The End Point of Lateralization for Dichotic Clicks*

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* This research was supported under grants M 586 and MH-07776 from the United States Public Health Service. The authors are indebted to Dr. Joseph Zubin and Dr. Jurgen Tonndorf for their helpful comments, to Dr. David Raab and to Dr. Jurgen Tonndorf for their assistance with special calibrations, to Mr. Robert Laupheimer and Mr. Raymond Simon for their assistance with the equipment, and to Dr. Nathan Beckenstein, Director of Brooklyn State Hospital for the provision of facilities which made this research possible.
ABSTRACT

A series of experiments were undertaken to study systematically one aspect of binaural interaction for clicks presented through earphones, namely the end point of lateralization, or as referred to in this paper the lag click threshold. In Section I results are reported for experiments designed to study the lag click threshold when click parameters were manipulated. These results show that an increase in the sensation level of both clicks, an interaural intensity asymmetry favoring the lag click or a decrease in the low-frequency components of the click pair all tend to decrease the lag click threshold. In Section II results are reported for experiments designed to study the lag click threshold when background noise parameters were manipulated. These results show that when the sensation level of binaural broad-band noise (125-8000 cps) is increased to 30 dB, the lag click threshold decreases; further increase in the noise level increases the lag click threshold. The finding of a minimum point at 30 dB is related to the broad spectrum of the noise. Narrow bands of noise (one-octave wide) produce monotonic functions. Narrow band low-frequency noise presented either to both ears or to the ear receiving the lead click decreases the lag click threshold, whereas narrow band high-frequency noise increases the lag click threshold. Narrow band low- or high-frequency noise presented to the ear receiving the lag click produces a very large increase in the lag click threshold. The data is discussed briefly in terms of some available physiological literature and a model is proposed.
In the study of phenomena of binaural interaction, one method which has been extensively used in recent decades involves the presentation of independently controlled acoustic transients to the two ears. Under these experimental conditions, if the clicks are identical at the two ears subjects report hearing a single sound or click image located "inside" the head approximately at the median plane. If one of the clicks is slightly more intense or is slightly earlier in time, subjects still report hearing a unitary click but it is now displaced from the median plane in the direction of the ear receiving the earlier, or more intense click. If the time interval (t) between a pair of equal sensation level clicks is of the order of one half to one millisecond, most subjects report hearing a unitary click located at the lead ear 1-4.

Still further on the time continuum, when the interval between dichotic clicks is increased to a value of approximately 1 to 4 milliseconds, subjects report hearing two clicks — one at the ear receiving the earlier click (lead ear) and a very low, just perceptible click at the ear receiving the later click (lag ear) 3,4,6.

The dependent variable which was investigated in this study was the report of one or two clicks. The independent variable was the temporal interval separating the dichotic clicks. As indicated above, this is the t region between 1 and 4 milliseconds. Very little systematic work has been reported in the lateralization literature concerning this point on the binaural interaction continuum which will be referred to in this paper as the lag click threshold, or tlc2. The present paper is a report of a series of experiments on the effect of manipulating level and spectral composition of both clicks and background noise (monaural and binaural) on the lag click threshold. Section I of the paper deals with the effect of manipulating click parameters, while Section II deals with the effect of manipulating the background noise.

5 The term dichotic is used to refer to stimuli which are in any way different at the two earphones.
APPARATUS

The design of the apparatus allowed for physical independence and separate attenuation of the electrical pulses to be transduced as clicks, control of the temporal interval separating the clicks, filtering of noise with independent attenuation of the noise at the two earphones, control of the duration of the noise bursts and the temporal position of the pulse in the noise burst, and automatic presentation of trials and of intertrial intervals. A description of the apparatus will be made with reference to a functional block diagram shown in Fig. 1.

A. Click Delay Generator: Tektronix Type 163 Pulse Generator with a Type 160A Power Supply. The pulse generator produced a rectangular pulse whose duration could be varied from 5 microseconds to 14 milliseconds. The pulse was modified so that the leading edge was used as one trigger (direct trigger) and the lagging edge was used as a second trigger (delay trigger).

B. The time interval between the direct and delayed trigger was monitored during the experiment with a Tektronix Type 561 Oscilloscope, having a Type 67 time base and a Type 75 amplifier. Oscilloscope reading errors were ±2% for Δt's less than 5 milliseconds and ±4% for Δt's greater than 5 milliseconds. All the Δt's reported in this paper refer to the time interval between the onset of the lead click and the onset of the lag click.

