8-1-1962

Localization of Interaural Intensity Differences

Ann Carolyn Adams

LOCALIZATION OF INTERAURAL INTENSITY DIFFERENCES

BY

ANN CAROLYN ADAMS

B.A., University of Mississippi, 1961

A Thesis
Submitted to the Faculty of
The University of Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Master of Arts
in the Department of Psychology

The University of Mississippi

August, 1962

LOCALIZATION OF INTERAURAL INTENSITY DIFFERENCES

BY

ANN CAROLYN ADAMS

William A. Wilbanks
Associate Professor of Psychology
(Director of the Thesis)

Chairman of the Department of Psychology

Associate Professor of Psychology

Lewis Nahler
Dean of the Graduate School

TABLE OF CONTENTS

INTRODUCTION

The most characteristically 'binaural' auditory phenomenon is localization, by which is meant responding to the distance and direction of the source of a sound.

Although there is some evidence, experimental and clinical, that persons with only one functioning ear can localize a sound source, most of the experiments in this area of sound perception have assumed it to be a binaural affair.

The stimulus factors involved in determining the location of a sound source are the relative values of sound pressure at the two ears and the interaural time or phase difference. For a pure tone stimulus, the instantaneous sound pressure at one ear, say the right, may be written:

$$P_r = A_r \sin wt,$$

and at the other (left) as:

$$P_l = A_l \sin (wt+\omega),$$

where A_r is the peak pressure at the right ear, A_l is the peak pressure at the left ear, and ω is the phase difference between the sounds at the two ears.

The second expression may also be written:

$$P_l = A_l \sin w(t+\tau)$$

where τ is the interaural time difference. The phase angle is $\omega = w\tau$

In the case of a single source located directly in front of the subject τ, and consequently ω, will be zero and the two amplitudes A_r and A_l will be equal, assuming that the head is symmetrical. For a sound source displaced to one side, say 90 degrees to the right, A_r will be somewhat larger than A_l due both to the slightly longer path to the left ear and the greater shadowing of the left ear be the head. ω and consequently τ will be negative for the left ear since the signal at that ear lags the signal at the right.

The experimental literature on sound localization has been concerned with relating interaural time (phase) and internsity differences to the listener's behavior with respect to these physical attributes of sound.

Work on tones has shown a different basis of localization of low frequency and high frequency tones. In the now classical study by Stevens and Newman (8), a subject was placed on a chair at the top of a post rising above the roof of a building, in order to reduce the extra sounds which would have been present in a reverberant room. The sound in this study came from a loudspeaker located at the end of a rotatable boom and at the same level as the listener's ears. The subject localized tones from 60 to 1000 c. p. s. accurately. Above 1000 c. p. s. localization became poor and was worst at some point between 2000 and 4000 c. p. s. Then localization improved again, until at 10,000 c. p. s. it was quite as precise as it had been at 1000 c. p. s.

Stevens and Newman analyzed this function into two, indicating (1) that dichotic phase is effective for low tones and (2) dichotic intensity for high tones; (3) that one of these principles begins to work after the other leaves off, and (4) that the poor localization near 3000 c. p. s. is due to the fact that there is just not enough overlap of these two basic functions to make the organism as adequate in this critical region as it is at both extremes of frequency.

That interaural time or phase changes play a small role in localization of frequencies above 1500 c. p. s. was shown by Licklider and Webster (4), and also by Klumpp (3). Licklider and Webster presented a pair of high frequencies to each ear in a way that permitted them to reverse the phase of either component. They found that when either of the pair of frequencies was below about 1500 c. p. s., reversing its phase produced a detectable change in the sound heard by the subject. If both tones had frequencies well above 1500 c. p. s., either could be reversed in phase without a detectable change unless the two frequencies lay within 1500 c. p. s. of each other, in which case the change was again noticeable. They shower that in the latter case reversing the phase change in the low-frequency resultant, and that it was this phase change at a frequency below 1500 c. p. s. that the subject was able to detect.

