INTRODUCTION

Various methodologies have been employed in studying the stimulus parameters involved in the lateralization of transients. One method utilizes the ability to offset interaural intensity asymmetry (e.g., $\Delta I$ favoring the stimulus at the right ear) by an opposing interaural time asymmetry (e.g., $\Delta t$ favoring the stimulus at the left ear) to produce a sound image usually perceived in the "center" of the head (the $\Delta t - \Delta I$ trade; Shaxby and Gage, 1932; Deatherage and Hirsh, 1959; David, Guttman, and van Bergeijk, 1959; Harris, 1960). A second method has been to have the subject identify the apparent location of a lateraledized image (which he perceives "inside his head") by means of some external pointer (Békésy, 1960). A third method has been to match the apparent location of a binaurally presented sound (lateralized by means of an interaural intensity asymmetry or by a combination of interaural time and intensity asymmetries) by manipulating the interaural time asymmetry of a second binaurally presented sound (matching technique; Moushegian and Jeffress, 1959; Whitworth and Jeffress, 1961). A fourth method has utilized a scaling technique in which the subject assigns a numerical value to the apparent location of pairs of dichotic stimuli (of fixed sensation levels, interaural intensity and time asymmetries) and in which increasing displacement of the image from center is represented by increasingly larger numbers (Sayers and Toole, 1964; Toole and Sayers, 1965; Sayers and Lynn, 1968).

Most of the quantitative data on the role of interaural time and intensity asymmetry in lateralization have been obtained by the centering and matching techniques, and are expressed as either the amount of interaural time asymmetry required to offset an interaural intensity asymmetry in order to obtain a centered image (the $\Delta t / \Delta I$ ratio in microseconds/decibel) or as the $\Delta t$ required to match another pair of stimuli having a fixed interaural time and intensity asymmetry. These studies have indicated that the spectral characteristics and intensity of the stimuli are the important parameters determining the qualitative and quantitative aspects of lateralization. Low-frequency tones, low-pass clicks at all levels, and high-sensation-level clicks containing frequencies of 1500 Hz and above, all require small $\Delta t / \Delta I$ ratios or short $\Delta I$'s in order to match a given $\Delta I$ (Shaxby and Gage, 1932; Moushegian and Jeffress, 1959; Harris, 1960; Whitworth and Jeffress, 1961). Conversely, high-frequency tones and high-pass clicks of low sensation level both require high $\Delta t / \Delta I$ ratios or long $\Delta I$'s in order to match a given $\Delta I$ (Deatherage and Hirsh, 1959; David, Guttman, and van Bergeijk, 1959; Harris, 1960).

The meaning of the $\Delta t / \Delta I$ ratio as calculated by the centering technique is not clear, however, for several
reasons. First, the trade is essentially an "unnatural" event since, in free-field stimulation by a single sound source, the same ear that is stimulated first also receives the more intense stimulus (sound shadow effect), that is, interaural time and intensity asymmetry favor the same ear. Second, the trade as usually defined measures one phenomenon only, i.e., centering. Whatever the $\Delta t/\Delta I$ ratio represents, therefore, is obtained from measurements at one lateralization criterion only, a procedure which would be justified only if there were an orthogonal and linear relationship between $\Delta t$ and $\Delta I$. This last assumption has been challenged by Whitworth and Jeffress (1961), who reported that subjects presented with pairs of tones whose interaural time asymmetry was opposed by interaural intensity asymmetry heard two sound images, one affected relatively more by time and the other relatively more by intensity, and that subjects could selectively attend to either sound image. They report finding different trading ratios for the two images, 0.3 and 20 $\mu$sec/dB. More recently, Hafter and Jeffress (1968) extended these findings to include high-pass clicks as well as tonal stimuli of different durations, and reported that with all stimuli subjects can learn to hear and respond separately to either of the two images.

Although the matching technique is not open to the same criticisms as the centering technique, the matching technique is, however, open to question for other reasons. For example, several researchers (Hafter and Carrier, 1969; Hershkowitz and Durlach, 1969) have pointed out that even when $\Delta t$ and $\Delta I$ of pulsed tone pairs are matched for position, forced-choice discriminations may be obtained on the basis of other "residual" cues, i.e., cues other than apparent location, such as the perceived size of the lateralized pulses, which may differ dependent upon the type of dichotic asymmetry ($\Delta t$ or $\Delta I$). These studies are discussed in more detail below (Discussion).