C. Click Shaping (local design). The direct and delayed triggers were shaped as negative going pulses with exponential return to base. The decay time constant of these pulses could be varied from 100 microseconds to 1 millisecond.

D. At this point, either the direct or the delayed pulse could be led into either the right or the left channel.

E1, E2. Krohn-Hite Band-Pass Filters (Model 330-M) for filtering of pulses. Minimum bandwidth for a 24db/octave cutoff is one octave. A separate filter was available for each channel. Selection was provided to bypass the filters when desired.

F1, F2, F3, F4. Attenuators. Separate attenuation was provided for the pulses in each channel. F1 and F2 were Hewlett-Packard, 5 watt, 600 ohm attenuators with a range of 110 dB, adjustable in 1 dB steps. At F1 and F3, another pair of attenuators F2 and F4 (local design) was provided for balancing of the pulses in the two channels. After balancing the channels at 0 dB attenuation the balance was checked at several other levels of attenuation. This procedure simultaneously provided a check on the performance of the attenuators over the range from 0 to 50 dB within a 3 to 4% measurement error.

G1, G2, G3, G4. Four adjustable timers (local design, accurate within ±2%), which controlled the relative onset time of clicks and noise, the duration of the noise, and intertrial intervals.

H. Noise Gate (local design). The noise was turned on and off by an
Fig. 1 (top, left) A schematic diagram of the experimental apparatus. See text.

Fig. 2 (bottom, left) Frequency response of the circumaural Sharpe H. L. 10 earphones. Acoustic response in dB SPL is plotted on the ordinate. Frequency is plotted on the abscissa.

Fig. 3 (top, right) Oscilloscope tracings of the acoustic output of the Sharpe H. L. 10 phones in response to pulses of three different decay time constants. Acoustic output in millivolts is plotted on the ordinate. Time in milliseconds is plotted on the abscissa. The peak voltage input to the phones is 0.35 volt.
electronic noise gate which prevented the occurrence of audible clicks when
triggering the noise generator.

I. General Radio Model 1290-A Random Noise Generator. Bandwidth from
20 to 20,000 cps.

A Ballantine RMS Voltmeter Model 320A was used to calibrate and to moni-
tor noise input to the phones. Day to day readings did not deviate by more than
±1%. Readings were checked at several levels of attenuation.

F₅ and F₆. *Attenuators.* (Hewlett-Packard as described above). Separate
attenuators were provided for the noise in each channel.

J₁ and J₂. *Mixer-Amplifier* (local design). Noise and pulses were
separately mixed and amplified for each channel.

K. *Sharpe HL-10 Circumaural phones.* The procedure for calibrating cir-
cumaural earphones is described by Shaw and Thiessen⁷. The procedure was
modified on the basis of a communication from Sharpe Instruments concerning
the particular dimensions of the coupler. The diameter of the Western Elec-
tric 640AA microphone was 0.936 inches and the opening of the flat plate
Lucite coupler was 0.938 inches. The microphone was mounted flush with the
coupler face and connected to the Audio Instrument unit consisting of a
Model 164 preamplifier and a Model 16P₁ amplifier and cathode follower. The
output of the latter was measured with a voltmeter. Input voltage to the
phones was 0.1 volt rms.

Figure 2 shows the obtained frequency response of the earphones. The
curves for the two phones seem to be rather well matched with rises and dips
occurring for both phones at the same frequencies; although at every fre-
quency the values for the right phone are slightly less than for the left
phone.

After measuring the frequency response of the phones, measurements were
made of the acoustic output of the phones (click) in response to the elec-
trical pulses used in these experiments. The click was generated by a negative
going electrical pulse with a rise time of 12.5 microseconds and a peak
amplitude of 0.35 volts. The "duration" or time constant of the exponential
return to base (1/e of peak amplitude) could be varied by the experimenter.
The output from the microphone and Audio Instruments unit which was used to
measure the response of these phones to the pulse was displayed on the
oscilloscope. Measurements of the phone response to the pulses were made from
the oscilloscope face in peak voltage for three different click decay time
constants—0.1, 0.5, and 1.0 milliseconds (Fig. 3).