Klumpp employed an electrical lag-line to produce a variable time delay to one ear and found that subjects could respond to changes in the interaural time difference for tones up to about 1500 c. p. s. but that at frequencies much above this they were unable to respond up to possibly 1700 c. p. s. and some failing to hear changes at 1300 c. p. s.

The most recent of studies on the localization of air-borne sounds, reconfirming the above data that below 1500 c. p. s., localization depends on time (phase), and not on intensity, was done in 1955 by Sandel, Teas, Feddersen, and Jeffress (5). They performed three experiments in this study. These were conducted in an anechoic room and employed an acoustical "pointer" as the subject's method of indicating the direction of the stimulus tone. The pointer was a small loudspeaker carried on a boom which rotated about a vertical axis through the subject's head. This speaker presented a wide-band noise which alternated with the tone to be localized. The switching was transientless and was performed by an electronic gate having a 100-millisecond rise and decay time.

Three small loudspeakers in enclosures, one mounted directly in front of the subject and one 40° to each side, presented the stimulus tones to be localized. In the first experiment the speakers were employed singly. In the other two experiments they were used in pairs. In the second experiment the pairs of speakers were in phase; in the third, they were in phase opposition.

The stimulus conditions of Experiment 2 generated a "phantom source" which appeared to lie between the two speakers employed. The predicted location was compared with the subjects' responses.

The stimulus conditions of Experiment 3 generated a phantom source which according to the prediction of the experimenters, would lie toward the side opposite to the asymmetrically placed speaker and would move in direction with frequency. This prediction was borne out by the subjects' responses for frequencies where interaural time was the dominant basis for localization.

The results of the three experiments showed a high degree of accuracy in subjects for localizing signals consisting of noise or of tones having frequencies up to about 1200 c. p. s. For high frequencies both bias errors and random errors increased--the random errors reaching a maximum at about 2000 c. p. s. and then diminishing, and the bias errors reaching their maximum at about 3000 c. p. s.

The role of interaural intensity differences in the localization of sounds is less clear than that of time differences. Stevens and Newman explained the reduction of errors in their experiment as the frequency is raised from about 3000 c. p. s., where the errors were greatest, to 10,000 c. p. s. as due to the increased intensity difference that results from the increased shadowing of the distant ear by the head.

The work of Wiener (9), and of Sivian and White(10), suggests the likelihood that the behavior of the intensity difference with azimuth would depend upon frequency. It would depend in an unpredictable way, since the size of the various parts of the ear relative to the wavelength of the sound would affect the intensity finally delivered to the eardrum.

As an extension of their previous work on localization, Fedderson, Sandel, Teas, and Jeffress (2), studied localization of high-frequency tones. The stimuli to be localized were provided through earphones, and the subject was required to match the position (in his head) of a noise and a tone. The noise to one ear was delayed, and the tone presented with no time or phase difference. The subject adjusted alternately by means of a gate having a 150-m. s. e. c. rise and decay time. The conclusions were, for the localization of high-frequency pure tones, where there is no cue provided by the onset of the tone, a difference of level is needed at the two ears which can be provided only by tones above about 5000 c. p. s. At lower frequencies where diffraction around the head is less and the differences of level, therefore, smaller, the subject consistently underestimates the azimuth angle. This underestimation decreases with increasing frequency and increases with increasing azimuth angle.

Below 5000 c. p. s. it would appear that the interaural intensity difference in hearing must be large to have an appreciable effect on localization. Shaxby and Gage (6), performed the first of studies in this area. In their study, the subject was fitted with earphones by which the phase could be advanced or retarded in either earphone. At the other end of the apparatus, a pure-tone generator was used to produce sound waves. The oscillations passed to an amplifier, then to a phase-splitting device, through a second-stage amplifier, which used an amplifier for each wire--a left amplifier and a right amplifier now, and then to the earphones.