A recent use of the forced-choice technique has been made by Hafter and Carrier (1972) to test discrimination of pairs of tone pulses in which $\Delta t$ is opposed to $\Delta I$. In the course of experimentation on dichotic transients, we have also become interested in applying forced-choice techniques to the study of the relationship of $\Delta t$ to $\Delta I$. One rationale for the interest in applying forced-choice techniques is that, in general, they have been shown to yield lower estimates of the threshold than other techniques and have been applied quite successfully to the study of various perceptual phenomena (Blackwell, 1953; Kietzman and Sutton, 1968). One might therefore infer that the application of such techniques to the study of the relationship between $\Delta t$ and $\Delta I$ may produce more sensitive estimates of binaural thresholds. Furthermore, the use of a three- or more alternative forced-choice technique, allows the subject to utilize any and all (including residual) cues in his discrimination of the test from the comparison stimuli. This type of technique, therefore, emphasizes discrimination behavior rather than any particular cue such as the perceived position of the sound image. Furthermore, this technique involves the discrimination of pulses dichotic with respect to time from pulses dichotic with respect to intensity when both asymmetries favor the same ear.

This study was therefore undertaken to investigate the feasibility of applying a three-alternative temporal forced-choice (3ATFC) technique to the discrimination of pairs of pulses dichotic with respect to time from pairs of pulses dichotic with respect to intensity and to seek an index which might reflect the degree of equivalence of $\Delta t$ to $\Delta I$ pulse pairs.

I. APPARATUS AND METHOD

The design of the apparatus permitted independent control of the intensity and temporal relationships of binaurally presented pulses as well as the temporal separation of comparison from test stimuli and the length of intertrial intervals.

The apparatus is described with reference to a functional block diagram for one channel (Fig. 1). An independent and equivalent arrangement was available to the other ear.

(A1 and A2). Intertrial intervals were controlled by two timers that were set to recycle so that the time between the offset of one trial and the onset of the next trial in Experiment I was 10 sec and in Experiments II and III was 5 sec.

(B1 and B2). The temporal separation between the comparison and test stimuli was controlled by two timers which were triggered by A2. The B1 and B2 timers generated intervals of 0.53 sec between comparison and test stimuli.

(C). Program matrix, sequence selector, and timers. The pair of pulses dichotic with respect to intensity were generated by programming a pulse at $T_0$ at one ear (steered to D1 or D2) and another pulse at $T_0$ at the other ear (steered to D2 or D1). The pair of pulses dichotic with respect to time were generated by programming a pulse at $T_0$ at one ear (steered to D2) and another pulse at $T_1$ at the other ear (steered to D1). The comparison and test stimuli could be programmed to occur in any order. The interval between the pulses at $T_0$ and $T_1$ ($\Delta t$) could be varied from 10 to 800 $\mu$sec. This interval was generated by a crystal-controlled timer (local design) calibrated and monitored with a Systron Donner counter timer model 1034. Error was found not to exceed 0.05%.

(D1 and D2). Pulse steering. Either pulse, generated at $T_0$ or $T_1$ could be steered into one of two channels, D1 or D3.

(E1 and E2). The pulses were shaped as negative-going pulses with exponential return to base. The time constant of the exponential return to base of the electrical pulse was 0.1 msec.
(F₁ and F₂). In Channel D₂, the pulse was attenuated by a Hewlett-Packard 5-W 600-Ω attenuator (F₂) with a range of 110 dB adjustable in 1-dB steps. In Channel D₁, the pulse was attenuated by cascaded sets of Hewlett-Packard 5-W 600-Ω attenuators, F₁ and F₂.

(G). Amplifier. The pulses were amplified at G (amplifier, local design) and transduced as clicks by a set of Sharpe MK-II-S circumaural earphones (Experiment I) or by a set of Sharpe HL-10 circumaural earphones (Experiments II and III). Pictures of the clicks as transduced by the Sharpe HL-10 phones are shown elsewhere (Babcock and Sutton, 1966). The shape of the clicks as transduced by the Sharpe MK-II-S phones is not essentially different.

