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THE INTERAURAL INTENSITY DIFFERENCE LIMEN

A DISSERTATION

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THE INTERAURAL INTENSITY DIFFERENCE LIMEN

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THE INTERAURAL INTENSITY DIFFERENCE LIMEN

CHAPTER I

THE PROBLEM

Introduction

The present study was designed primarily to examine the intensity discrimination of the human auditory system using pure-tone stimuli under conditions which were dichotic[1] for intensity. The resulting phenomenon may be termed the interaural intensity difference limen ($DL(\underline{i})_{int}$)[2]. This phenomenon is of a dual nature with application to two distinct areas of psychoacoustics--differential sensitivity and sound localization.

As a phenomenon of differential sensitivity, the $DL(\underline{i})_{int}$ was investigated along conventional lines as a function of frequency and level. In order to determine the relation of the $DL(\underline{i})_{int}$ to other measures of intensity discrimination, a comparison was made using equivalent techniques under monotic and diotic conditions, which yield the monaural intensity difference limen ($DL(\underline{i})_{mon}$) and the binaural

[1]Dichotic refers to situations in which two ears are simultaneously stimulated with different stimuli. Diotic refers to situations in which two ears are simultaneously stimulated with the same stimuli. Monotic refers to situations in which only one ear is stimulated.

[2]The subscripts int (interaural), bin (binaural), and mon (monaural) denote the condition used in obtaining the intensity difference limen ($DL(\underline{i})$). The $DL(\underline{i})_{int}$ is obtained when the stimulus condition is dichotic for intensity. The $DL(\underline{i})_{bin}$ is obtained when the stimulus condition is diotic for intensity. The $DL(\underline{i})_{mon}$ is obtained when the stimulus condition is monotic for intensity.

intensity difference limen ($DL(\underline{i})_{bin}$) respectively. As a phenomenon of sound localization, the $DL(\underline{i})_{int}$ was studied as a function of two additional variables--interaural phase and apparent azimuth.

An understanding of the nature of the $DL(\underline{i})_{int}$ and of the rationale for its investigation requires a discussion of both sound localization and intensity discrimination.

Sound Localization

In the past, localization phenomena have been discussed on the basis of those stimulus variables--intensity, spectrum, and time--which have been identified as contributing to localization (Steinberg and Snow, 1934). The isolation of any one of these variables for investigation depends in part upon the condition (sound-field or earphone) in which the sound is presented.

Sound-Field versus Earphone Conditions

Early experiments designed to study stimulus effects in localization and more recent investigations interested in localization behavior under "actual" conditions have been performed with the sound source placed away from the head.

Consider an observer placed in a sound-field environment with a complex acoustic stimulus presented at an azimuth of 90° from the face (Fig. 1). As the stimulus travels through the air at a rate of approximately 1100 feet per second, pressure from the initial portion of the sound wave reaches the ipsilateral ear between 0.6 and 0.7 msec before arriving at the contralateral ear some eight inches away. Since the intensity of a sound changes inversely with the square of the distance from the sound source, the overall sound pressure level will be greater at the ipsilateral than at the contralateral ear. Differences for the two ears will also occur in the spectrum since the longer wavelengths of low-frequency components move through the space around the head while the higher frequencies are partly reflected by the head surface. In this situation, the three cues of time, intensity, and spectrum exist dichotically to give the observer a localization which is perceived as being external to the head.

If the sound source is moved to a point in front of the observer so that it is equidistant from the two ears (Fig. 2) the situation is now diotic for all three cues, and the sound is perceived as being external to the head and located somewhere along the median plane of the head.

If two sound sources are placed equidistant from the ears (Fig. 3) and if the emitted signals are of identical wave form, the observer will hear a "phantom" sound somewhere in the median plane, but external to the head (Matsumoto, 1897).

If two sound sources are placed as close as 4 cm from the ears or against the head as with earphones, the perceived sound is no longer externalized, but is heard as a "sound image" somewhere along the median plane inside the head (Pierce, 1901).

Externalization of the image in the sound field has been attributed by Wallach (1940) to small changes in the relations of the stimulus variables at the two ears produced by slight head movements. The fact that the use of earphones produces an intra-cranial image has not been found to affect the subjects' ability to perceive a relative location of the sound (Jeffress and Taylor, 1960).

Fig. 1 - Sound-field presentation of an acoustic stimulus which is dichotic for time, intensity, and spectrum

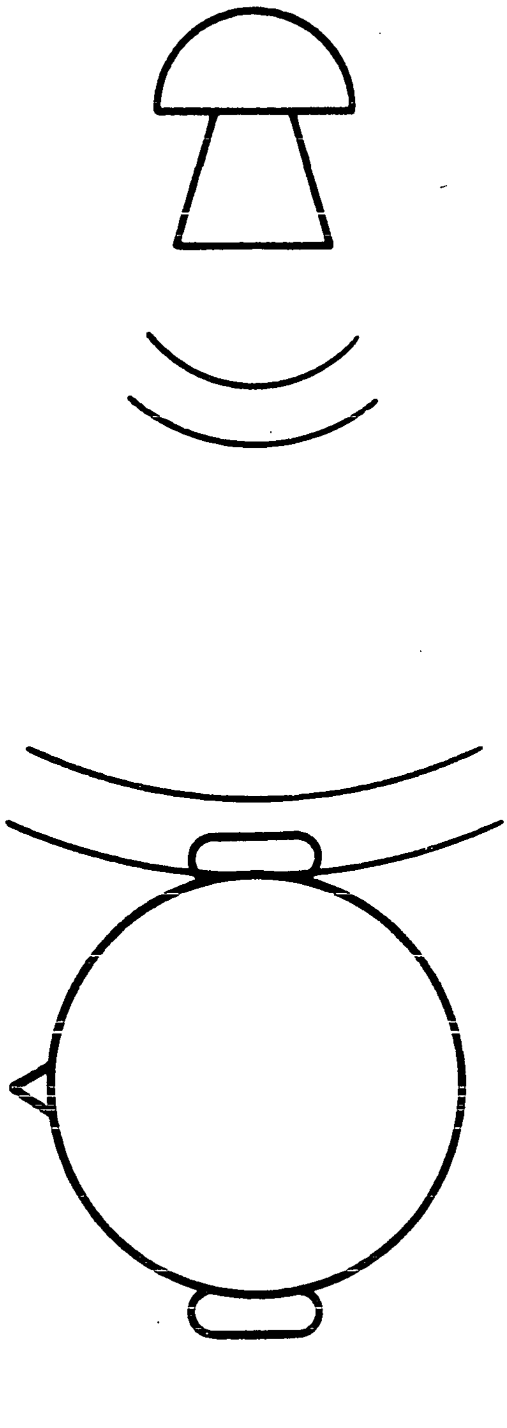


Fig. 2 - Sound-field presentation from a single source of an acoustic stimulus which is diotic for time, intensity, and spectrum

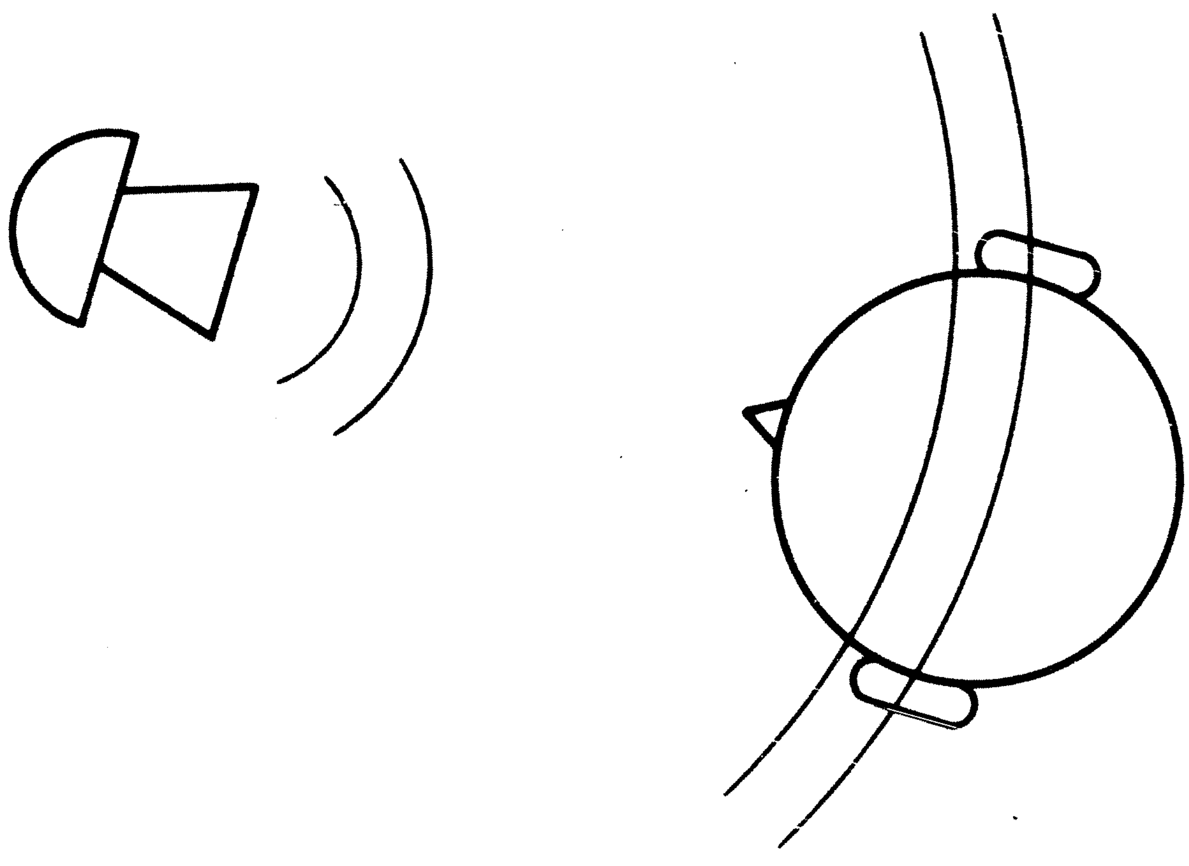
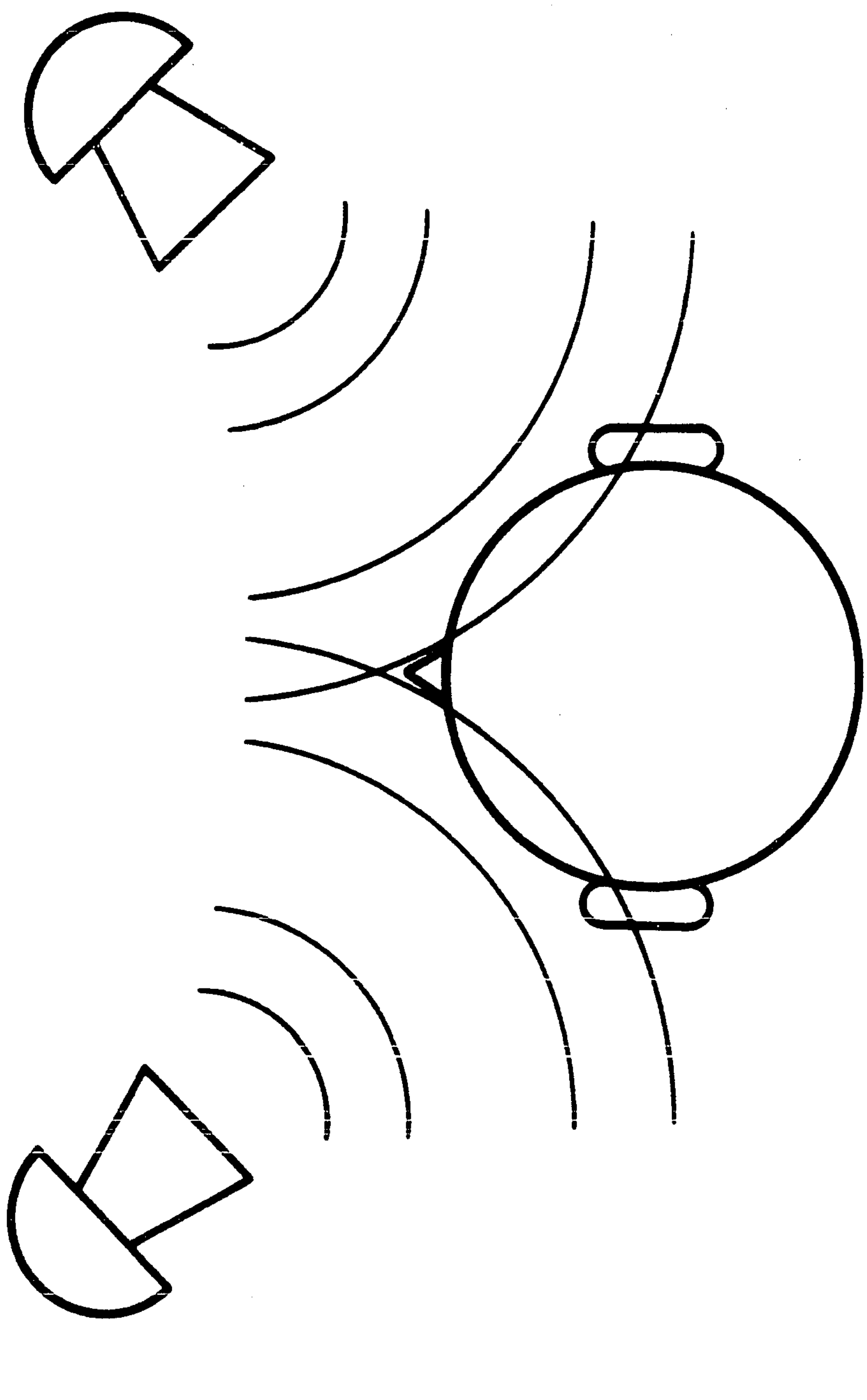