The authors found it difficult to get a quantitative estimate of each factor separately, since the extent of deviation of the sound from the central plane could not be measured with any certainty. The method of procedure adopted was to 'balance' the two effects of loudness and time difference against one another.

With the sound at the same intensity level in both ears a record was taken on paper of the setting of the phase balance when the sound appeared to be in the median plane. The sound was next increased in intensity by a known amount in the right ear, which in itself would "throw" the apparent sount over to the right side of the head. It was brought back to centrality by swinging the phase balance. Series of measurements were made for different frequencies, intensity levels, and intensity differences. The results showed that the relation between intensity differences and equivalent time differences is independent (1) of basic intensity and (20) of frequency. The authors concluded that: (1) The independence of frequency shows that time differences and not phase differences lie at the root of the faculty of binaural localization of a source of sound in the median plane; and (2) Loudness differences can play no appreciable part in localization. They concluded also, that within the limits of loudness and of frequency of their experiments, a given time difference at the two ears, T, can be compensated by an intensity difference of p decibels, where p=kT. If T is expressed in microseconds and p in decibels, the constant k of the linear relation between them was found, by their data, to be 0.60.

In their "Localization of Sound from Single and Paired sources," a study mentioned earlier, Sandel, Teas, Feddersen, and Jeffress (5), found, in the five subjects differential sensitivity in decibels to have a large range between the two ears, especially at frequencies between about 1000 c. p. s. and about 3000 c. p. s.

One group of experimenters, Blodgett, Wilbanks, and Jeffress (1), used bands of noise instead of tones, but bound large interaural intensity differences were necessary to offset time differences.

The maximum interaural time difference that could be introduced into one channel without loss of sidedness was determined by various noise bands. Through the presentation of stimuli by several methods it was found that time values vary with frequency of the noise bands, being greater for lower bands.

Two experimental procedures were employed. In each the noise was recorded on the twin tracks of a binaural Magnecorder, and delay was effected by lateral displacement during playback of one of the reproducer heads of the tape. It was possible to obtain delays from 0 to 24 m. s. e. c.

In the first experiment the subject was instructed to adjust the setting until he was able to make judgment of "sidedness" and designate the side on which the sound was located. All judgments were correct.

The technique employed in the second experiment was for the subject to press one button if the sound appeared to be at the left and another button if it appeared to be at the right. The first experiment used two noise bands, with the micrometer set for maximal delay. The second experiment used delay in one of the channels while presenting the envelopes simultaneously and with gradual increase in intensity at the two ears. The subjects responded with judgments of sidedness on the basis of interaural time difference against intensity bias with lagging channel 12 to 15 db more intense than the leading channel. The length of delay was greater, for all subjects, with noise bands of low frequency than with higher bands.

It would appear that intensity effects do play a significant role in binaural localization. The present problem is to extend the research on this problem.

APPARATUS AND METHOD

The following equipment was used in this experiment: an R. C. A. beat frequency oscillator, a Hunter Timer, an Ampex MX-10 four position, two channel mixer, a Hewlett-Packard 350B attenuator set, a McIntosh 225 two channel amplifier, a Calrad 500C microphone, an R. C. A. WV-77E vacuum tube voltmeter, and a pair of Grason-Stadler TDH-39 10 ohm headphones. This equipment is represented in Figure 1.

The oscillator provided the signal source. The timer, providing a one-second tone presentation, was connected to the oscillator. From here the line carrying the tone was connected to a two channel mixer. The tone was now divided into a channel A and a channel B.

The channel B output from the mixer was connected directly to an attenuator set, where the attenuation dial which was used ranged from 0 to 10 decibels in 1 db steps. Channel B then passed to one amplifier; channel A passed from the mixer to a second amp. A switch was used which switched the attenuation from channel B to channel A when called for in the experiment.