The subject, wearing the circumaural earphones, was seated in a sound-treated booth. A panel in front of the subject had a warning light and three feedback lights marked 1, 2, and 3, aligned with three response buttons. He was instructed to listen to three stimuli (pairs of transients) presented during each trial, to choose which one of the stimuli differed from the other two, and to record his choice by depressing the response button corresponding to the temporal position of the “different” stimulus. If the choice was correct, the light aligned with the depressed button automatically turned on, informing the subject of the correctness of his choice.

The three-alternative forced-choice methodology does not specify whether the independent variable should be kept constant within a block of trials or randomized from trial to trial. This seemingly minor variation in procedure raises rather subtle issues which cannot be dealt with here, nor in fact have they been resolved. It might be pointed out, for example, that keeping the independent variable constant within a block of trials makes it easier for the subject to identify the relevant cue (or cues) but by the same token permits the subject to arbitrarily select and become familiar with one cue, ignoring others (Kietzman and Sutton, 1968). As our thinking on these questions was developing at the time these experiments were undertaken, the first experiment was performed with the independent variable random from trial to trial, while the second and third experiments were performed with the independent variable constant within a block of trials (but random from block to block).

Fig. 1. Block diagram of apparatus, explanation in text.

II. EXPERIMENT I

The purpose of the initial experiment was to investigate the feasibility of applying the 3ATFC technique to the discrimination of pulses dichotic with respect to time from pulses dichotic with respect to intensity under several different parametric conditions.

Two subjects, one male, V.M., and one female, R.B., both 24 years of age, were used in this experiment.

For subject V.M., the test stimulus consisted of a pair of pulses, dichotic with respect to time, with the lead pulse always presented to the right ear. The comparison stimuli consisted of pairs of pulses, dichotic with respect to intensity, with the more intense pulse presented to the right ear. For subject R.B., the earlier or more intense pulse was presented to the left ear.

The independent variable was the interaural time asymmetry (Δt) separating members of the test stimulus pair. Ten Δt's were used to generate each Δt−Δt function.

Four different conditions were used:

1. Δt of the comparison stimuli, 7 dB; summed sensation level, 31 dB.
2. Δt of the comparison stimuli, 7 dB; summed sensation level, 41 dB.
3. Δt of the comparison stimuli, 7 dB; summed sensation level, 51 dB.
4. Δt of the comparison stimuli, 5 dB; summed sensation level, 41 dB.

Threshold was determined for each ear by a variation of the Block-Up-Down-Two-Interval-Forced-Choice method (Campbell and Lasky, 1968). Since the Δt of the comparison stimulus pairs is generated by an asymmetry of the intensity of the pulses at the two ears, care was taken to equate the overall sensation level of Δt and Δt pulse pairs. This procedure was utilized in order to minimize the possibility that a disparity in loudness between the test and comparison stimuli would aid in discrimination. For example, when the members of the Δt pair were 45 dB SL, thus yielding a summed sensation level at the two ears of 51 dB, the more intense member of the pair was 48 dB SL and the less intense member was 41 dB SL, thus yielding a summed sensation level at the two ears of 51.2 dB. For all conditions in Experiment
I, the range of difference in summed sensation level between $\Delta t$ and $\Delta f$ pairs did not exceed $\pm 0.2$ dB.

Each subject completed nine training sessions before data were recorded. Four blocks of 50 trials separated by 5-min rest intervals constituted a daily session lasting approximately 65 min. Conditions were separated by blocks and their order was counterbalanced over the 20 sessions of the experiment. Each block consisted of five trials at each of the 10 $\Delta t$ values randomized by trial.

### III. RESULTS

Data for both subjects are plotted together for the four parametric conditions, so as to facilitate comparisons. Figure 2 shows the data for a $\Delta f$ of 7 dB, at summed sensation level of 31 dB (top panel), 41 dB (middle panel), and 51 dB (bottom panel). Figure 3 shows the data for a $\Delta f$ of 5 dB at a summed sensation level of 41 dB. Each data point is based on 100 trials. Data are plotted as percent correct discrimination as a function of interaural time asymmetry ($\Delta t$) in microseconds on the abscissa. No correction for chance guessing is included; rather it should be remembered that the level of discrimination based on chance expectancy is at 33% in a three-alternative forced-choice procedure.