Fig. 3 - Sound-field presentation of an acoustic stimulus from two sources. The signal at the ears is diotic for time, intensity, and spectrum



Early experimenters who conducted studies under sound-field conditions assumed that intensity was the primary cue for localization (Pierce, 1901; Boring, 1942). Lord Rayleigh (1877) observed that the localization of high-frequency pure tones is enhanced by the relatively large intensity difference created between the ears. He also observed that the ability to localize low-frequency pure tones was good even though the intensity differences were quite small. Although Thompson (1878) suggested the importance of interaural phase for localization of both pure tones and complex signals, for the next quarter of a century, experimenters continued to interpret the ability of observers to detect angular differences between sounds in the sound-field as being representative of dichotic intensity differences.

Due to the dichotic nature of the stimulus in sound-field conditions, examination of the effect of any one dimension of the stimulus is best done using earphones.

Temporal Cues

So far, differences in time have been discussed as though localization effects occur only when a temporal disparity exists in the signal as it arrives at the two ears. However, for low-frequency pure tones and for wide-band noise signals, a difference in the phase relation between the two ears (interaural phase) may be perceived as a difference in location of the sound although the signal is present at the two ears simultaneously.

If a 500 Hz (cycles per second) pure-tone signal which is dichotic for interaural phase is presented, the subject will perceive the tone as moving toward the side which leads in phase (Stewart, 1920). When the phase relation reaches 180°, the subject will hear the signal as being present at both ears (Halverson, 1922). Although there has been some disagreement concerning the upper limit of phase and/or time effects of pure tones (Wever, 1942; Licklider, et al., 1950), concurrence of data from several investigators using different techniques indicates that only pure tones below 1500 Hz may be localized on the basis of phase or time (Stewart, 1920; Klumpp and Eady, 1956; Zwislocki and Feldman, 1956).

The sensitivity of the binaural system may be studied as a function of dichotic temporal disparity of the signal. The smallest reported temporal disparity which can be perceived by the binaural system is 6 μsec for wide-band random noise (Tobias and Zerlin, 1957).

Spectrum Cues

The present study, which was conducted with earphones, did not involve spectrum cues, and no further discussion of them will be included.

Intensity Cues

Stenger (1907), suggesting a test to detect a simulated unilateral hearing loss, reported that if tones from two matched tuning forks were presented to a subject to be louder (nearer) for one ear than for the other ear, the subject would not perceive the softer (farther) fork, but would hear the tone only on the louder side.

The original test has since been modified to use earphones and standard audiometers. Variations of the test can be found in most text books on audiometry (Watson and Tolan, 1949; Davis and Silverman, 1960; Newby, 1964). The test methods usually proposed include presenting a tone to the admittedly good ear at a fixed level above threshold while varying the intensity of the same tone at the supposedly bad ear. As the intensity of the tone at the "bad" ear becomes greater than the intensity of the tone at the "good" ear, the subject hears the tone shifting to the "bad" ear. Using similar methods, Taylor (1949) verified the lateralization effect and the data suggest that, if the intensity of the tone is gradually changed at one ear, sophisticated subjects are able to use intensity localization cues to defeat the test.

In an open-air study designed to examine the relative effects of phase and intensity in localization, Stevens and Newman (1936) found the greatest error in ability to locate the source of a pure tone occurred at 3000 Hz. Stevens and Newman concluded that phase difference is the primary localization cue of pure tones for frequencies below 3000 Hz and that intensity is the primary cue for higher frequencies.

In a similar sound-field study, Mills (1958) found that low and high frequencies were more easily localized than the region surrounding 2000 Hz.

Intensity Discrimination

In the past, intensity discrimination of pure-tone stimuli has been studied as a function of frequency and level. Reported trends for these variables are important for establishing some of the hypotheses of this study. Previous data can be reviewed as a function of the stimulus condition--monotic, diotic, or dichotic.

A considerable lack of agreement appears to exist concerning the effects of frequency and level. However, it has been suggested (Hirsh, Palva, and Goodman, 1954) and to some extent demonstrated (Harris, 1963) that most of the differences in reported data can be attributed to the particular technique used by the experimenter. A discussion of some of the variables which have been found to affect the DL(i) will follow the discussion of conditions.

Monotic Condition

Effect of level. Despite the fact that many different methods have been used to investigate the $DL(i)_{mon}$, and that some disagreement exists concerning the degree to which overall level affects the $DL(i)_{mon}$, there is general agreement that an effect exists.

An early electroacoustic study by Knudsen (1923) using an abrupt switching method produced a $DL(i)_{mon}$ which decreased from 1.0 dB at 10 dB sensation level (SL) to 0.5 dB at 40 dB SL. Additional decrease is slight (0.3 dB at 100 dB SL).

An extensive study of the $DL(i)_{mon}$ was done by Riesz (1928). By combining two tones of slightly differing (3 Hz) frequency, thus producing objective beats, Riesz examined differential sensitivity for several frequencies from 35 Hz to 10000 Hz and at levels which range from near the auditory threshold to near the threshold of feeling. He found that the $DL(i)_{mon}$ decreases as sensation level is increased to about 60 dB SL. Above 60 dB SL the $DL(i)_{mon}$ is relatively constant.

Using a continuous amplitude modulation technique which was more abrupt than the sinusoidal method of Riesz, Lüscher and Zwislocki (1951) found a gradual decrease in the size of the $DL(i)_{mon}$ as sensation level was increased.

In a comparative study of normal and pathological subjects, Hirsh, Palva, and Goodman (1954) reported a decrease in the size of the $DL(\underline{i})_{mon}$ with an increase in sensation level from 5 to 40 dB.

Effect of frequency. Riesz's (1928) method of beats produced greater differences in the $DL(\underline{i})_{mon}$ as a function of frequency than did the earlier work of Knudsen (1923). Riesz reported that the $DL(\underline{i})_{mon}$ is largest at low frequencies, reaching a minimum at about 2500 Hz, and increases at higher frequencies. He concluded (p. 874): "Thus the region of least differential sensitivity of the ear, which means greatest ability to detect small differences in intensity, corresponds to the frequency range of greatest absolute sensitivity of the ear."

The findings of Lüscher and Zwislocki (1951) were that there is little difference in the size of the $DL(\underline{i})_{mon}$ for low and mid-range frequencies, but that the $DL(\underline{i})_{mon}$ tends to be somewhat larger for higher frequencies.

Harris (1963) found no significant differences in the $DL(\underline{i})_{mon}$ for 125, 1000, and 6000 Hz. However, only 1000 Hz was presented to all four subjects (125 Hz, N=2; 6000 Hz, N=3).

Diotic Condition

Effect of level. Churcher, King, and Davies (1934) examined intensity discrimination with telephone receivers at 800 Hz under both monotic and diotic conditions. They found the $DL(\underline{i})_{bin}$ to vary from 2.1 dB at 10 dB SL to 0.38 dB at 90 dB SL. The resulting curve for the $DL(\underline{i})_{mon}$ was somewhat parallel, and ranged from 2.47 dB at 10 dB SL to 0.75 dB at 90 dB SL.