The acoustic response is a rarefaction click with two main peaks and
with "ringing", whose duration is a function of the decay time constants

Accoust. Soc. Amer. 34, 1233-1246 (1962)
of the input to the phones. The rise time (as measured from the onset of the acoustic response to the first peak) is 100 microseconds for all pulses used. As the click decay time constant is lengthened, several things occur: 1) the amplitude of the first peak increases, 2) the ratio of the amplitude of the first to the second peak decreases, 3) the duration of the ringing increases, and 4) the point in time at which the curve returns to base occurs later. Measurements were checked for a .035 peak voltage input to the phones and these relations were found to be similar.

SUBJECTS AND PROCEDURE

Subjects were tested for hearing acuity prior to training. The hearing tests consisted of pure tone audiometry, speech threshold, and a simultaneous loudness balance test for recruitment (when there were threshold differences between the ears). All subjects had normal hearing (defined as less than a 10 dB loss at any frequency tested), no recruitment, and less than a 4 dB difference between ears for click threshold. Each subject was trained for a period of approximately 10 to 20 sessions before the experiments were begun. During this period noise and click masking thresholds were determined. Since experiments were conducted over a period of approximately one year, thresholds were monitored throughout.

To avoid complication arising from possible "cross-stimulation" or "cross-conduction" leakage, no click or noise sensation levels greater than 50 dB re monaural threshold were used except in one experiment in which the highest level used was 58 dB.

The psychophysical procedures which were followed for all the experiments are reported here. A brief section will also precede the report of each experiment specifying the conditions studied and any differences in procedure.

A. Constant Stimuli. An experimental session consisted of four or five blocks of 30 trials each with a 3 minute rest between blocks. Trials were separated by 15 second intervals. Three seconds before a trial a warning light was turned on and remained on until the end of the trial. The subject was instructed to respond immediately after the termination of the warning light by reporting whether he heard one or two clicks.

B. Method of Limits. The response recorded was the threshold crossing, that is, the at which reports of "one" changed to "two" (increasing at) and the at which reports of "two" changed to "one" (decreasing at). The experimental conditions were randomized and measurements for each condition were made in blocks of five threshold crossings each. Each session consisted of 15 or of 20 blocks. A 5 minute rest period was given after the tenth and fifteenth block. A 5 second interval separated all trials. No warning light was used.

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The difference between the peak response for a decay time constant of 1.0 millisecond and the peak response for the 0.1 millisecond decay time constant is 1.8 dB.
SECTION I. THE EFFECT OF MANIPULATING CLICK PARAMETERS

The most recent studies of lateralization which present data on the $\Delta t$ required for the lag click threshold are those of Guttman\textsuperscript{9} and of Teas\textsuperscript{10}. Guttman does not discuss the results pertaining to the $\Delta t$ required for the detection of the lag click in the text of his paper but he does show these values in two figures (ibid., Figs. 4 and 6) and he refers to them in his abstract. Inspection of these figures shows that the lag click threshold decreases with a 20 dB increase in sensation level of the click pair. If click sensation level is maintained constant at the lead ear and lowered by 10 dB at the lag ear, it appears from Guttman's plots that the lag click threshold is increased. If click sensation level is maintained constant at the lag ear and lowered by 10 dB at the lead ear, these plots indicate that the lag click threshold does not change.

Teas studied the "extremes" of lateralization extending from the reported presence of a unitary click at the median plane (for a $\Delta t$ of 0 milliseconds) to "...the appearance of an "echo" at the lag ear..." (for longer $\Delta t$'s). He used both "high-pitched" and "low-pitched" condensation clicks as stimuli, presented at four different sensation levels. The largest interaural time difference was 3.5 milliseconds, so that if for a given condition this amount of time was not sufficient for the subject to detect an "echo" at the lag ear only this value and not the "true $\Delta t$" was plotted. An examination of his curves reveals that for "high-pitched" clicks this last point is a function of the sensation level of the clicks; i.e., the longest $\Delta t$ was found for the lowest sensation level and the shortest $\Delta t$ for the highest sensation level.\textsuperscript{11} No clear cut relation between sensation level and the $\Delta t$ required for the detection of the lag click can be seen for the "low-pitched" clicks. Teas, however, qualifies these results in a footnote as follows: "Although polarity was not a parameter in this investigation, preliminary observations suggest that for the opposite polarity, i.e., rarefaction, the low-pitched transient follows a path similar to that of the high-pitched transient..."\textsuperscript{12}

The studies cited above dealt only incidentally with the end point


\textsuperscript{11} A personal communication with the author verified this interpretation of his findings.