Except for the summed sensation level of 31 dB (top panel, Fig. 2), all of the data indicate V-shaped functions, i.e., higher levels of discrimination are associated with the lowest and highest $\Delta t$ values, as opposed to the mid-range of $\Delta t$ values. The minimum point of each curve represents the $\Delta t$ at which discrimination falls to its lowest level, i.e., the $\Delta t$ most confused with the $\Delta f$. As sensation level increases, (1) the sharpness of the functions increases, (2) a well-defined minimum appears, (3) the discrimination level associated with the minimum decreases, and (4) the data of both subjects tend to superimpose upon one another (Fig. 2). A decrease in interaural intensity asymmetry also tends to sharpen the function and reduce the discrimination level associated with the minimum (contrast Fig. 2 at 41 dB with Fig. 3).

Since the data indicate that both sensation level and $\Delta f$ influence these functions, a more systematic exploration of these parameters was undertaken in Experiment II.

### IV. EXPERIMENT II

The psychophysical method employed was identical with that of Experiment I except that different $\Delta t$ conditions were constant within a block of trials but random across blocks of 12 to 15 trials each.

At a 38-dB summed binaural sensation level, five $\Delta f$ conditions (4, 6, 7, 8, and 9 dB) were used. At a 48-dB
summed binaural sensation level, six Δf conditions (4, 5, 6, 7, 8, and 9 dB) were used. As in the previous experiment, the design also included an attempt to minimize the possibility that a disparity in loudness between the test and comparison stimuli would aid in discrimination. At both the 38- and 48-dB summed binaural sensation levels of the Δf pairs, the summed sensation levels of the Δf pairs were matched to within ±0.4 dB.

In Fig. 4, data for one well-trained subject (K.H.) at 38 dB SL are plotted in the left panel, and data at 48 dB SL for the same subject are plotted in the right panel. Percent correct discrimination is plotted on the ordinate as a function of Δf separating the members of the test pair of clicks in microseconds on the abscissa. The parameter of the curves is the Δf of the comparison pair of clicks. Each data point is based on 51–72 trials. As in Experiment I, each curve consists of two limbs and one minimum point (except for Δf of 9 dB at 38 dB SL). Particularly at 48 dB SL, and to some extent at 38 dB SL, the greater the Δf the greater the temporal spread of the V-shaped curve. There is also a trend for the temporal extent of the V-shaped curves to be greater at 38 dB SL than at 48 dB SL. The curves representing a Δf match to a Δf of less than 8 dB generally (except for Δf of 6 dB at 38 dB SL) have minima which correspond to a discrimination level of less than 40%, while the curves representing a Δf match to a Δf of 8 or 9 dB have minima which correspond to discrimination level of 50% or higher.

The relationship between the Δf at the minimum points and Δf can be seen more clearly in Fig. 5. No point is plotted for the Δf of 9 dB at 38 dB SL because of the inability to specify the minimum of that function, as noted above. The summed binaural sensation level of the pulse pairs is the parameter. A least-squares fit shows that neither curve departs significantly from linearity with the Δf at the minimum increasing as Δf increases. The intercept can be seen to be higher and the slope somewhat steeper for the 38-dB-SL function.

Given that these functions are linear, it becomes unnecessary to measure the Δf at the minimum point at every Δf for each sensation level. It should be sufficient to measure the Δf at one Δf for each sensation level. This is done in Experiment III for three sensation levels ranging from 24 to 54 dB. By noting whether the findings of Experiment III can be extrapolated from the data of Experiment II, the linearity of the relationship between Δf at the minimum point and Δf is further tested.

V. EXPERIMENT III

Measurements were made for the same subject using a Δf of 5 dB at 24-, 39-, and 54-dB summed binaural sensation levels. The matched sensation level for the Δf pulse pair was within ±0.2 dB of the Δf pulse pair.