In a study of differential sensitivity as a function of exposure time under monotic and diotic conditions, Upton and Holway (1937) found a similar trend for the $DL(\underline{i})_{bin}$ and $DL(\underline{i})_{mon}$. Their results for an 800 Hz tone show a decrease in size of the $DL(\underline{i})$ as the overall level is increased and a smaller $DL(\underline{i})_{bin}$ than $DL(\underline{i})_{mon}$ for the same tasks.

Effect of frequency. Dimmick and Olsen (1941) conducted an intensity discrimination study under sound-field conditions using one speaker directly in front of the observer. They did not find any definite frequency effect for the five frequencies (128 to 1000 Hz) examined. Their averaged $DL(\underline{i})_{bin}$ obtained is much larger (4.6 dB at 10 dB SL to 2.3 dB at 70 dB SL) than previous studies of the $DL(\underline{i})$.

Dichotic Condition

Effect of level. Upton (1936) measured the amount of intensity change required to cause the apparent sound to shift from the median plane toward the receptor receiving the greater stimulation. Using a tone of 800 Hz, Upton found that the shape of the curve from levels "somewhat above the lower threshold" to the approximate "threshold of feeling" resembled other curves for differential intensity sensitivity. The ΔI reported is largest (approximately 5.5 dB) at the lowest level, diminishes to approximately 0.8 dB between 70 and 100 dB SL and then increases to approximately 1.9 dB at the highest level.

Effect of frequency. Ford (1942) raised two major objections to previous studies of what he termed the "binaural intensity disparity limen." He pointed out that Upton (1936) did not furnish proof of control of time or phase differences and that Stewart's (1917) inconclusive results for intensity differences could be the result of using a static technique. Using an apparatus which produced a dynamic imbalance in intensity between phones as the subject rotated his head in a horizontal plane, Ford found a difference in response for 200 and 2000 Hz at 50 dB SL. Ford's results are reported as average-error-in-degrees-of-head-rotation and are difficult to translate into decibels-required-to-notice-that-a-shift-has-occurred. An important finding was an apparent improvement in ability to localize the 2000 Hz tone compared to the 200 Hz tone. However, of seven subjects used, only two received both treatments.

In a study of the "just noticeable dichotic difference in intensity," Mills (1960) tested eleven frequencies from 250 Hz to 10000 Hz at 50 dB SL. He found the $DL(\underline{i})_{int}$ largest (about 1 dB) at 1000 Hz, slightly smaller at lower frequencies (about 0.75 dB at 250 Hz), and still smaller (about 0.5 dB) at higher frequencies.

Effect of phase. Although it is known that varying conditions of dichotic phase create differences in the perceived location of the sound, it is not known whether the $DL(\underline{i})_{int}$ is affected by these differences. Previous data on this subject do not exist.

Apparent azimuth. In 1935, Gage reported on the effect upon the $DL(\underline{i})_{mon}$ of simultaneously introducing a tone of the same frequency at different levels to the opposite ear. Such a condition satisfies our definition of an apparent-azimuth study of the $DL(\underline{i})_{int}$. Gage reports essentially the same results for the three frequencies (300, 500, and 800 Hz) and for the three levels (25, 30, and 40 dB SL) used. He found that, as the constant stimulus in the ear opposite the varying stimulus was reduced, there was a very slight decrease in size of the $DL(\underline{i})_{int}$. When the constant stimulus was increased relative to the varying stimulus, the $DL(\underline{i})_{int}$ increased rapidly to a point about 15-20 dB difference where it declined slightly and then increased again at higher levels. It is interesting to note that, as the constant stimulus was increased, the perception of the fluctuating tone shifted to the side of greater intensity.

A similar study was reported by Chocholle (1957) in which the $DL(\underline{i})_{mon}$ was tested in the presence of a contralateral tone of the same frequency. Using 1000 Hz as the test frequency, Chocholle found that, as the constant signal was increased in one ear relative to the varying signal of the opposite ear, the size of the resulting $DL(\underline{i})_{int}$ increased. Chocholle's data do not show a tendency for the $DL(\underline{i})_{int}$ to become smaller after the difference between ears reaches 15-20 dB as was reported by Gage (1935). Chocholle suggests that the $DL(\underline{i})_{int}$ increases gradually until the difference between ears reaches 60-80 dB whereupon the size of the $DL(\underline{i})_{int}$ becomes stabilized.

Influence of Technique

It is obvious from the preceding discussion that many differences in results for DL(i) can be attributed to the unique methods used by the various investigators.

Montgomery (1935) investigated the influence of experimental technique on the measurement of the DL(i). Among the factors he found to affect the size of the DL(i) were: (1) the interval of silence between tones (which decreases the sensitivity of the ear to the intensity change), (2) the number of presentations to subjects (which increases sensitivity), and (3) the control of presentation by subjects (which increases sensitivity).

Pollack (1954) studied the DL(i)$_{mon}$ at 400 Hz under five experimental procedures in which the primary variables were presence or absence of an objective comparison signal and the stability of the reference signal. He concluded (p. 1059):

> In short, the detection threshold is a function of the availability of an objective reference standard and of the stability of the reference signal. Over the range of conditions examined, the latter factor is the more important.

Using Montgomery's (1935) "optimum" method, Harris (1963) examined the DL(i) at three frequencies and six sensation levels. He stated (p. 8):

> We conclude at this point that our data confirm and considerably extend previous data to the effect that under optimal conditions the human ear can yield a relatively very small $DL_{75\%}$ of the order of 0.5 db and less over the major portion of the auditory area and is thus almost completely independent of frequency and loudness.

Rationale for the Present Study

The previous discussions of sound localization and intensity discrimination illustrate that the DL(i)$_{int}$ has been studied variously but incompletely. It has been studied as a function of level at one frequency (Upton, 1936). It has been studied as a function of frequency at one level (Mills, 1960). It has been studied as a function of apparent azimuth at low and mid-range frequencies (Gage, 1935; Chocholle, 1957). These studies show an obvious need for an investigation to complete the information concerning the DL(i)$_{int}$ as a function of level, frequency, and apparent azimuth.

The diversity of results and methods found in previous DL($\underline{i}$) studies suggests a need for an empirical comparison of the DL($\underline{i}$)$_{mon}$, DL($\underline{i}$)$_{bin}$, and DL($\underline{i}$)$_{int}$ using an equivalent method.

Although it is known that, for some frequencies, an interaural phase relation of 180^{o} between the ears results in a difference in the perceived image, no previous study has determined whether this difference in perception affects intensity discrimination under dichotic or diotic conditions.

Predicted Results

Effect of Level

Previous studies of the DL($\underline{i}$)$_{mon}$ under "optimum" conditions suggest a relative stability in the size of the DL($\underline{i}$) at levels well above threshold, but at levels slightly above threshold the DL($\underline{i}$) should be much larger. So it was expected that the DL($\underline{i}$)$_{int}$ would be largest near threshold and would decrease and stabilize at higher levels.

Effect of Frequency

Sound-field localization studies have demonstrated that: (1) phase cues dominate the low-frequency range, (2) localization ability is poor in the middle range, and (3) actual intensity differences are large in the high-frequency range. None of these findings suggest a strong basis for assuming any large variation in intensity discrimination throughout the range. However, the report by Ford (1942) of better localization ability at 2000 Hz than at 200 Hz suggests that the effect of frequency on the DL($\underline{i}$)$_{int}$ might resemble the effects reported by Riesz (1928) for the DL($\underline{i}$)$_{mon}$. It was predicted that the DL($\underline{i}$)$_{int}$

would be smaller in the mid-range than at lower or higher frequencies.

Effect of Phase

Since time information for pure tones has been found to be restricted to frequencies below 1500 Hz, it was predicted that no phase effect would be demonstrated above that frequency.

It was assumed that the condition of dichotic intensity in the present study measured a minimum shift in localization from a centered sound image, and since opposing phase conditions diffuse the sound image at low frequencies, it was expected that the condition of opposing phase would tend to increase the size of the $DL(\underline{i})_{int}$ at the low frequency when the stimulus condition is dichotic for phase and intensity.

Apparent Azimuth

Both Gage (1935) and Chocholle (1957) found an increase in the size of the $DL(\underline{i})_{int}$ as the constant signal was increased relative to the varying signal. Gage also reported a very slight decrease in the $DL(\underline{i})_{int}$ as the constant signal was reduced relative to the varying signal. Data from the present study were expected to show similar trends.

Comparison of the $DL(\underline{i})_{int}$ with the $DL(\underline{i})_{bin}$ and the $DL(\underline{i})_{mon}$

There are at least two possible conclusions concerning the relation of the $DL(\underline{i})_{int}$ to the $DL(\underline{i})_{bin}$ and to the $DL(\underline{i})_{mon}$: (1) The $DL(\underline{i})_{int}$ is an independent phenomenon related to binaural localization and the $DL(\underline{i})$ or (2) the $DL(\underline{i})_{int}$ is a dependent phenomenon resulting from the measurement of the $DL(i)_{mon}$ in the presence of a tone of equal frequency in the contralateral ear. The selection of the conclusion as to whether the $DL(\underline{i})_{int}$ is an independent phenomenon must be dependent upon the number and degree of differences in the data.

CHAPTER II

METHOD

Instrumentation

Figure 4 presents a simplified block diagram of the apparatus used in the experiment. Three intensity conditions of stimulation--dichotic, diotic, and monotic--were provided by the circuit shown in Fig. 4.