From the two 25 watt amplifiers, channels A and B passed to the headphones, with channel A passing to the right headphone and channel B to the left headphone.

A microphone, with an on-off switch, operated by way of the mixer, was used. The experimenter could talk into it to the subject, with the sound received in the subjects' headphones.

A vacuum tube voltmeter, which measured the voltage across the headphones, was attached to channels A and B after their emergence from the amplifier. The level measured across the subject's earphones was for each 10 db below 1 millivolt.

The subject sat at a desk in an adjoining soundproof room, where he recorded his R's on a data sheet. The lines from the amplifier, containing the two channels, were anchored at the back of the desk. From here the channels went separately to the respective headphones.

The subjects used in this experiment were five undergraduate and graduate students at the University of Mississippi. Three males and two females were used. None had known hearing difficulties, and all were considered to have normal hearing ability. None of the subjects were experienced listeners in experiments on sound perception.

At the beginning of each experimental session, each subject was handed a data sheet, and given a warm-up period of about three minutes, which consisted of presenting several tone frequencies to him at random. Mid-way through a session, that is, after S recorded 25 responses, a two minute rest period, with headphones taken off, was given.

Preliminary experimentation determined that the critical range of decibels was from 0 to 4 decibels, which was varied by use of the attenuator set. Frequencies of 200 c. p. s., 500 c. p. s., 1000 c. p. s., 3000 c. p. s., and 5000 c. p. s. were chosen. The lower frequencies were chosen because of the possible large intensity changes which effect localization changes on frequencies of this kind. Conversely, the higher tone frequencies were chosen because of the supposedly smaller intensity changes which would bring about equal effects on localization. The 1000 c. p. s. tone frequency appeared to lie between the low tones, with large intensity differences as effective, and the high frequency tones, with smaller intensity differences as effective in producing localization.

The procedure used was for the experimenter to present 50 tones of one of the five frequencies used which were presented randomly, in one second duration, and with decibel changes, which had been chosen beforehand. These 50 tones were presented with a switch which switched the channels to be attenuated. Thus, either a 'left' or a 'right' tone was presented, with 25 'lefts' and 25 'rights'. An equal number of attenuator settings was used for the 50 tones. These decibel changes were in one-step intervals, from 0 to 4. Thus, each 'left' and 'right' tone was paired with five of each of the decibels. These 50 pairings were presented at random.

The subject responded, in the soundproof room, by writing his judgement of right or left, and these judgements were checked against E's list for the results.