\textsuperscript{12} Teas, ibid., p. 1462.
of the lateralization continuum, i.e., the lag click threshold. The experiments reported in this section were designed to obtain systematic information on three aspects of the lag click threshold: the effect of click sensation level, the effect of interaural intensity asymmetry, and the effect of click spectral composition.

Experiment A: Click Sensation Level

Four sensation levels (15, 25, 35, 45 dB) of a click having a 500 microsecond decay time constant were used. The data for two subjects were gathered with the method of limits. Results for both subjects are plotted in Fig. 4. Each point is an average of 30 threshold crossings.

For both subjects an increase in click sensation level results in a monotonic decrease in \( \Delta t_2 \). For subject H. B., the decrease in \( \Delta t_2 \) is 1.0 millisecond for a 10 dB increase in click level, while for subject I. H. the decrease in \( \Delta t_2 \) is 0.6 millisecond for the same range. The positive deceleration of the function found for subject I. H., seems to be limited to this subject. All other subjects tested showed negatively decelerated functions (e.g., see Fig. 9 below). On the whole the variability as measured by one standard deviation is greater for subject H. B. (range, .210 to .430 millisecond) than for subject I. H. (range, .187 to .276 millisecond).

The results of this experiment confirm the results of Guttman and of Teas, i.e., an increase in click sensation level results in a decrease in the lag click threshold.

Experiment B: Interaural Intensity Asymmetry

In Guttman's findings cited above, it was reported that when click sensation level at the lag ear is reduced by 10 dB \( \Delta t_2 \) was increased, while the reverse intensity asymmetry did not appear to affect \( \Delta t_2 \). It is not clear how to interpret Guttman's results, since his manipulations produced not only intensity asymmetry at the two ears but also an overall decrease in summed sensation level. The latter would, by itself, tend to increase \( \Delta t_2 \) (see Experiment A above). However, the lack of change when the intensity asymmetry favors the lag ear would tend to indicate that the direction of the intensity asymmetry is also important.

In order to separate the intensity asymmetry effect from the effect of a decrease in summed sensation level, in Experiment B summed sensation level is increased as intensity asymmetry is increased. This was brought about by maintaining a fixed sensation level for one of the clicks while the other was increased in intensity. Since the effect of increasing sensation level is to decrease \( \Delta t_2 \), any increase in \( \Delta t_2 \) as a function of interaural intensity asymmetry cannot be attributed to summed sensation level. The experiment was also so designed that there was the same increase in summed sensation level for an intensity asymmetry favoring the lead click as for the identical intensity asymmetry favoring the lag click.

The procedure can best be described with reference to Fig. 5. The method of constant stimuli was used for one subject. Four \( \Delta t \)'s presented 30 times each were used to determine each point (the \( \Delta t \) corresponding to a 50%
Fig. 4 The average temporal interval (Δt) for the detection of the lag click is plotted on the ordinate for each of two subjects. Click sensation level is plotted on the abscissa.

Fig. 5 The temporal interval (Δt) required for a 50% detection of the lag click is plotted on the ordinate. The left side of the abscissa represents the intensity increment of the lead click while the lag click is held at a fixed intensity. The right side of the abscissa represents the intensity increment of the lag click while the lead click is held at a fixed intensity. The parameter is the sensation level of the fixed intensity click. The upper part of the figure is a visual illustration of the stimulus arrangements.
report of two clicks) plotted in the figure. There were two sensation levels for the click held constant, 20 and 50 dB. On the left side of the graph are the data for interaural intensity asymmetries (Δl) favoring the lead click (4, 8 dB) whereas on the right side of the graph are the data for the same interaural intensity asymmetries favoring the lag click. At the midpoint of the abscissa (0) clicks are equal in intensity at the two ears.