Dichotic Intensity Condition

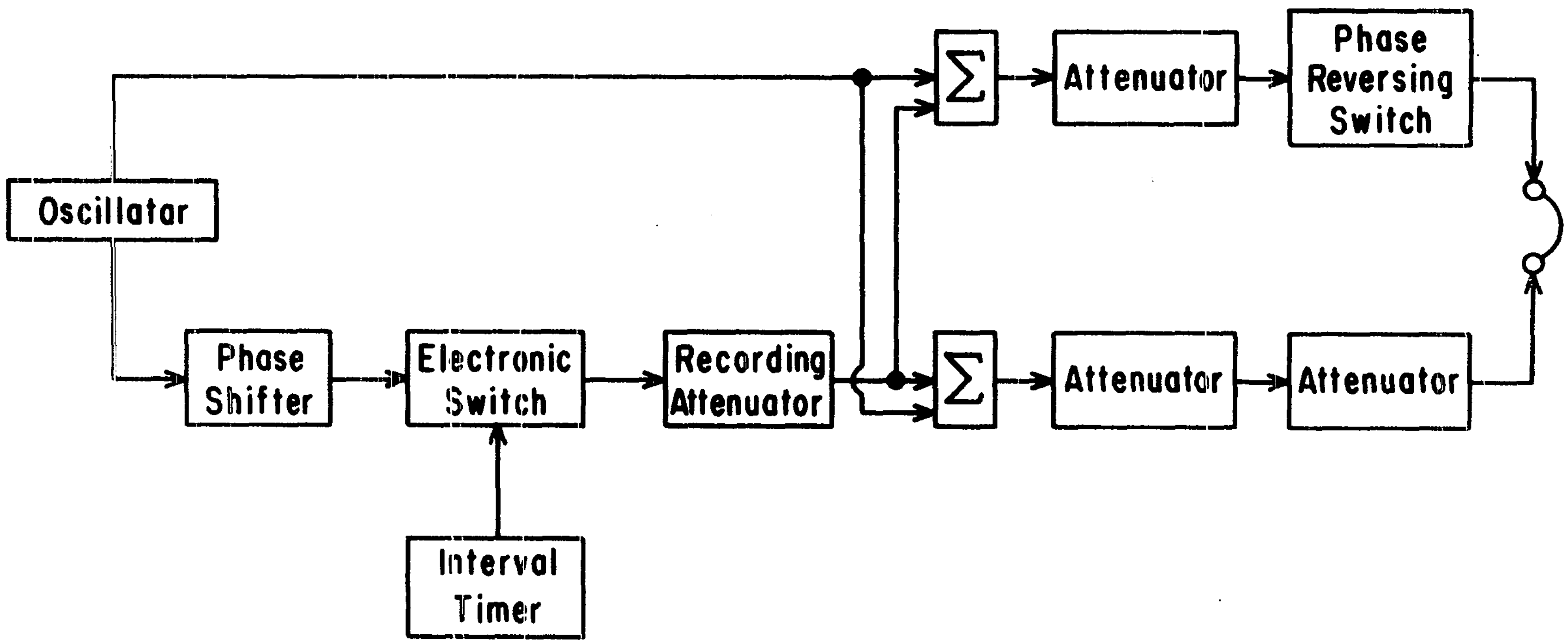
Each of the three test frequencies of 250, 2000, and 6000 Hz was produced by a Hewlett-Packard 201 CR audio oscillator. The tone from the oscillator was split into two channels: one channel to become the constant signal and one channel to become the varying signal.

The constant signal. The constant signal was split again and fed through two mixers. One part of this split signal was combined with the signal in the opposite channel and one part remained as the constant signal.

The constant signal went next to a Hewlett-Packard 350-D attenuator set, then to a phase-reversing switch.

From the phase-reversing switch, the constant signal was fed to one of a matched pair of Telephonics TDH-39 earphones with NAF 48490-1 cushions.

Fig. 4 - Simplified block diagram of apparatus used in present study


Oscillator
Phase Shifter
Electronic Switch
Recording Attenuator
Interval Timer
Σ
Σ
Attenuator
Attenuator
Phase Reversing Switch
Attenuator

The varying signal. In the channel carrying the varying signal, the tone was first fed to a Grason-Stadler E3520B phase shifter. The phase shifter was used to compensate for unwanted shifts in relative phase between the constant and varying signals resulting from differences in the two channels.

The tone proceeded to a Grason-Stadler electronic switch, model E3382B, which was activated by a Grason-Stadler 471-1 interval timer. The electronic switch was set for a rise-decay time of approximately 50 msec, and the interval timer was set to gate the signal in a 0.5 sec on, 0.5 sec off cycle.

The gated signal was fed to a Grason-Stadler recording attenuator, E4554A, set for a rate-of-change of 1 dB/per sec. The recording attenuator was controlled by a Rauland SW-141 switch and a Grason-Stadler E362D control box.

From the recording attenuator, the gated signal was fed to a mixer where it was combined with the constant tone split from the opposite channel to form the varying signal. For a period of 0.5 sec, the varying signal from the mixer was equal to the constant signal in the opposite channel in frequency, phase, and intensity; for 0.5 sec, the two signals differed in intensity.

The varying signal proceeded to a Hewlett-Packard 350-D attenuator set. This attenuator set and the 350-D attenuator set in the constant-signal channel were used to control the signal levels. Differences between the two attenuators were found to be 0.1 dB or less.

A Daven T-326-F attenuator with a 2.0 dB range in 0.1 dB steps was placed between the 350-D attenuator set and the remaining TDH-39 earphone to correct for differences in the output between the phones for the test frequencies. These differences were: 250 Hz, 1.5 dB; 2000 Hz, 0.5 dB; 6000 Hz, 2.0 dB.

The earphones were also matched for phase. A tone from the oscillator was split and fed to each phone. The phase shifter was placed between the oscillator and one phone. The phones were placed at each end of a specially constructed, T-shaped coupler with a Brüel and Kjaer condenser microphone, model 4131, inserted in the foot. A Brüel and Kjaer frequency analyzer, model 2105, was connected to the microphone. The phase shifter was adjusted until a minimum reading was obtained on the voltmeter of the frequency analyzer. This value on the phase shifter was noted. The phones were then commutated and the process was repeated. The degrees of shift from the setting on the phase shifter required to reproduce a minimum reading on the voltmeter showed the extent to which the system was out of phase. The phase difference for the phones was found to be less than 2^{o} for any of the test frequencies.

A Ballantine Laboratories, Inc., model 320A voltmeter was used to calibrate and balance intensity. Phase balance for the two channels was obtained by using the phase shifter in conjunction with a differential amplifier plug-in on a Tektronix 535A oscilloscope.

Subjects were tested in a sound-treated room.

Diotic Intensity Condition

To present the varying signal to both earphones, the gated signal coming from the recording attenuator and the constant signal from the opposite channel were fed to both mixers.

Monotic Intensity Condition

Presentation of the varying signal to one earphone and no signal to the other earphone was accomplished by disconnecting the signals from one mixer.

Stimulus

Range of Intensity

Previously cited studies of dichotic intensity used sensation levels to specify the intensities at which discriminations were performed (Chocholle, 1955; Mills, 1960; Upton, 1936). However, the fact that more parameters were included in the present study indicated the desirability of using a fixed physical reference--hearing level (HL) was chosen.

There are two recognized reference standards for pure-tone thresholds: the American standard (American Standards Association [ASA]) and the international standard (International Standards Organization [ISO]). The data for determining the American Standard for audiometric zero were obtained from a cross-section of the population in the U.S. Public Health Service population survey of 1935-36 (Davis and Usher, 1957). The data for the International Standard audiometric zero were obtained from young, otologically normal ears under controlled acoustical conditions (Davis, 1959). Since the population from which subjects were selected and the conditions of testing were similar to ISO, it was selected as the reference standard.

Pilot studies indicated that the collection of reliable data at levels below 20 dB HL was difficult. The stimulus was often at or very near threshold, and subjects tended to confuse the experimental stimulus with physiological noises (heartbeat, tinnitus, breathing, etc.). The possibility of cross stimulation around the head at higher levels suggested 50 dB HL as the upper limit of stimulation.

Three levels, 20, 35, and 50 dB HL, comprise the baseline levels of the experiment. Apparent azimuth and ΔI are calculated from these baseline levels.

Range of Frequency

Three frequencies were selected to represent the auditory range: 250, 2000, and 6000 Hz. The frequency of 250 Hz was selected because it requires less intenstiy for threshold than 125 Hz and is less effected by masking from low-frequency ambient noise than is 125 Hz. The selection of 2000 Hz as representative of the mid-range makes possible a comparison of data obtained under earphone conditions with the sound-field phenomena observed by Stevens and Newman (1936) and by Mills (1958)--namely the difficulty in localizing pure tones in the 1500-3000 Hz range. As frequency increases past about 2000 Hz, the probability increases that standing waves will be created within the ear canal. Therefore, 6000 Hz was selected as being far enough removed from 2000 Hz to provide information concerning the high-frequency range of hearing but low enough to reduce the probability of a severe standing wave problem.

Apparent Azimuth

Using the three baseline levels (20, 35, and 50 dB HL) as pivots, a portion of the study was designed to examine the $DL(\underline{i})_{int}$ when the reference portion of the duty cycle appeared to be left or right rather than centered, and in situations where the varying signal was either more or less intense than the constant signal. The constant signal was presented at 20, 25, 30, 35, 40, 45, and 50 dB HL. With the varying signal to one ear at a baseline of 20 dB HL, the range of the constant signal presented to the contralateral ear provided difference levels between the two signals from 0 dB to +30 dB. With the varying signal at a baseline of 35 dB HL, the difference levels ranged from -15 to +15 dB, and with the varying signal at a baseline of 50 dB HL, the range of difference levels was from -30 dB to 0 dB.

Phase

All tasks in the dichotic and diotic intensity conditions were presented at both 0° and 180° interaural phase.

Subjects

Five young adult men between the ages of 18 and 27 were selected for the experiment. Criteria for selection were no history of ear pathology and an air-conduction threshold of 15 dB HL (ISO) or better through the range of 250-8000 Hz.

Subjects were paid for their participation in the experiment.

Procedure

Subjects were instructed to listen for rhythmical changes in a steady tone which would be presented at low, medium, and high pitch and at several different loudness levels. They were told that the rhythmical changes might sound like fluctuations in loudness or changes in the position of the sound. They were instructed to indicate when they heard the fluctuations by pressing the subject switch and to release the switch when the signal returned to a steady tone. Each subject received an initial practice period of at least two hours and was given a 15 minute practice period before each session.

Air-conduction thresholds were obtained before each session. In the event that the 15 dB HL criterion was exceeded, the subject was rescheduled.

Ninety-six randomly presented tasks for one frequency constituted one set. The monotic tasks were presented to left and right ears. The dichotic tasks were presented with the varying signal in the left ear and the constant signal in the right and also with the varying signal in the right ear and the constant signal in the left (Appendix A). Each set was presented on two occasions for each frequency for a total of 576 tasks per subject. Time required to complete one set was approximately five hours. Subjects were scheduled for one set per visit.

Response

The recording attenuator has a continuous graph on which the subject responses were traced. The experimenter observed the tracing and allowed the subject to continue with the task until the tracing was stable for four maximum and four minimum excursions. This procedure provided approximately 4600 data points per subject. Stimulation was not continued for more than three minutes per task.