The data are plotted in Fig. 6 as percent correct discrimination on the ordinate as a function of interaural time asymmetry (Δf) in microseconds on the abscissa. Each data point is based on an N ranging from 49 to 60.
trials. The data can be summarized as follows. First, as the summed binaural sensation level is increased, the V-shaped function relating a $\Delta t$ match to a $\Delta I$ of 5 dB is displaced to the left, i.e., to a shorter $\Delta t$ range. As a consequence, the $\Delta t$ corresponding to the minimum of each curve is shortened as binaural sensation level increases. Second, the temporal extent, or spread of the V-shaped curves becomes sharper with increase in sensation level.

Following from the evidence of linearity of the relationship of the $\Delta t$ at the minimum point to $\Delta I$ obtained in Experiment II, the ratios between $\Delta t$ and $\Delta I$ for the data of Experiment III are plotted on a logarithmic ordinate as a function of sensation level in decibels in Fig. 7. The ratios were also calculated for the two sensation levels of Experiment II and plotted in the same figure. A least-squares analysis yields a single linear function relating the five $\Delta t/\Delta I$ ratios to the summed binaural sensation level.

VI. DISCUSSION

A. The Minimum Point as an Index

The data presented above indicate the feasibility of applying a forced-choice technique to the discrimination of pairs of pulses dichotic with respect to time from pairs of pulses dichotic with respect to intensity. The discrimination level at any point along the V-shaped curves in Figs. 2, 3, 4, and 6 may be interpreted as indicative of the extent to which the perceptual events associated with the pairs of $\Delta t$ pulses differ from the perceptual events associated with the $\Delta I$ pairs of pulses. Furthermore, the discrimination level at the minimum of these curves may be interpreted as indicative of the extent to which it is possible to equate a $\Delta t$ pair of pulses to a $\Delta I$ pair of pulses.

The fact that a V-shaped function is generated by manipulating $\Delta t$ suggests that the major cue associated with this parameter goes through some minimum. Furthermore, since it is $\Delta t$ which is manipulated, it is reasonable to assume that the cue is lateralization in one direction away from the $\Delta I$ pair of pulses resulting in one limb of the function, and lateralization in the other direction away from the $\Delta I$ pair of pulses resulting in the other limb of the function. It is also reasonable to assume that when the minimum point is at chance performance, the $\Delta t$ and $\Delta I$ pairs of stimuli share an equivalent lateral position. Under some conditions, however, e.g., $\Delta I$ of 8 dB or greater, although the functions pass through a minimum point, the discrimination level at the minimum is above 33%. As
argued previously, the use of a forced-choice technique allows the subject the opportunity of using any cues at his disposal to discriminate a $\Delta t$ pair of pulses from $\Delta t'$ pairs of pulses. Following this reasoning, although the lateralization cue cannot be operative at the minimum point, cues other than lateralization must be responsible for discrimination accuracy better than chance at the minimum point of the functions. One can therefore infer, that at $\Delta t'$'s less than 8 dB, and at higher sensation levels, those other cues are not available at the $\Delta t$ associated with the minimum point, as the discrimination level decreases to chance.

However, this methodology does provide a means of measuring the relative degree of equivalence between interaural time asymmetry and interaural intensity asymmetry. The minimum point of each V-shaped function represents the interaural time asymmetry ($\Delta t$) most often confused with the $\Delta t'$ pair of pulses. This $\Delta t$ value also appears to be linearly related to $\Delta t'$ (in decibels).