For the curve labelled 20 dB, at each point on the abscissa the intensity at one of the ears is 20 dB. For the 0 point, the intensity of the clicks at each ear is 20 dB and the summed sensation level is 26 dB. For an intensity asymmetry of 4 dB, data on the right side of the graph refer to the condition where the click at the lead ear was 20 dB and the click at the lag ear was 24 dB, resulting in a summed sensation level of 28 dB. On the left side of the graph, for the same intensity asymmetry of 4 dB, the lag click was 20 dB and the lead click was 24 dB, resulting in the same summed sensation level of 28 dB. For an intensity asymmetry of 8 dB, data on the right side of the graph refer to the condition where the click at the lead ear was 20 dB and the click at the lag ear was 28 dB, resulting in a summed sensation level of 31 dB. On the left side of the graph, for the same intensity asymmetry of 8 dB, the lag click was 20 dB and the lead click was 28 dB, resulting in the same summed sensation level of 28 dB. The curve labelled 50 dB is generated in a parallel way, except for the shift in intensity level.

With this procedure, a comparison could be made between a pair of dichotic clicks whose overall summed sensation level was equal to another pair of dichotic clicks but whose direction of intensity asymmetry was opposite. In addition, the summed sensation level increases as intensity asymmetry increases.

The findings may be summarized as follows:

1. As was found in Experiment A, an increase in overall click sensation level (from 20 to 50 dB) results in a decrease in Δt2 as shown by the parameter.

2. Interaural intensity asymmetries favoring the lag click result in a decrease in Δt2 while interaural intensity asymmetries favoring the lead click result in an increase in Δt2. The difference in Δt2 for equal intensity asymmetries of opposite direction can be as large as 3 milliseconds e.g., for an intensity asymmetry of 8 dB (when the constant level click is 20 dB).

3. The effect of intensity asymmetry on Δt2 is dependent upon the sensation level of the click held constant. The effect of both the direction of intensity asymmetry and its magnitude is much greater when the level of the fixed click is 20 dB than when the level of the fixed click is 50 dB. For example, with the fixed click at a sensation level of 20 dB, an 8 dB increment in the lead click yields a Δt2 of 5.2 milliseconds whereas an 8 dB increment in the lag click yields a Δt2 of 2.4 milliseconds. On the other hand, with the fixed click at a sensation level of 50 dB, an 8 dB increment in the lead click yields a Δt2 of 2.5 milliseconds whereas an 8 dB increment in the lag click yields a Δt2 of 2.9 milliseconds.

4. An interaural intensity asymmetry of 8 dB favoring the lag click (when the lead click is 20 dB SL) can result in a decrease in Δt2 which is approximately equal to the decrease in Δt2 found when the sensation level of both (lead and lag) clicks is increased by 30 dB.
These results, therefore, confirm Guttman's findings with respect to intensity asymmetry favoring the lead click but do not confirm his findings with respect to intensity asymmetry favoring the lag click. The reason for the difference between these findings and Guttman's findings seems to lie in the fact that in his experiment summed sensation level was less for the condition of intensity symmetry than for the condition of intensity asymmetry, while in the present experiment summed sensation level is always greater for the asymmetrical conditions. When summed sensation level is equated across comparable conditions of intensity asymmetry, a more intense lead click increases $\Delta t_2$ whereas a more intense lag click decreases $\Delta t_2$.

Experiment 8: Click Spectrum

In both Experiments A and B an increase in click sensation level resulted in a decrease in $\Delta t_2$. In these experiments, the click used had a 500 microsecond decay time constant (Fig. 3). These results were in agreement with the findings of Guttman who used 100 microsecond rectangular pulses transduced as clicks and the findings of Teas' for his "high-frequency" condensation clicks. However, for his "low-frequency" condensation clicks these results do not hold. The question arises, then, as to the role of the spectral composition of refection clicks in determining $\Delta t_2$.

The spectral composition of the clicks can be manipulated in two ways and the effect of each is studied separately. In Part I, click spectral composition is manipulated by changing the decay time constant. In Part II, click spectral composition is manipulated by filtering the pulses.

Part I: Decay time constant: A spectral analysis was performed on the acoustic response of the phones to pulses of three different decay time constants. Several months elapsed between the calibration of the earphones as described above and the spectral analysis described in this section. The following procedure was performed with different calibration equipment and with a different type of coupler which was required because of the smaller dimensions of the microphone used for the spectral analysis.