The arithmetic mean of the four maximum and four minimum scores provided the average dB difference between the gated and steady tones which made up the varying signal. This number was converted to ΔI in dB by referring to a table of intensity increments resulting from mixture of two tones of the same phase but with differing intensity levels (Appendix B).

CHAPTER III

RESULTS AND DISCUSSION

The Data

Three *t* tests were performed upon the paired data (left ear --right ear) for monotic and dichotic conditions and upon the two complete samples of data for all subjects. No significant differences were found.

Scores presented in the tables and data points of the graphs are averaged for ears, subjects, and replications. Curves were fitted primarily by the method of moving averages with some fitting by eye.

Four analyses of variance were run.

Comparison of the Intensity Difference Limens

Table I presents the mean DL(*i*) values for the three experimental conditions (dichotic, monotic, and diotic) at the three frequencies (250 Hz, 2000 Hz, and 6000 Hz), and at the three baseline levels (20, 35, and 50 dB HL). Figure 5 provides a graphic representation of the data, and Table II presents a summary of the data analysis.

Effect of condition. The values obtained under dichotic conditions are larger than those of the monotic condition except for 6000 Hz at 35 dB HL. The diotic condition consistently showed the smallest DL(*i*). Differences in obtained values by condition were significant ($p<.01$).

TABLE I. - Mean DL(i) values (in dB) for three stimulus conditions at three levels and at three frequencies

Frequency (Hz)	Hearing Level (dB)	Condition		
		Dichotic	Monotic	Diotic
	20	2.70	1.80	1.51
250	35	1.44	1.28	0.93
	50	1.15	0.88	0.60
	20	1.33	1.08	0.95
2000	35	1.17	1.06	0.75
	50	0.72	0.65	0.53
	20	1.95	1.88	1.14
6000	35	1.25	1.32	0.90
	50	0.92	0.93	0.60

Effect of level. The largest scores for all conditions were consistently obtained at the lowest level (20 dB HL) and were smallest at the highest level (50 dB HL) (Fig. 5). The tendency of the DL(i) to decrease with an increase in level was significant ($p<.01$).

Effect of frequency. The values in Table I and the curves in Fig. 5 show a tendency for the DL(i) to be smaller at the middle frequency (2000 Hz) and larger at the low and high frequency (250 and 6000 Hz). The general analysis did not indicate an acceptable level of significance for this trend ($p<.10$); however, the interaction effect of Condition X Frequency did ($p<.05$). Therefore an analysis of the simple main effects for frequency within conditions was calculated (Winer, 1962). This procedure produced the following significance levels by condition (Table II): dichotic ($p<.01$), monotic ($p<.01$), and diotic ($p<.05$).

Fig. 5 - Comparison of the monaural, binaural, and interaural DL($\underline{i}$) as a function of hearing level and frequency

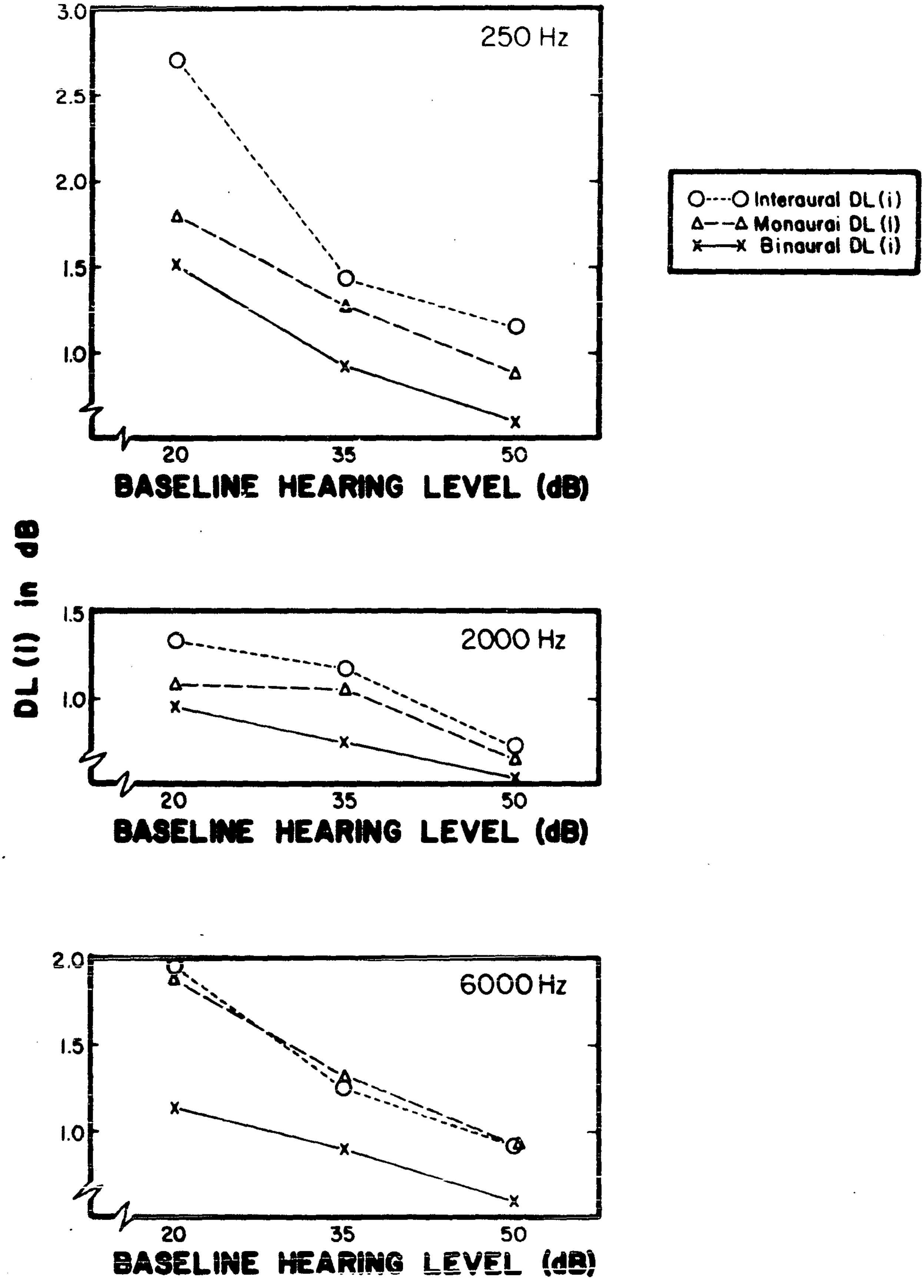

250 Hz
2000 Hz
6000 Hz
3.0
2.5
2.0
1.5
1.0
20
35
50
BASELINE HEARING LEVEL (dB)
DL (I) in dB
O----O Interaural DL (i)
Δ--Δ Monaural DL (I)
X——X Binaural DL (i)

TABLE II. - Analysis of variance of mean DL(i) values obtained for dichotic, monotic, and diotic conditions at three frequencies (250, 2000, and 6000 Hz) and at three levels (20, 35, and 50 dB HL)

Source	df	MS	F	p
Conditions	2	3.27	54.50	<.01
Frequencies	2	2.24	3.56	<.10
Levels	2	7.22	24.51	<.01
Subjects	4	2.89		
C X F	4	0.31	3.00	<.05
C X L	4	0.27	5.40	<.01
C X S	8	0.06		
F X L	4	0.53	4.42	<.05
F X S	8	0.63		
L X S	8	0.15		
C X F X L	8	0.08	4.00	<.01
C X F X S	16	0.10		
C X L X S	16	0.05		
F X L X S	16	0.12		
Error	32	0.02		
Total	134			
Simple Effects				
Frequency for Dichotic Condition	1	3.78	47.25	<.01
Frequency for Monotic Condition	1	1.44	18.00	<.01
Frequency for Diotic Condition	1	0.51	6.38	<.05

Apparent Azimuth

Baseline of 20 dB HL. Table III presents the mean scores in dB obtained at seven difference levels from the 20 dB baseline for the three frequencies (250, 2000, and 6000 Hz) under dichotic intensity conditions. The division of scores by interaural phase (0^{o} and 180^{o}) will be discussed in another section. At present, only the scores obtained for 0^{o} interaural phase will be considered. Graphic representation of the results for all three baseline levels is found in Fig. 6. An analysis of variance summary for the 20 dB baseline is presented in Table IV.

As the intensity of the constant signal is increased relative to the variable signal, the size of the $DL(\underline{i})_{int}$ increases. The function becomes asymptotic for 250 Hz when the difference reaches 15 dB[1]. The effect is least at 6000 Hz. The differences for the effect of Difference Level (apparent azimuth) are significant ($p<.01$).

Baseline of 35 dB HL. The results for the 35 dB baseline portion of the study are presented in Table V and the summary of the analysis of variance is presented in Table VI. The second graph of Fig. 6 shows that, as the constant signal is increased from -15 dB to +15 dB relative to the varying signal, the size of the $DL(\underline{i})_{int}$ increases most at 250 Hz and least at 6000 Hz. Of all the variables only the overall effect of Difference Level was found to be significant ($p<.01$).

---

[1]The method of moving averages produces a rather smooth curve for the line representing 250 Hz. However, a closer inspection of the locations of the averaged data points shows that a peak is reached when the difference is 15 dB and a slight decline occurs thereafter. This "ripple" in the data, although less exaggerated, is like the ones reported by Gage (1935). The ripple did not appear at higher frequencies.

