for both A' and B' as high as one subject from Group 1 (subject 6). Subject 5 had the highest total score of any subject and seemed to be more adept at localization than the other subjects. This analysis would tend to suggest that those subjects who were more familiar with the task before being asked to localize with the pinnae altered did better than those subjects who were asked to localize with the pinnae altered first. Since this study encompassed a small sample, more research is warranted before any far reaching conclusions can be made.

The reports of the subjects during the actual testing may have a bearing on the disrupted localization ability of the experimental condition. Two subjects complained about having something in their ears which consequently, could have affected their attendance to the task. Several subjects reported that they felt that it helped to "look", i.e., to move their eyes toward the stimulated side. A pilot study conducted prior to the present experiment did not verify this report. However, Weerts and Thurlow (1971) report that their subjects showed a localization shift up to 9° as a function of a shift in perceived head direction caused by eye movement and a change in the expectation of the placement of the source. Such a small shift of 9° or less in localization judgments would not have been identified in the pilot study. During the control condition, all subjects were relatively certain that their localization judgments were accurate. However, most subjects felt much less certain about the accuracy of their judgments under the altered pinnae condition. This uncertainty and confusion exemplified itself, as shown in Figure 6, when several errors were made as to which side (left or right) the sound was coming. It was felt

Figure 6.



Histogram illustrating frequency of reported judgments of sound position and their relationship to the true sound position.

that these errors were not due to scoring error or a mistake in perceiving left from right. This assertion can be made when consideration is given to the fact that the subjects were asked to point to the speaker in addition to verbally identify which speaker was the sound source. The pointing served as an orienting device for the subjects and a secondary cue for the examiner in identifying responses. Yet, other researchers (Hochberg, 1966; Rosenweig, 1961) have reported that their subjects had no difficulty detecting if a sound came from the left or right. It is interesting to note from Figure 6 that the subjects in the present study reported that the stimuli were originating from the left front (LF) speaker more frequently than from any other speaker. It is not known whether this phenomenon is a function of a dominant ear, placement of the speaker, shifts in perceived head direction due to eye movements, or some other factor.

In its final analysis, the pinnae theory seems to have increasing validity and should be considered whenever sound localization is discussed. Frequently, localization is used as an argument for the binaural fitting of ear level hearing aids (Carhart, 1958; Kodman, 1961; Dirks and Wilson, 1969). However, a realistic look of sound localization theory raises serious questions about this assumption. Whereas binaural hearing aids may provide gross cues to identify the side from which a sound emanates, they cannot provide the discrete information which is provided by the pinnae. If one considers the problem several subjects had in identifying from which side the sound was coming, then even these gross cues may not be useful all the time for all people. Another consideration to be accounted for when binaural hearing aids are discussed in conjunction with sound localization is the possibility that phase cues, time cues, intensity cues, and the pinnae all play a role in providing maximum information for sound localization. All of these prerequisites are disrupted by the use of a hearing aid. With the manufacturing tolerances makers must use, no two hearing aids are exactly alike. They may be similar but not exactly the same. Consequently a binaural hearing aid wearer may be getting two sets of distorted localization cues. Phase, time, and intensity cues are all modified by hearing aid circuitry. This modification may be small but it may be sufficient to disrupt any of these cues that were available. As far as the cues provided by the pinnae, a hearing aid and its consequent ear-mold also disrupt localization cues that are provided by the pinnae. The sound is picked up at various points with different hearing aids and fed into the ear canal thereby functionally removing the pinnae. The extent to which localization cues provided by the pinnae are retained or modified with all-in-the-ear type hearing aids is unknown at this time and should be investigated.

Successful localization is an important function for everyone. This is especially true in our modern society of fast moving automobiles and in the military. Therefore, all the auditory localization cues that one can gather and process are frequently paramount to staying alive. If auditory localization is important for those with normal vision, what about the blind or partially sighted person?

> A blind person, deprived of the advantage of sight, becomes dependent upon his hearing for maintaining adequate contact with his environment. Thus, hearing becomes crucial in daily living for group conversation, family communication, social and recreational activities, and mobility (Conkey and Schneidermann, 1968, p. 705).