By way of interpretation, several points may be made regarding the V-shaped functions, and the effect of sensation level on the $\Delta t'/\Delta t$ ratio. The fact that at small $\Delta t'$'s and at high sensation levels, the $\Delta t$ associated with the minimum is generally at chance level (indicating the absence of residual cues) whereas at larger $\Delta t'$'s and at low sensation levels the $\Delta t$ associated with the minimum is generally found at levels above chance (indicating the presence of residual cues), requires some comment. One interpretation may be that residual cues increase with increases in $\Delta t$. Since the entire V-shaped function is moved to a shorter $\Delta t$ range as sensation level increases, or as $\Delta t'$ decreases, the minimum point is found at relatively short $\Delta t'$'s. At low sensation levels or when the $\Delta t$ pulse pair is discriminated from a large $\Delta t'$ pulse pair, the V-shaped function is moved into a longer $\Delta t$ range. This results in a minimum point at relatively long $\Delta t'$'s. If, as postulated, the residual cues increase with increased $\Delta t$, then it follows that for low-sensation-level stimuli and for large $\Delta t'$'s, the residual cues will be more effective, leading to higher discrimination levels at the minimum point, while for high-sensation-level stimuli and for small $\Delta t'$'s, the residual cues are less effective, leading to low discrimination levels at the minimum point. This assumption can be tested by noting whether discriminations would move to chance level (no residual cues) when for a relatively large $\Delta t'$ the sensation level is increased, thus moving the entire function to a short $\Delta t$ range. This experiment has yet to be done.

The argument may be made that equating pairs of pulses on the basis of summed binaural sensation level, and thereby assuming summation of the inputs at the two ears to produce a given loudness, does not insure equal loudness, perhaps thereby allowing for the presence of differences in the "total sensation" which may serve as cues for discrimination. This argument, however, cannot account for the fact that for $\Delta t$'s of less than 8 dB, the discrimination level at the minimum of the curve is at chance.

### B. Effect of Sensation Level

The effect of sensation level on the discrimination of $\Delta t$ from $\Delta t'$ may be related to what is known about the $\Delta t$ and $\Delta t'$ jnd's. Several authors have reported that the $\Delta t$ jnd (i.e., the minimal change in $\Delta t$ required to obtain a change in lateralization) is inversely related to sensation level (Zwislocki and Feldman, 1956; Hall, 1964). That is, increasing sensation level results in an increase in lateralization sensitivity. On the other hand, we have shown in a prior publication (Babkoff and Sutton, 1969) that such is not the case for the $\Delta t'$ jnd (i.e., the minimal change in $\Delta t'$ required to obtain a change in lateralization). That is, increasing sensation level does not necessarily lead to a decrease in the $\Delta t'$ jnd. If the $\Delta t'$ pair of pulses do not alter their lateralized position as sensation level increases, while the entire V-shaped function is moved to a shorter $\Delta t$ range, this may indicate that smaller changes in $\Delta t$ are effective in altering the position of the $\Delta t'$ pair of pulses. This may explain the increased sharpness of the V-shaped function as sensation level increases.

This finding that the $\Delta t'/\Delta t$ ratio is inversely related to sensation level is consistent with the findings reported in the literature concerning the effect of sensation level on the $\Delta t$-$\Delta t'$ trade phenomenon, the matching of $\Delta t$ to $\Delta t'$, and the scaling technique (see Introduction). The difference in this experiment, however, lies in the use of the minimum point of the functions relating discrimination level to $\Delta t'$ in the current experiment. For this technique emphasizes the relationship of maximally
confused pairs of dichotic stimuli, i.e., the most equivalent pairs of dichotic stimuli whose $\Delta t - \Delta f$ values make up the $\Delta t/\Delta f$ ratios.

This point is an important one when one considers some of the implications of the Hafer and Jeffress (1968) finding reported above, that for all types of auditory stimuli, including high-pass pulses, two "images" could be generated by opposing interaural intensity asymmetry to interaural time asymmetry within a pair of stimuli. For this meant that if two "images" are audible for pairs of pulses having $\Delta t$ opposed to $\Delta f$, then much of the reported decrease in the $\Delta t/\Delta f$ trading ratio as a function of increasing sensation level might be due to a selective change in listening on the part of subjects, consisting of a greater probability of listening to the "intensity" image at low SLs and a greater probability of listening to the "time" image at higher SLs. In fact, Hafer and Jeffress conclude, regarding the different estimates of $\Delta t/\Delta f$ trading ratios reported in the literature, "... probably much if not all of the range of trading ratios reported across experiments can be accounted for by subjects who were not expecting two images but sometimes responded to one and sometimes to the other. . . ."