TABLE III. - Mean $DL(\underline{i})_{int}$ values (in dB) for decibel differences between the constant and variable (20 dB baseline) intensities for three frequencies (250, 2000, and 6000 Hz) and for two interaural phase conditions (0^{o} and 180^{o})

Decibel Difference	Phase	Frequency		
		250 Hz	2000 Hz	6000 Hz
0	0	2.70	1.33	1.95
	180	2.10	1.54	2.28
+5	0	3.23	1.64	1.93
	180	2.92	1.79	2.11
+10	0	3.73	1.85	2.07
	180	2.74	1.66	1.94
+15	0	4.23	1.86	2.25
	180	3.69	2.11	2.10
+20	0	4.15	2.08	2.38
	180	3.59	2.18	2.04
+25	0	3.95	1.96	2.31
	180	4.15	1.99	2.56
+30	0	4.07	2.23	2.73
	180	4.06	2.03	2.44

Fig. 6 - The interaural DL(i) as a function of phase, frequency, and apparent azimuth

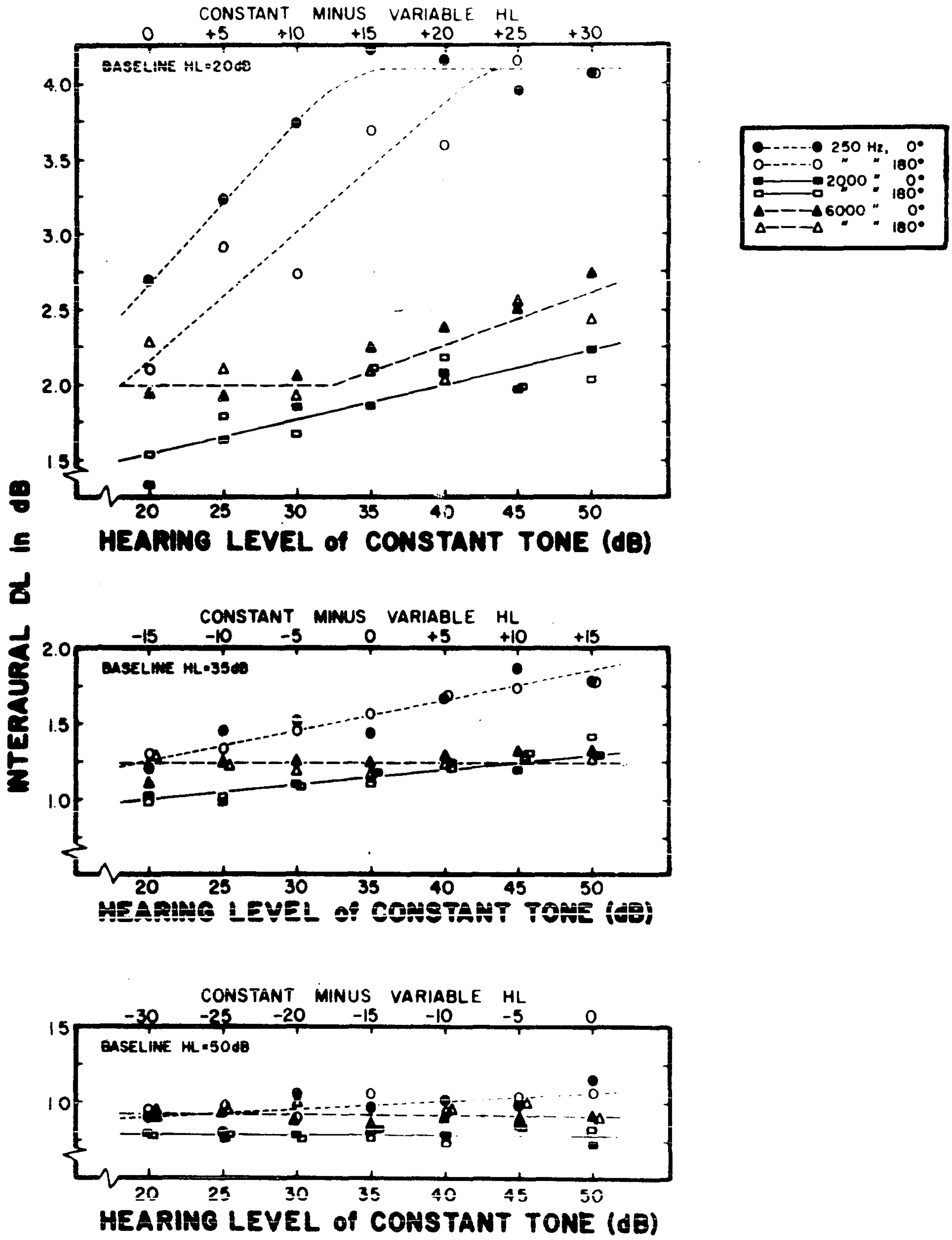

CONSTANT MINUS VARIABLE HL
0 +5 +10 +15 +20 +25 +30
BASELINE HL=20dB
4.0 3.5 3.0 2.5 2.0 1.5
20 25 30 35 40 45 50
HEARING LEVEL of CONSTANT TONE (dB)
INTERAURAL DL in dB
250 Hz, 0°
" " 180°
2000 " 0°
" " 180°
6000 " 0°
" " 180°
CONSTANT MINUS VARIABLE HL
-15 -10 -5 0 +5 +10 +15
BASELINE HL=35dB
2.0 1.5 1.0
20 25 30 35 40 45 50
HEARING LEVEL of CONSTANT TONE (dB)
CONSTANT MINUS VARIABLE HL
-30 -25 -20 -15 -10 -5 0
BASELINE HL=50dB
1.5 1.0
20 25 30 35 40 45 50
HEARING LEVEL of CONSTANT TONE (dB)

TABLE IV. - Analysis of variance of mean $DL(i)_{int}$ values obtained for decibel differences between the constant and variable (20 dB baseline) intensities for three frequencies (250, 2000, and 6000 Hz) and for two interaural phase conditions (0^{o} and 180^{o})

Source	df	MS	F	p
Difference Level	6	3.34	6.82	<.01
Frequency	2	51.84	8.80	<.05
Phase	1	0.65	4.64	<.10
Subject	4	16.72		
D X F	12	0.99	8.25	<.01
D X P	6	0.30	1.58	N.S.
D X S	24	0.49		
F X P	2	1.08	4.32	<.05
F X S	8	5.89		
P X S	4	0.14		
D X F X P	12	0.27	3.38	<.01
D X F X S	48	0.12		
D X P X S	24	0.19		
F X P X S	8	0.25		
Error	48	0.08		
Total	209			
Simple Effects				
Phase for 250 Hz	1	2.81	35.12	<.01
Phase for 2000 Hz	1	0.04	0.5	N.S.
Phase for 6000 Hz	1	0.0		

TABLE V. - Mean $DL(\underline{i})_{int}$ values (in dB) for decibel differences between the constant and variable (35 dB baseline) intensities for three frequencies (250, 2000, and 6000 Hz) and for two interaural phase conditions (0° and 180°)

Decibel Difference	Phase	Frequency		
		250	2000	6000
-15	0°	1.25	1.02	1.11
	180°	1.30	0.98	1.29
-10	0°	1.45	0.99	1.25
	180°	1.33	1.01	1.22
- 5	0°	1.51	1.10	1.26
	180°	1.45	1.08	1.18
0	0°	1.44	1.17	1.25
	180°	1.56	1.10	1.17
+ 5	0°	1.66	1.24	1.28
	180°	1.69	1.20	1.23
+10	0°	1.86	1.19	1.32
	180°	1.73	1.30	1.27
+15	0°	1.78	1.29	1.32
	180°	1.78	1.41	1.26

TABLE VI. - Analysis of variance of mean $DL(\underline{i})_{int}$ values obtained for decibel differences between the constant and variable (35 dB baseline) intensities for three frequencies (250, 2000, and 6000 Hz) and for two interaural phase conditions (0^{o} and 180^{o})

Source	df	MS	F	p
Difference Level	6	0.43	21.50	<.01
Frequency	2	3.19	1.30	NS
Phase	1	0.00		
Subjects	4	7.92		
D X F	12	0.08	1.00	NS
D X P	6	0.01	0.20	NS
D X S	24	0.02		
F X P	2	0.01	1.00	NS
F X S	8	2.46		
P X S	4	0.02		
D X F X P	12	0.02	2.00	<.05
D X F X S	48	0.08		
D X P X S	24	0.05		
F X P X S	8	0.01		
Error	48	0.01		
Total	209			

Baseline of 50 dB HL. The results for the 50 dB baseline portion of the study are presented in Table VII and a summary of the analysis of variance is found in Table VIII.

The data in Table VII and the third graph for the 50 dB baseline of Fig. 6 show a very slight decrease in size of the $DL(\underline{i})_{int}$ as the constant signal is reduced relative to the varying signal. This decrease was not found to be significant. No significant effects were demonstrated for the other variables.

TABLE VII. - Mean $DL(\underline{i})_{int}$ values (in dB) for decibel differences between the constant and variable (50 dB baseline) intensities for three frequencies (250, 2000, and 6000 Hz) and for two interaural phase conditions (0^{o} and 180^{o})

Decibel Difference	Phase	Frequency		
		250	2000	6000
-30	0^{o}	0.90	0.79	0.91
	180^{o}	0.95	0.78	0.94
-25	0^{o}	0.80	0.76	0.94
	180^{o}	0.98	0.79	0.94
-20	0^{o}	1.06	0.78	0.89
	180^{o}	0.90	0.78	1.00
-15	0^{o}	0.97	0.82	0.82
	180^{o}	1.07	0.77	0.86
-10	0^{o}	1.01	0.78	0.91
	180^{o}	0.94	0.73	0.96
- 5	0^{o}	0.98	0.85	0.91
	180^{o}	1.04	0.84	1.00
0	0^{o}	1.15	0.72	0.92
	180^{o}	1.06	0.83	0.90

TABLE VIII. - Analysis of variance of mean DL(i)$_{int}$ values obtained for decibel differences between the constant and variable (50 dB baseline) intensities for three frequencies (250, 2000, and 6000 Hz) and for two interaural phase conditions (0^{o} and 180^{o})

Source	df	MS	F	p
Difference Level	6	0.01	1.00	N.S.
Frequency	2	0.85	2.36	N.S.
Phase	1	0.01	1.00	N.S.
Subjects	4	4.72		
D X F	12	0.02	1.00	N.S.
D X P	6	0.01	1.00	N.S.
D X S	24	0.01		
F X P	2	0.01	1.00	N.S.
F X S	8	0.36		
P X S	4	0.01		
D X F X P	12	0.01	1.00	N.S.
D X F X S	48	0.02		
D X P X S	24	0.01		
F X P X S	8	0.02		
Error	48	0.01		
Total	209			

Effect of Phase

Significant phase effects ($p<.05$) were obtained for only one group of tasks--the 20 dB baseline data for apparent azimuth. Predictably, and as the analysis of simple effects of phase for each frequency (Table IV) and the curves in the first graph of Fig. 4 show, phase effect was limited to 250 Hz ($p<.01$). The $DL(\underline{i})_{int}$ obtained under a condition of 180° interaural phase relation is smaller than the $DL(\underline{i})_{int}$ obtained under a 0° interaural phase condition when the constant signal and varying signal are presented at the same level. However, as the constant signal is increased relative to the varying signal the $DL(\underline{i})_{int}$ for 180° phase relation increases in size until it is equal to the $DL(\underline{i})_{int}$ for 0° interaural phase relation when the constant and varying signals are 30 dB apart.