A Bruehl and Kjaer Type 4134 microphone (0.5 inches in diameter) was inserted into the opening and mounted flush with the face (slightly larger than 0.5 inches in diameter) of a wooden plate coupler. The microphone was connected to a Bruehl and Kjaer Type 2615 cathode follower and the output was led to a Bruehl and Kjaer Type 2112 spectrometer. The earphone was placed on the coupler and an 800 gram weight was placed on top of it. The pulse input to the earphone and the output from the microphone were simultaneously monitored on an oscilloscope. The pulses were generated in the same manner described in previous sections. In order to obtain stable meter readings on the spectrometer, it was necessary to increase the repetition rate of the clicks to 100/sec. and to set the peak voltage input to the phones at 0.623 volts (i.e., -15 dB re 3.5 volts). With this procedure, the obtained meter readings were very stable and repeatable. Measurements were obtained for the three pulse decay time constants, 0.1, 0.5, and 1.0 milliseconds. Results are shown in Fig. 6 in the form of peak voltage in dB (re 0.1 millivolt) plotted as a function of the center frequency of a 1/3 octave-wide band. The difference between the spectral characteristics of a single pulse and that of a train of pulses is the appearance of energy at the repetition rate (i.e., the fundamental frequency) and at the
Fig. 6 The spectral composition of clicks of three different decay time constants as measured by a spectrometer. Acoustic response in dB re 0.1 millivolt is plotted on the ordinate. Log frequency points, 1/3 octave apart, are plotted on the abscissa.

Fig. 7 Percent report of two clicks is plotted on the ordinate. The temporal interval separating the dichotic clicks is plotted on the abscissa. Decay time constants and sensation level appear as parameters.
harmonics of the pulse train; energy which is not present in the spectrum of a single pulse. The high readings found (Fig. 6) at 100 cps and 200 cps are probably due to the 100 per second repetition rate of the click input and its second harmonic. These readings obscure the real contributions of energy for a single pulse at these frequencies.

The effect of varying the click decay time constant appears to be identical for both phones. Ignoring the energy probably contributed by click repetition rate, the 0.1 millisecond click shows a steady rise in peak voltage with increasing frequency up to about 1000 cps and drops off steadily above 5000 cps. The 0.5 and 1.0 millisecond clicks show a rise in peak voltage up to approximately 400 cps and then remain essentially level up to 5000 cps when they also drop off. In summary, it appears that for the short decay time constant (0.1 millisecond), the relative magnitude of the lower frequency components is less than for clicks with longer decay time constants (0.5 and 1.0 milliseconds).

Having ascertained that a decrease in click decay time resulted in a relative decrease in the magnitude of the low-frequency components, the effect on $\Delta t_2$ of click decay time constants (0.1 and 1.0 milliseconds) at two sensation levels (15 and 45 dB SL) was studied. The method of constant stimuli was used for one subject.

Results are plotted in Fig. 7 as the percent report of two clicks on the ordinate and $\Delta t$ separating the dichotic clicks on the abscissa. Curves are based on 60 presentation of each $\Delta t$. As can be seen from the figure, an increase in the click decay time constant results in a slight increase (about 200 microseconds) in the lag click threshold at both sensation levels. In addition, as was shown in Experiments A and B an increase in click level (30 dB) results in a substantial decrease in the lag click threshold.

Part II. Filtered Clicks: The clicks used in Part I may be viewed in two ways: in terms of spectral composition, as shown in Figure 6, or in terms of sound pressure as a function of time as shown in Figure 3. While these two modes of analysis may be considered as equivalent in a monotonic situation, assuming the cochlea as a peripheral spectral analyzer, it is not clear that they are equivalent when one is considering the comparison at some central locus of the activity at the two ears. We have implied in Part I that the shift in $\Delta t_2$ is due to the difference in spectral content between the two decay time constants compared. However, since $\Delta t_2$ measurements are made from the onset of the first click to the onset of the second click, the decreases in $\Delta t_2$ for the click having the shorter decay time constant may equally well be attributed to the increase in 'dead time' between the two clicks. In other words, since with a shorter decay time constant the first click ends earlier the decrease in $\Delta t_2$ may be a direct correlate of this factor. Actually, the obtained decrease in $\Delta t_2$ (200 microseconds) is slightly smaller than might be predicted from the decrease in decay time as measured at the point 1/e. This difference in dead time is approximately 400 microseconds (Fig. 3)

The following experiment was undertaken to explore further the role of click spectral composition in determining $\Delta t_2$. An electrical pulse having a 0.1 millisecond decay time constant was passed through a Prohn-Hite 330-M.
filter. Two different filter settings (each having a width of one octave) were used to produce two different types of clicks. The "low-frequency" clicks were generated by passing the electrical pulse through the filter set at a low-frequency cutoff of 1000 cps and a high frequency cutoff of 2000 cps. The "high-frequency" clicks were generated by passing the electrical pulse through the filter set at a low-frequency cut-off of 4000 cps and a high-frequency cut-off of 8000 cps. The resultant clicks are shown as a spectral distribution plot in Figure 8.