Auditory localization cues are even more important for the blind. But how does a visually impaired person who is auditorily impaired receive sufficient localization cues for social independence and mobility. Successful localization for this group of people is of even greater magnitude. The Reverend Mr. Thomas J. Carroll and Dr. Leo H. Riley (1970) raise the following point.

> Every professional in the rehabilitation of blind persons is aware of the fact that there is some correlation between ability in hearing and ability in making use of mobility skills--but no audiologist has given the exact correlation (p. 76).

What can be or is being done to help these doubly handicapped people localize? Rintelmann, et al. (1970) and Conkey and Schneidermann (1968) have noted that a problem exists for the aurally and visually handicapped person and have attempted to aid localization of unilaterally deaf-blind subjects with the use of a CROS hearing aid. They reported good success but evidently did not consider the fact that monaural localization can be quite accurate (Angell and Fite, 1901; Bauer, et al., 1966). The use of hearing aids with the deaf/blind person is an interesting question that should be researched much more extensively.

In returning to one of the questions that was originally investigated in this paper, it is interesting to note that there was no evidence of a statistically significant amount of adaptation. There are several possible explanations for this. One explanation is that the task performed in this experiment (i.e. localizing one of six speakers) may not have been discrete enough to detect a small improvement in localization during the altered pinnae condition. A second explanation is that the subjects may not have had enough opportunity to adapt to the loss of pinnae. One hour per day for five days is not a great amount of time. It may be necessary for a longer period of time to transpire before adaptation will occur. Of course, one must not rule out the possibility that a human organism cannot adapt to the functional loss of pinnae in sound localization ability.

Research Recommendations

This entire phenomenon of sound localization remains in need of further research. Several suggested areas for research are listed below:

1) monaural localization.

2) adaptation to the functional loss of pinnae in sound localization ability over a longer period of time than in the present study.

3) sound localization with the use of
   a) monaural and binaural behind-the-ear type hearing aids (with varying microphone positions),
   b) monaural and binaural all-in-the-ear type hearing aids,
   c) CROS and BICROS type hearing aids.

4) sound localization ability with individual conchae or cavities of the pinnae filled in.

5) Sound localization ability of the blind.

6) Training the blind in sound localization.

CHAPTER IV

CONCLUSIONS

The purpose of this study was to investigate the role of the pinnae in sound localization and to investigate the possibility of adaptation to the functional loss of pinnae in sound localization ability.

The following null hypotheses were rejected:

1) There is no significant difference between scores obtained on a discrete localization task under conditions of CC_A and CC_B.

2) There is no significant difference between scores obtained on a discrete localization task under conditions of CC_{A+B} and $EC_{A'+B'}$.

Results of this study failed to reject the following null hypothesis:

3) There is no significant difference between scores obtained on a discrete localization task under conditions of $EC_{A'}$ and $EC_{B'}$.

Apparently, the functional loss of pinnae had a marked negative effect on sound localization ability that was not overcome by either practice in localizing or a subliminal adaptative phenomenon. Successful sound localization is evidently a function of more than phase, intensity, and time cues. The functional removal of the pinnae caused a significant deterioration in localization ability suggesting that the pinnae play a definite role in sound localization.

It is suggested that enough time may not have been allotted for adaptation to occur or that the task was not sufficiently discrete to identify any adaptation that may have occurred.

CHAPTER V

SUMMARY

This study reviewed the role of the pinnae in the phenomenon of sound localization and investigated the ability to adapt to the functional loss of pinnae. A train of pulses of white noise were presented to six normal hearing subjects individually. The subjects were asked to identify the source of sound from one of six speakers in the absence of head movement under two conditions. The control condition (CC) tested sound localization with the pinnae unaltered. The experimental condition (EC) tested localization with the pinnae covered by a modified earphone for a period of one hour per day for five days. In both conditions, the testing was done at the beginning of an hour and again at the end of an hour.

A statistical analysis of the data indicated that under the conditions of this study subjects could localize significantly better with the pinnae uncovered than when covered by the modified

earphone. There was not sufficient evidence to conclude, though, that these subjects adapted to the functional loss of pinnae by regaining their ability to localize as well as they did with the pinnae uncovered.