Discussion

An important conclusion is that the intensity discrimination phenomenon obtained under a dichotic condition differs sufficiently from similar phenomena under monotic and diotic conditions to warrant its differentiation as the interaural intensity difference limen. Had the $DL(\underline{i})_{int}$ appeared only as consistently larger than the $DL(\underline{i})_{mon}$ and the $DL(\underline{i})_{bin}$, the earlier descriptions of Gage (1935) and Chocholle (1957) of a $DL(\underline{i})_{mon}$ in the presence of a contralateral sound of equal frequency would have seemed more logical. However, the larger separation of the $DL(\underline{i})_{int}$ from the $DL(\underline{i})_{mon}$ at 250 Hz and its eventual equivalence at 6000 Hz suggests an independent nature.

The differential response to frequency is what might be expected of a system which need not depend upon intensity differences alone for localization cues at lower frequencies.

Although the previous reports of Churcher, King, and Davies (1934) and of Upton and Holway (1937) showed that intensity discrimination under diotic conditions was superior to discrimination under monotic conditions, the findings in the present study that this difference is significant is worth noting. Figure 6 provides a comparison of data from the present study for 250 Hz with the data for 800 Hz from Churcher, King, and Davies.

The prediction that the DL(i)$_{int}$ would show a decrease in size as overall level was increased is clearly demonstrated by the data. The predicted "leveling off" effect of the increasing intensity is somewhat less definite, but a tendency in that direction is indicated.

The predicted increases and decreases in the size of the DL(i)$_{int}$ as a function of increases and decreases in the constant signal relative to the varying signal are found to have a reasonable fit with previous data from Gage (1935) and Chocholle (1957) (Figs. 7 and 8). The occurrence of Gage's "ripple" at the low frequency and the lack of it at higher frequencies suggests the need for additional research. A repetition of the apparent-azimuth portion of this study with the change in location of the perceived image as a controlled variable would help in determining the nature of this phenomenon.

Phase effects were not found in the two higher frequencies, just as was predicted. The assumption that phase might have more effect on a localization task such as the DL(i)$_{int}$ than on a non-localization binaural task such as the DL(i)$_{bin}$ is reflected in the data. The decrease in size of the DL(i)$_{int}$ for the 180^{o} interaural phase relation is the reverse of

Fig. 7 - Comparison of monaural and binaural DL(*i*) of present study with monaural and binaural DL(*i*) from Churcher, King, and Davies (1934)

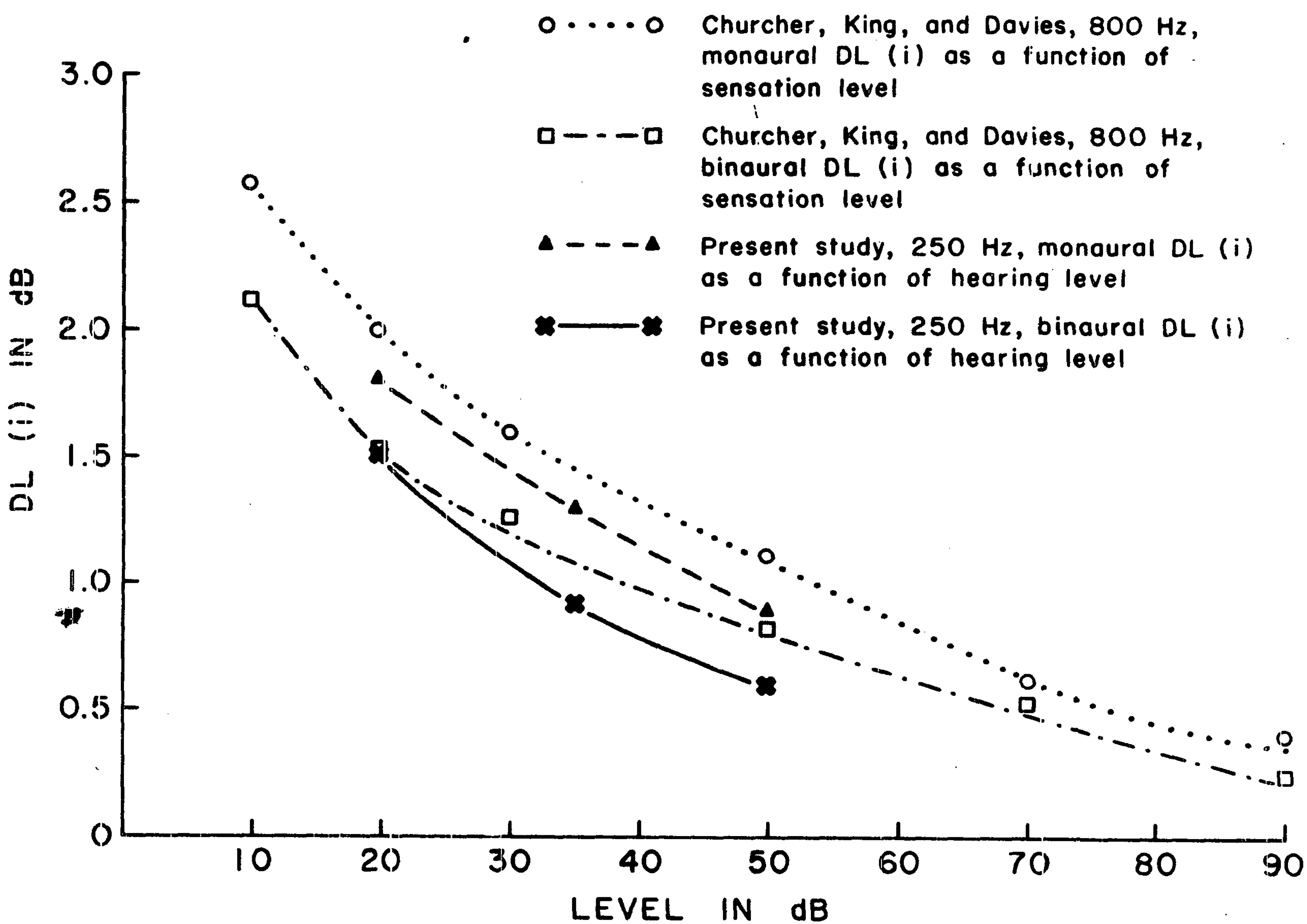

Churcher, King, and Davies, 800 Hz, monaural DL (i) as a function of sensation level
Churcher, King, and Davies, 800 Hz, binaural DL (i) as a function of sensation level
Present study, 250 Hz, monaural DL (i) as a function of hearing level
Present study, 250 Hz, binaural DL (i) as a function of hearing level
DL (i) IN dB
3.0
2.5
2.0
1.5
1.0
0.5
0
10
20
30
40
50
60
70
80
90
LEVEL IN dB

Fig. 8 - Comparison of low-frequency interaural DL(i) of present study with low-frequency interaural DL(i) from Gage (1935)