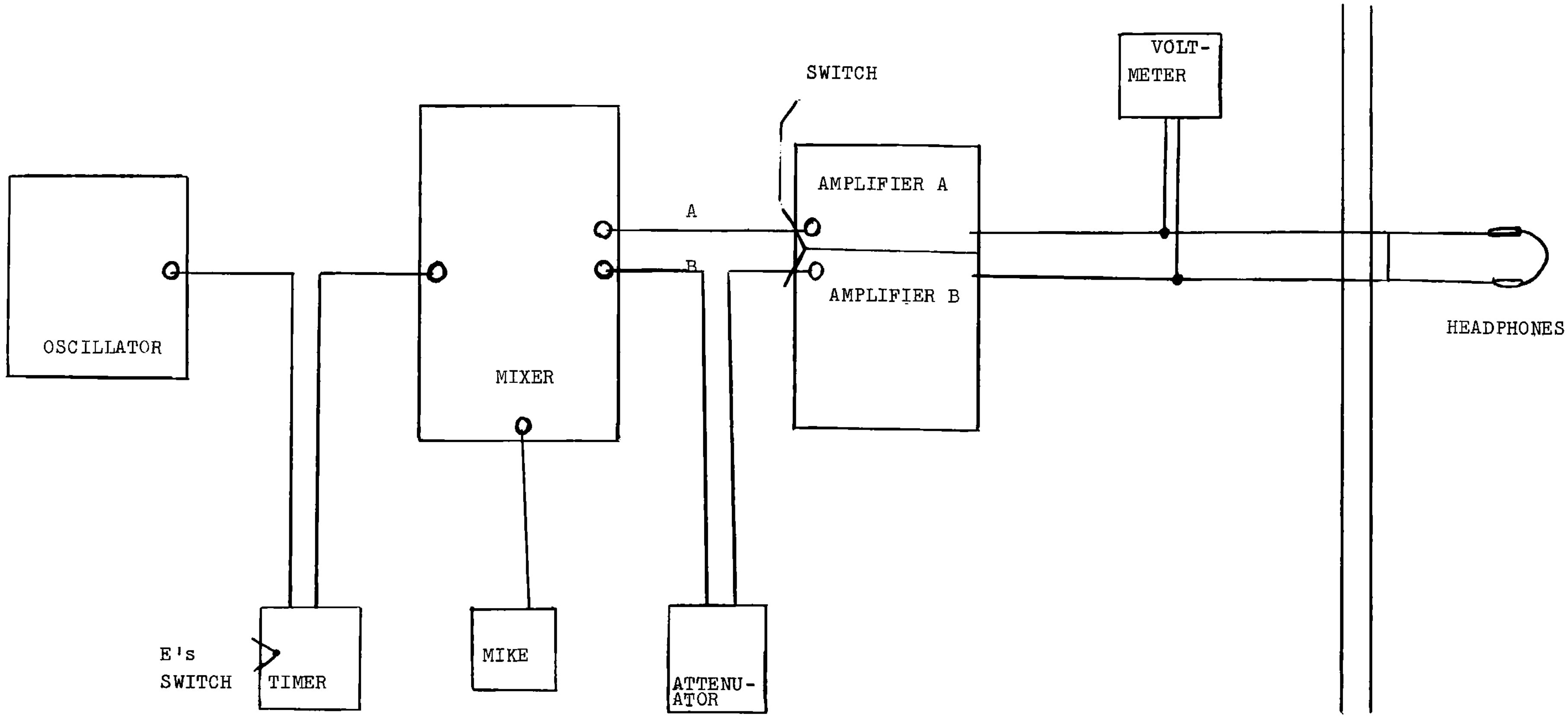

FIGURE I APPARATUS

RESULTS

Table I shows the mean of the fifty responses made by each subject to each frequency. The standard deviation of each mean is shown. An over-all mean and standard deviation for each frequency, combining the individual means and standard deviations, is shown.

Figure II presents the combined means for each frequency in graph form.

The mean for each subject was obtained by using the Müller-Urban weights, which used the least-square solution. This is the most refined statistical process for the method of constant stimuli in the psychophysical methods. The proportion of correct responses for each decibel unit of the raw data was entered into the Müller-Urban table to fit a normal ogive. The mean thus computed was the limen for each subject for each set of stimuli in one tone frequency.

A small change can be noted in the combined means, from the lower tone frequencies to the higher tone frequencies. As the tones increase in pitch, the mean decibels of the limen decrease. The separate means do not show this relation as well as the combined means do.

TABLE I

THRESHOLDS IN DECIBELS
MEANS AND S D's

SUBJECTS	FREQUENCY IN CPS				
	200	500	1000	3000	5000
J C	2.5 - 2.7	2.3 - 2.4	1.6 - 3.1	2.5 - 1.9	2.1 - 1.5
J R	3.2 - 1.5	3.3 - 1.2	2.7 - 1.2	3.0 - 1.2	1.0 - 1.4
C R	2.9 - 2.4	1.8 - 2.3	2.0 - 1.7	2.2 - 1.1	2.3 - 1.3
A S	3.6 - 4.1	2.49 - 2.7	1.5 - 5.8	2.2 - 1.6	2.1 - 1.5
W W	2.5 - 2.7	2.1 - 2.9	2.2 - 2.2	2.5 - 1.9	2.3 - 1.9
MEAN	2.9 - .42	2.4 - .49	2.0 - .44	2.48 - .30	1.96 - .49