APPENDIX A

Score Sheet

Pretest--to assure subject understands task

RB LF L R LB RF

First Daily Test							Correct	Incorrect
Test Day One	R	LF	LB	RB	RF	LF		
Test Day Two	RB	L	R	RB	LF	RF		
Test Day Three	L	LB	R	RB	LF	RB		
Test Day Four	L	RF	RB	RF	R	LF		
Test Day Five	RF	LF	L	LF	R	RB		
					Total			

Second Daily Test						
Test Day One	LF	LB	R	L	RF	LF
Test Day Two	RB	LB	L	LF	R	RB
Test Day Three	LB	RB	LB	R	LF	LF
Test Day Four	L	LF	R	LF	RB	LB
Test Day Five	LF	RF	L	RB	LF	LB
					Total	

CC
EC
Group I/Group II

Name
Brace Setting
1) Back
2) Top
3) Nose

RF--Right Front   LF--Left Front
R---Right   L---Left
RB--Right Back   LB--Left Back

BIBLIOGRAPHY

Angell, J. R., Fite, W. "The Monaural Localization of Sound." Psychological Review, VIII (1901), 225-246; 449-458.

Arkins, Herbert, Colton, Raymond R. Tables For Statisticians. New York: Barnes & Nobel, Inc., 1963.

Batteau, D. W. "The Role of the Pinna in Human Localization." Proceedings of the Royal Society, London, CLXVIII no. 1011 Series B (1967), 158-180.

Bauer, R. W., Blackmer, R. F. "Auditory Localization of Noises." U. S. Army Human Engineering Laboratory Technological Memo 4-65. Aberdeen, Maryland, January, 1965.

Bauer, R. W., Matuzsa, J. L., Blackmer, R. F., Glucksburg, S. "Noise Localization After Unilateral Attenuation." Journal of Acoustical Society of America, XL (1966), 441-444.

Bekesy, G. von, Rosenblith, W. A. "The Mechanical Properties of the Ear." Handbook of Experimental Psychology. Edited by S. S. Stevens. New York: John Wiley & Sons, Inc., 1951.

Carhart, Raymond. "The Usefulness of the Binaural Hearing Aid." Journal of Speech and Hearing Disorders, XXII (1958), 42-51.

Carroll, Reverend Thomas J., Riley, Leo H. "Human Communication and Its Disorders: An Overview." U. S. Department of Health, Education, and Welfare Monograph No. 10. Bethesda, Maryland: National Institute of Neurological Diseases and Stroke, 1970.

Conkey, H. O., Schneidermann, C. R. "The Effect of CROS on Auditory Localization and Mobility of a Blind Person." Exceptional Child, XXXIV (1968), 705-706.

Dirks, D., Wilson, R. "Binaural Hearing of Speech for Aided and Unaided Conditions." Journal of Speech and Hearing Research, XII (1969), 650-664.

Fisher, H. Geoffrey, Freedman, Sanford J. "Role of the Pinna in Auditory Localization." Journal of Auditory Research, VIII No. 1 (Januray, 1968), 15-26.

Hochberg, Irving. "Median Plane Localization of Speech." Journal of Auditory Research, VI No. 3 (July, 1966), 277-281.

Kodman, Frank Jr. "Successful Binaural Hearing Aid Users." Archives of Otolaryngology, LXXIV (1961), 302-304.

Myklebust, Helmer. "Sensory Deprivation and Behavior." Psychology of Deafness. New York: Grune and Stratton, Inc., 1964.

O'Neill, John J., Oyer, Herbert J. Applied Audiometry. New York: Dodd, Mead & Company, 1966.

Pophams, W. James. Educational Statistics. Evanston: Harper & Row, Publishers, 1966.

Rintelmann, William, Harford, E., Burchfield, S. "A Special Case of Auditory Localization: CROS for Blind Persons with Unilateral Loss." Archives of Otolaryngology, LXLI No. 3 (March, 1970), 284-288.

Rosenweig, Mark R. "Auditory Localization." Scientific American, CCV No. 4. San Francisco: W. H. Freeman Company, October, 1961, 132-142.

Stevens, S. S., Davis, H. Hearing. New York: John Wiley & Son, Inc., 1938.

Stevens, S. S., Warshofsky, Fred. Sound and Hearing. Editors anonymous. Time-Life Books. New York, 1970.

Weerts, Theodore C., Thurlow, Willard R. "The Effects of Eye Position and Expectation on Sound Localization." Perception and Psychophysics, IX (January, 1971), 35-39.