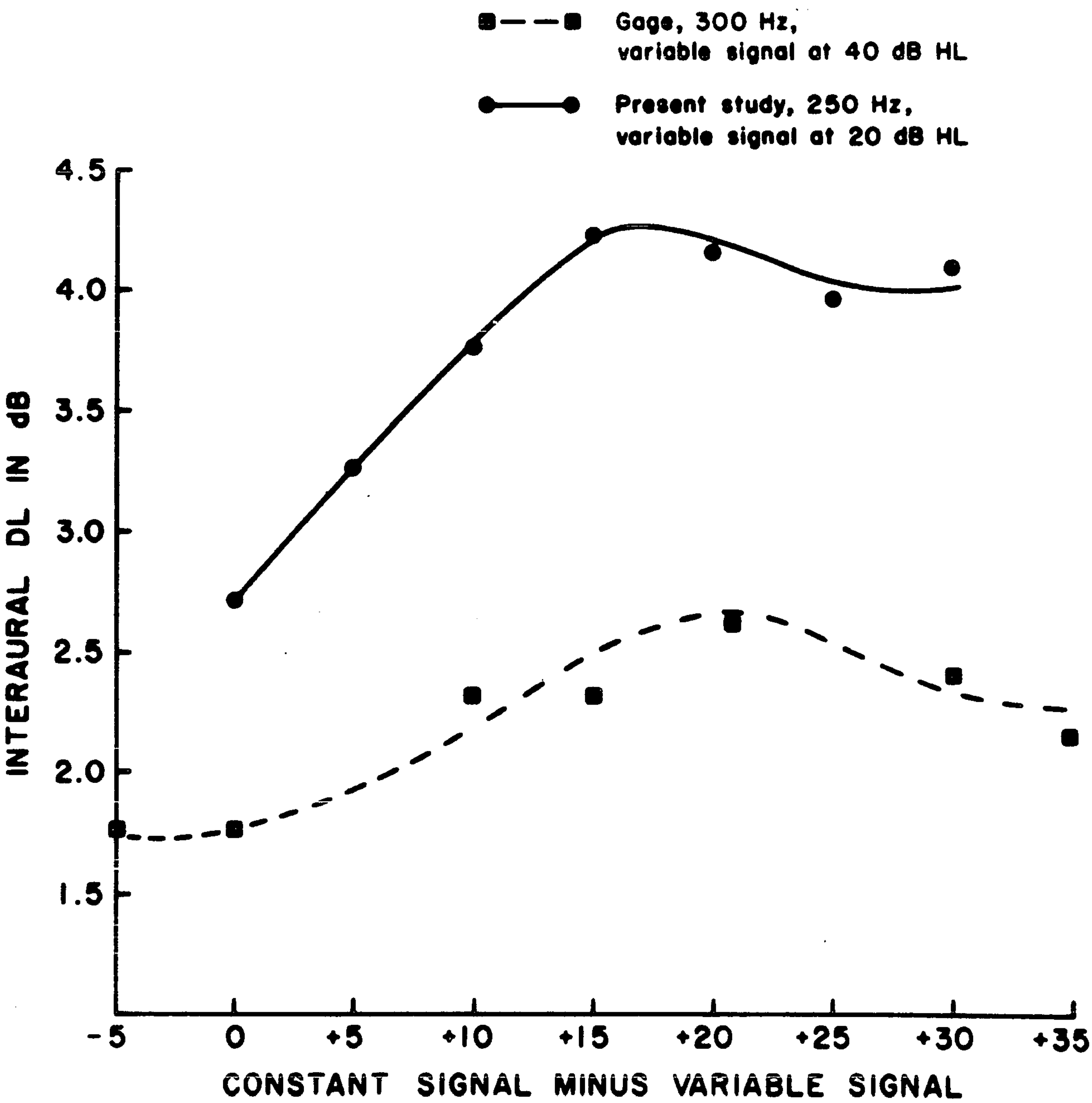
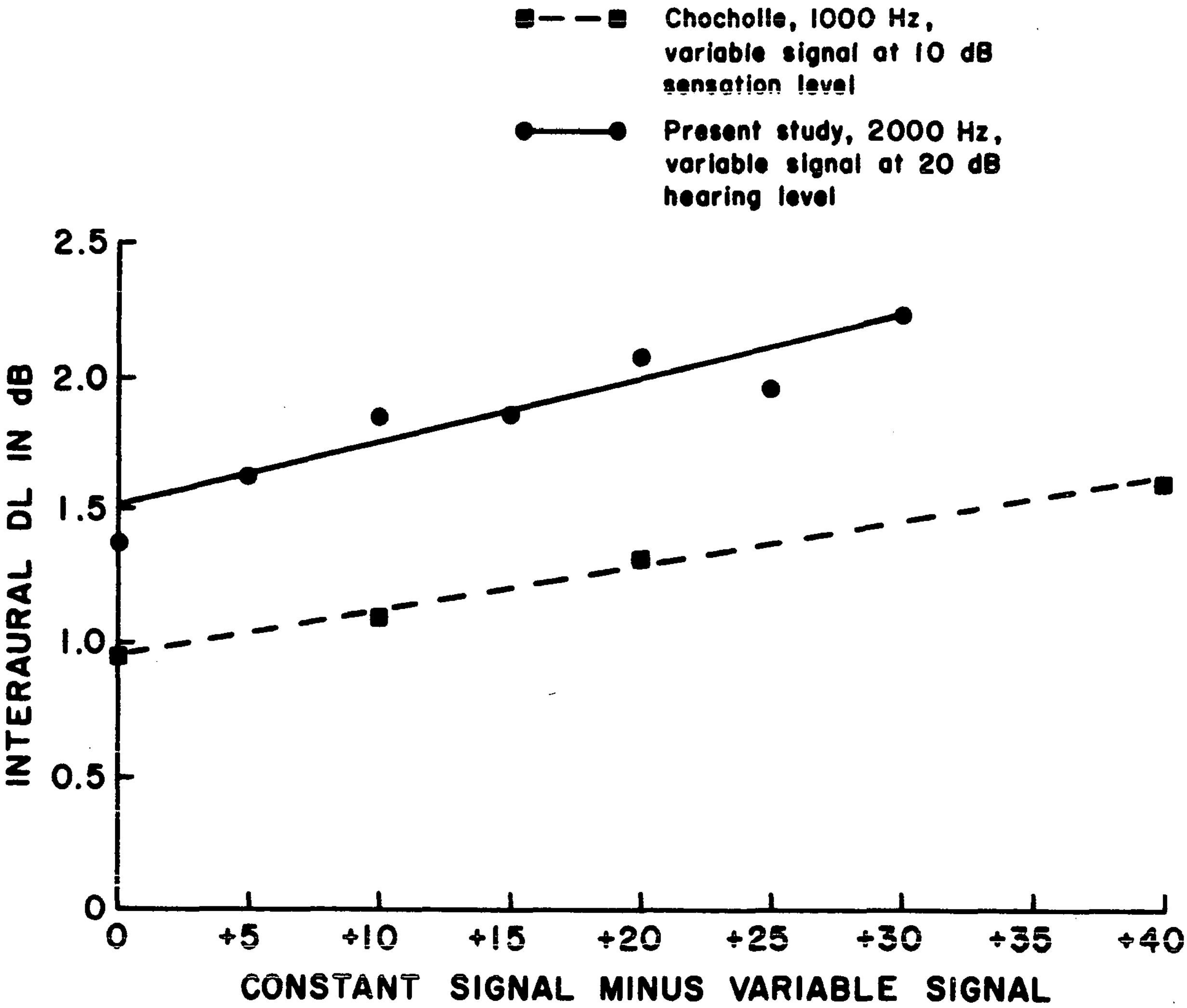

Gage, 300 Hz,
variable signal at 40 dB HL
Present study, 250 Hz,
variable signal at 20 dB HL
INTERAURAL DL IN dB
4.5
4.0
3.5
3.0
2.5
2.0
1.5
-5
0
+5
+10
+15
+20
+25
+30
+35
CONSTANT SIGNAL MINUS VARIABLE SIGNAL

Fig. 9 - Comparison of mid-frequency interaural DL(i) of present study with interaural DL(i) from Chocholle (1957)


Chocholle, 1000 Hz, variable signal at 10 dB sensation level
Present study, 2000 Hz, variable signal at 20 dB hearing level
INTERAURAL DL IN dB
2.5
2.0
1.5
1.0
0.5
0
0
+5
+10
+15
+20
+25
+30
+35
+40
CONSTANT SIGNAL MINUS VARIABLE SIGNAL

the prediction. The smaller $DL(\underline{i})_{int}$ obtained for the 180° interaural phase relation might be related to binaural signal detection phenomena which show similar differences in data as a result of altering phase relations of the signal or of the noise. In the case of the present study, the "noise" may be of a physiological nature (breathing, heartbeat, etc.).

The demonstrated ability of the human auditory system to make localization judgments on the basis of relatively small changes in intensity suggests that the Stenger test for detecting simulated unilateral hearing loss would be more effective if discrete presentations of stimuli were used rather than a continuous technique.

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APPENDIX A

Task Combinations

of the Present Study

Dichotic Condition

Varying Signal	Hearing Level		Phase
Right	Left	Right	0°
"	50	50	"
"	45	50	"
"	40	50	"
"	35	50	"
"	30	50	"
"	25	50	"
"	20	50	"
"	50	35	"
"	45	35	"
"	40	35	"
"	35	35	"
"	30	35	"
"	25	35	"
"	20	35	"
"	50	20	"
"	45	20	"
"	40	20	"
"	35	20	"
"	30	20	"
"	25	20	"
"	20	20	"
"	50	50	180°
"	45	50	"
"	40	50	"
"	35	50	"
"	30	50	"
"	25	50	"
"	20	50	"
"	50	35	"
"	45	35	"
"	40	35	"
"	35	35	"
"	30	35	"
"	25	35	"
"	20	35	"
"	50	20	"
"	45	20	"
"	40	20	"
"	35	20	"
"	30	20	"
"	25	20	"
"	20	20	"
Left	50	50	0°
"	50	45	"
"	50	40	"
"	50	35	"
"	50	30	"

Varying Signal	Hearing Level		Phase
	Left	Right	
Left			0°
"	50	25	"
"	50	20	"
"	35	50	"
"	35	45	"
"	35	40	"
"	35	35	"
"	35	30	"
"	35	25	"
"	35	20	"
"	20	50	"
"	20	45	"
"	20	40	"
"	20	35	"
"	20	30	"
"	20	25	"
"	20	20	"
"	50	50	180°
"	50	45	"
"	50	40	"
"	50	35	"
"	50	30	"
"	50	25	"
"	50	20	"
"	35	50	"
"	35	45	"
"	35	40	"
"	35	35	"
"	35	30	"
"	35	25	"
"	35	20	"
"	20	50	"
"	20	45	"
"	20	40	"
"	20	35	"
"	20	30	"
"	20	25	"
"	20	20	"

Monotic Condition

Varying Signal	Hearing Level
R	50
R	35
R	20
L	50
L	35
L	20

Diotic Condition

Varying Signal	Hearing Level		Phase
	Left	Right	
Left and Right	50	50	0°
"	35	35	0°
"	20	20	0°
"	50	50	180°
"	35	35	180°
"	20	20	180°

APPENDIX B

Table of Calculated

Intensity Increments

TABLE I

Intensity Increments Resulting from Mixture of Two Tones of the Same Frequency and in the Same Phase but with Differing Intensity Levels

dB diff. between I_1 and I_2	I_1/I_2	$\frac{I_1 + I_2}{I_2}$	$\log \frac{I_1 + I_2}{I_2}$	$20 \log \frac{I_1 + I_2}{I_2}$	ΔI in dB
0	1.0000	2.0000	.30103	6.0206	6.0206
1	1.1220	2.1220	.32675	6.5350	5.5350
2	1.2589	2.2589	.35390	7.0780	5.0780
3	1.4125	2.4125	.38247	7.6494	4.6494
4	1.5849	2.5849	.41244	8.2488	4.2488
5	1.7783	2.7783	.44378	8.8756	3.8756
6	1.9953	2.9953	.47644	9.5288	3.5288
7	2.2387	3.2387	.51037	10.2074	3.2074
8	2.5119	3.5119	.54554	10.9108	2.9108
9	2.8184	3.8184	.58188	11.6376	2.6376
10	3.1623	4.1623	.61933	12.3866	2.3866
11	3.5482	4.5482	.65784	13.1568	2.1568
12	3.9811	4.9811	.69733	13.9466	1.9466
13	4.4668	5.4668	.73773	14.7546	1.7546
14	5.0119	6.0119	.77901	15.5802	1.5802
15	5.6234	6.6234	.82108	16.4216	1.4216
16	6.3096	7.3096	.86390	17.2780	1.2780
17	7.0795	8.0795	.907385	18.1477	1.1477
18	7.9433	8.9433	.951495	19.0299	1.0299
19	8.9125	9.9125	.996185	19.9237	.9237
20	10.0000	11.0000	1.0413927	20.827854	.827854
21	11.220	12.220	1.08707	21.7414	.7414
22	12.589	13.589	1.13319	22.6638	.6638
23	14.125	15.125	1.179695	23.5939	.5939
24	15.849	16.849	1.22657	24.5314	.5314
25	17.783	18.783	1.27377	25.4754	.4754
26	19.953	20.953	1.32124	26.4248	.4248
27	22.387	23.387	1.36897	27.3794	.3794
28	25.119	26.119	1.41695	28.3390	.3390
29	28.184	29.184	1.46515	29.3030	.3030
30	31.623	32.623	1.51352	30.2704	.2704
31	35.482	36.482	1.56207	31.2414	.2414
32	39.811	40.811	1.61078	32.2156	.2156