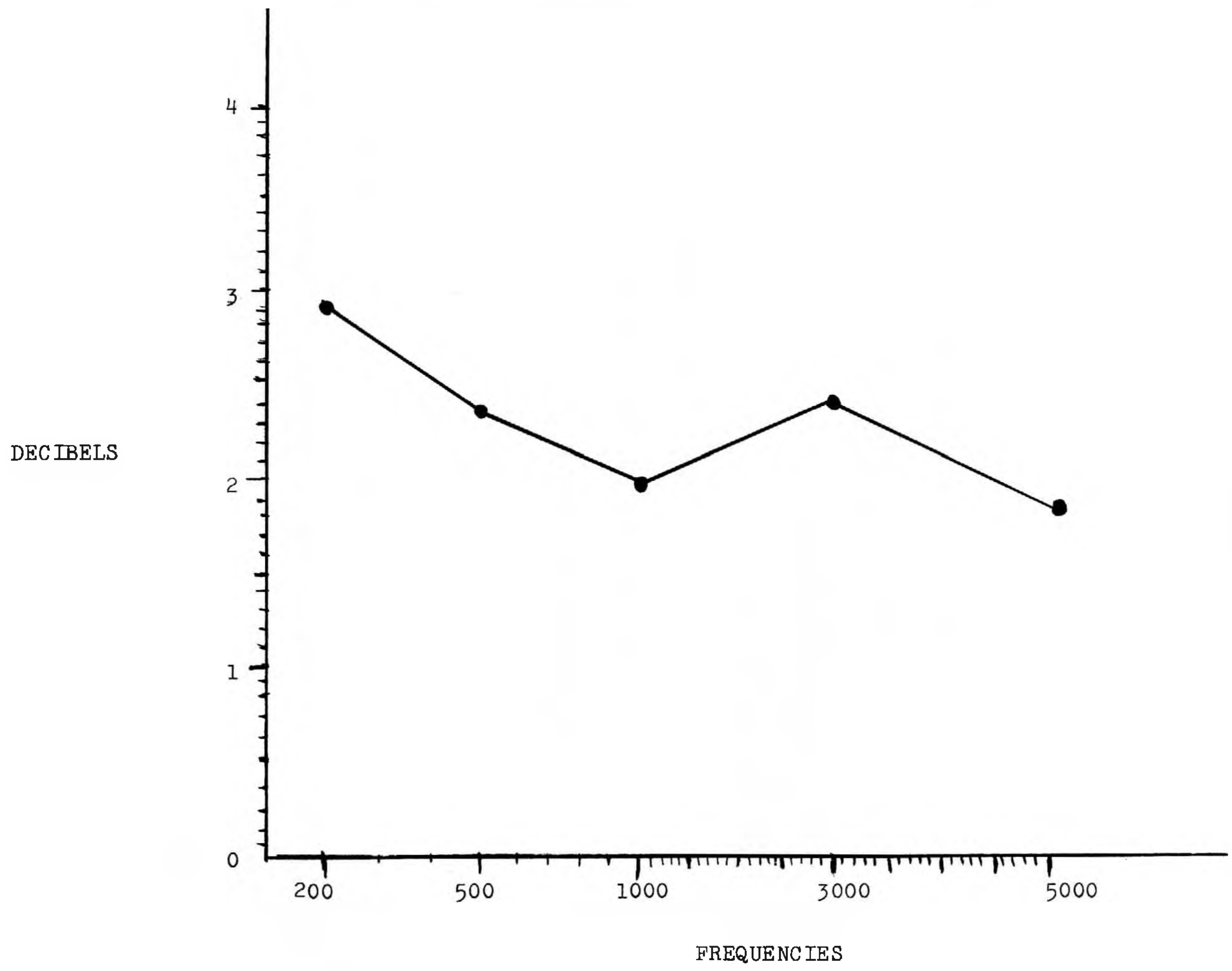

FIGURE II COMBINED THRESHOLDS

DISCUSSION AND SUMMARY

Much variation was found within the responses of each subject. This indicates a bias from the equipment. In addition to the large amount of variation within each subjects' responses, there was large variation with one subject, JR, in comparison with the other subjects' responses. As a result, his thresholds are much higher than are the other subjects.