The frequency distribution is plotted as the peak voltage of 1/3 octave-wide frequency bands as a function of the center frequency of each band. It can be seen that for the pulse passed between 1000 and 2000 cps (the low-frequency click) most of the acoustic energy lies in the region of 600 to 2400 cps with a slope-off of approximately 20 dB/octave at both ends. Most of the acoustic energy of the pulse passed between 4000 and 8000 cps (the high-frequency click) lies in the region of 2000 cps to 8000 cps with a slope-off of approximately 20 to 25 dB/octave at the low-frequency end and of approximately 30 dB/octave at the high frequency end. The steep slope-off of the high-frequency click at the high-frequency end of the spectrum probably reflects the sharp drop in the frequency response curve of the Hifon earphone at 10,000 cps (Figure 2).

The method of constant stimuli was used to gather data for two subjects. The low-frequency and high-frequency clicks were equated in terms of nonauditory thresholds. Four to five Δt's per condition were used. Each Δt was presented 30 times in random order within a block of trials. Sensation level and type of filtered click were randomized across blocks.

The data are summarized for each subject separately in Figure 9 in the form of a plot of the Δt corresponding to a 50% report of two clicks on the ordinate (Δt2) as a function of click sensation level on the abscissa. The parameter of the curves is the frequency cut-off of the filtered clicks (i.e., the high-frequency versus low-frequency clicks). The data may be summarized as follows:

1. There is a monotonic decrease in Δt2 as click sensation level is increased for both the high- and low- frequency clicks. The slope, or extent of decrease, differs for the two subjects.

2. For both subjects, at all sensation levels measured, Δt2 is smaller for the high-frequency clicks than for the low-frequency clicks. That is, the curve representing the results for the low-frequency clicks is displaced upward on the ordinate from the curve representing the results for the high-frequency clicks.

Oscilloscope pictures of the waveform of the response of the earphones to the filtered pulses were taken to provide a plot of sound pressure as a function of time. Tracings are reproduced in Figure 10, and are plotted as amplitude of the phone response in millivolts as a function of time in milliseconds.

The earphone response was monitored by means of a Bruel & Kjaer Type 4136 half inch microphone, a Type 2615 Cathode follower, and Type 2801 power
Fig. 8 (top, left) Spectral analysis of acoustic responses (Sharpe H. L., earphone) to filtered pulses. Acoustic output (peak voltage) in dB is plotted on the ordinate. The center frequency of 1/3-octave-wide bands is plotted on the abscissa.

Fig. 9 (bottom, left) The $\Delta t$ required for 50% detection of the lag click (lag click threshold) is plotted on the ordinate. Click sensation level in dB is plotted on the abscissa. Data for each of two subjects is shown separately. The parameter is click frequency.

Fig. 10 (top, right) Oscilloscope tracings of the acoustic responses (Sharpe H. L. 10 earphones) to filtered pulses. Acoustic output in millivolts is plotted on the abscissa.
supply. The earphone and microphone were mounted in the same fashion as reported previously. The output of the cathode follower was read from the oscilloscope.

Several points become evident from an examination of Figure 10. 1) Peak-to-peak amplitude as measured from the first negative to the first positive peak is approximately equal for both clicks. 2) The high-frequency click exhibits a great deal of ringing, which is not evident in the low-frequency click. 3) If click duration is measured from the first peak until the return to base level (i.e., after termination of the total ringing) then the total duration of both low- and high-frequency clicks is approximately equal. 4) If, however, click duration is measured as the interval between zero time and various peaks of the earphone response curve, then some of the differences between the high- and the low-frequency clicks approach the order of magnitude of the difference in the lag click threshold (Fig. 9) obtained for the two types of clicks.

In conclusion, one cannot decide with these stimuli what aspect of these stimuli is used by the auditory system to achieve a smaller lag click threshold for the high-frequency clicks than for the low-frequency clicks. Either spectral differences or sound pressure versus time differences can be invoked to explain the improvement in the psychophysical threshold (a decrease in \( \Delta t_2 \)) for the high-frequency clicks. Perhaps the use of noise bursts of equal duration with different frequency content would be more useful in discriminating between these two hypotheses.