Although their critique of the implications of the reduction of the $\Delta t/\Delta f$ ratio as a function of sensation level may be valid when applied to the $\Delta t - \Delta f$ trading procedure, this argument cannot be applied to the data reported in this paper. The procedure we used avoided the generation of multiple images for a given stimulus. Therefore, our data, which imply that the $\Delta t$ maximally confused with $\Delta f$ decreases as sensation level increases, in fact imply an increase in the effectiveness of $\Delta t$ relative to $\Delta f$ as a lateralizing cue as sensation level increases.

C. Limits of Equivalence between $\Delta t$ and $\Delta f$

Hafer and Carrier (1969, 1972) attempted to test the hypothesis that the binaural trading ratio implies that information from one parametric dimension (either interaural time asymmetry or interaural intensity asymmetry) is somehow transformed into the other. The prediction of such a model would be that a dichotic stimulus in which a $\Delta f$ favoring the stimulus at one ear is opposed by a $\Delta t$ favoring the stimulus at the other ear can be manipulated so as to be indiscriminable from a diotic stimulus ($\Delta t = \Delta f = 0$). They tested this prediction and found that subjects were still able to detect differences between the diotic and the dichotic pairs of stimuli over a wide range of $\Delta f$'s with $\Delta t$ fixed.

The use of a forced-choice technique to determine the extent to which $\Delta t$ pairs of stimuli (500-Hz tone bursts) can be discriminated from $\Delta f$ pairs of stimuli was attempted by Hershkowitz and Durlach (1969). These authors report great difficulty in eliminating intra- and intersession variability to the extent that they were unable to interpret their results meaningfully. They were able to account for a significant portion of the variability by discovering that small shifts in the fit of the earphones cause correspondingly large changes in discriminability. They point out that a lack of precaution in maintaining the position and force of the earphones so as to eliminate this source of variability may provide an erroneous underestimation of the tradability of time and intensity.

Several comments may be appropriate at this point. First, in accordance with Hafer and Jeffress's (1968) finding, variability as reported by Hershkowitz and Durlach, may also be due to shifts in attention on the part of the subject to either one, or to both, of the two "images" generated by opposing $\Delta t$ to $\Delta f$. Such shifts of attention from trial to trial are suggested as possible sources of variability by Hafer and Jeffress. The use of a technique which requires the subject to discriminate pairs of $\Delta t$ pulses from pairs of $\Delta f$ pulses, avoiding the opposition of $\Delta t$ to $\Delta f$ within the same pulse pair, together with the forced-choice design, should tend to eliminate this source of variability. Second, the quantitative index chosen to represent the matching data in this paper does not depend upon total equivalence, since the minimum point of the function reflects the $\Delta t$ most often confused with a given $\Delta f$ regardless of the level of discrimination at that $\Delta f$. However, this does not minimize the importance of the fact that at $\Delta f$'s of 7 dB or lower, complete equivalence is found, since discrimination at the minimum point is at chance level. Third, this procedure permits the specification of the parametric values within which equivalence can be found, thus promoting the investigation of the mechanisms underlying equivalence.

In relating the results of the current experiment, which indicate the feasibility of utilizing a forced-choice technique to discriminate $\Delta t$ from $\Delta f$ for transients to the lack of success reported by Hafer and Carrier and by Hershkowitz and Durlach, one more point may be emphasized. The stimuli themselves are different. We used transients, while the other authors used 500-Hz tones of 125-msec duration. The $\Delta f$'s which were used with 500-Hz tones may be of a magnitude which would not yield a minimum point of chance discrimination when matched with 500-Hz tone pairs diotic with respect to time. Even with transients, we found an upper limit of 7 dB for total equivalence. Perhaps an even lower limit exists for pure tones and the upper $\Delta f$ limit was exceeded in the experiments reported by those authors. (In neither study were the $\Delta f$ ranges reported.) This interpretation is reinforced by reference to the literature which indicates that trading ratios ("centering" technique) are much lower for low-frequency tones than for broadband transients.

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1Except in the cases of differential hearing loss for the two ears, when the sound source is close to the ear showing the loss. Under these circumstances, the ear showing the loss may be stimulated prior to, but less intensely than, the normal ear, thus yielding an effective time-intensity trade. The results of this "trade" may have important theoretical as well as practical implications in the study of these types of hearing loss.