At the 0 decibel attenuator setting, all responses should have been incorrect, and at or near the 4 decibel setting, all or nearly all of the responses should have been correct. The remainder of the decibel settings yielded responses in in-between proportions, and this resulted in a negatively accelerated curve, with the threshold at the 50% point in the curve. The 0 and the 4 decibel settings were chosen for this purpose of proportions.

This was a study to further the research on the part intensity plays in binaural localization of sound. It was presumed from previous studies that time differences play a large part in localization of low frequency tones, and thus, that intensity differences must be fairly large to play a role in localization at these frequencies. It was presumed that at high frequencies, intensity plays a more significant role in localization, thus, a smaller decibel change in the intensity of a sound would produce the same effect as a larger decibel change at lower frequencies. The thresholds for the five subjects at the five frequencies show a slight lowering from the low frequencies to the high frequencies. In other words, the 200 c. p. s. frequency had a higher threshold of intensity for the S's responses than the 5000 c. p. s. frequency had. Thus, a relationship between intensity and binaural sound localization is indicated, with special reference to the difference in effects intensity plays in localizing of high and low frequencies.

BIBLIOGRAPHY

PERIODICALS

(1) Blodgett, H.C., Wilbanks, W. A., & Jeffress, L. A. Effect of Large Interaural Time Differences upon the Judgment of Sidedness. _J. Acoust. Soc. Am._, 1956, 28, no. 4.

(2) Fedderson, W. E., Sandel, T. T., Teas, D. C., & Jeffress, L. A. Localization of High-Frequency Tones. _J. Acoust. Soc. Am._, 1957, 29, no. 9.

(3) Klumpp, R. G. _J. Acoust. Soc. Am._, 1953, 25. Cited by Sandel, et. al., _J. Acoust. Soc. Am._, 1955, 27, no.5.

(4) Licklider, J. C., & Webster, J. C. _J. Acoust. Soc. Am._, 1949, 21, Cited by Sandel, et. al., _J. &Acoust. Soc. Am._, 1955, 27, no. 5.

(5) Sandel, T. T., Teas, D. C., Feddersen, W. E., and Jeffress, L. A. Localizaion of Sound from Single and Paired Sources. _J. Acoust. Soc. Am._, 1955, 27, no. 5.

(6) Shaxby, J. H., & Gage, F. H. The Localization of Sounds in the Median Plane. _Medical Research Council Special Report_, 1932, Se▮ies 166.

(7) Sivian, L. J., & White, S. D. _J. Acoust. Soc. Am._, 1933, 4. Cited by Sandel, et. al., _J. Acoust. Soc. Am._, 1955, 27, no. 5.

(8) Stevens, S. S., & Newman, E. B., _Am. J. Psychol._, 1936, 48. Cited by Sandel, et. al., _J. Acoust. Soc. Am._, 1955, 27, no. 5.

BOOKS

(9) Boring, E. G. _Sensation and Perception in the History of Experimental Psychology_. New York: Appleton-Century-Crofts, Inc., 1942.

(10) Guilford, J. P. _Psychometric Methods_. New York: McGraw-Hill Book Company, Inc., 1954.

(11) Hirsh, I. J. _The Measurement of Hearing_. New York: McGraw-Hill Book Company, Inc., 1952.

(12) Woodworth, R. S. _Experimental Psychology_. New York: Henry Holt and Company, 1939.