An indirect approach to this problem can be made by studying the effect of the frequency content of background noise on the lag click threshold. Data on this question are presented in Experiments E and G of Section II below.

Summarizing the experiments in this section, it has been shown that an increase in sensation level of the lag click, or a manipulation of the click spectrum to reduce the low-frequency components (or a decrease in dead time) all result in a decrease in \( \Delta t_2 \). Conversely, the opposite conditions all result in an increase in \( \Delta t_2 \). In addition, an increase in the sensation level of the lead click also results in an increase in \( \Delta t_2 \).

SECTION II: THE EFFECT OF MANIPULATING BACKGROUND NOISE

In Section I, the end-point of lateralization was investigated by means of manipulating the click stimuli; in this section, the end-point of lateralization was investigated by manipulating the background against which a pair of dichotic clicks was presented. A search of the literature reveals no previous studies on this problem.

Since the results reported in Section I of this paper and those of Guttman\(^9\) and of Teas\(^10\) indicated that a decrease in the sensation level of dichotic clicks results in an increase in the lag click threshold, one implication which is interesting to explore is whether increasing the sensation level of a background noise is equivalent to decreasing the sensation level of the clicks. In other words, what is the effect of the masking level of the clicks and of the signal-to-noise ratio on the lag click threshold. Experiment D of this section is addressed to this issue.
Experiment D: Broad-band Background Noise

The method of constant stimuli was employed to gather data for three subjects. The background noise had a bandwidth of six octaves with a low-frequency cut-off at 125 cps and a high-frequency cut-off at 8000 cps. Seven background noise levels, and two click sensation levels were used. For a given trial, an 800 millisecond burst of noise was presented and a pair of dichotic clicks occurred midway in the noise burst, i.e., 400 milliseconds after noise onset. The values of Δt which were used differed from subject to subject. Results for the "no noise", (i.e., -20 dB SL noise) condition are based upon 100 presentations of each Δt, whereas the results for the noise conditions are based upon 40 presentations of each Δt randomized by trial within a block. For any one block of trials only one level of background noise was used. The levels of background noise used in each session were selected at random.

The data are summarized in Figure 11 for the 35 dB SL clicks and Fig. 12 for the 45 dB SL clicks. The Δt corresponding to a 50% report of two clicks is plotted on the ordinate and the sensation level of the noise is plotted on the abscissa. The masking level, determined for noise and click presented to the lead ear, is marked for each point on the curve. The masking levels indicate how much more noise would have to be added at each noise sensation level to completely mask the click.

The results may be summarized as follows:

1. For both click sensation levels, the lag click threshold decreased with increasing noise sensation level and reached a minimum value at 30 dB SL. With further increase in noise sensation level, Δt₂ increased.

2. For both click sensation levels, the minimal Δt, across subjects at 30 dB SL was found to be unrelated to masking levels. For clicks at 35 dB SL (Fig. 11) masking levels of -18, -25, and -32 dB were obtained. For clicks at 45 dB SL (Fig. 12) masking levels of -30, and -47 dB were obtained for the same noise sensation level. The 30 dB noise sensation level appears to be a critical value for obtaining a minimal Δt₂ regardless of click sensation level or masking level.

3. For both click sensation levels, the increase in Δt₂ for noise sensation levels above 30 dB appears to be related to masking level. This is indicated by the steeper slopes obtained for those curves for which higher masking levels were found.

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13 Results for both click sensation levels (35 dB and 45 dB are presented together). Actually, each click sensation level was investigated in a separate series of experimental sessions.

14 The masking level for the lag ear did not differ by more than ±3 dB when click sensation level was 35 dB. When click sensation level was 45 dB, no difference was found between the masking level of the lead and lag ears.
Fig. 11 The temporal interval ($\Delta t$) for a 50% detection of the lag click is plotted on the ordinate. Sensation level of the broad-band background noise is plotted on the abscissa. Click sensation level is 35 dB. The masking level is marked for each point on the curves.

Fig. 12 The temporal interval ($\Delta t$) for a 50% detection of the lag click is plotted on the ordinate. Sensation level of the broad-band background noise is plotted on the abscissa. Click sensation level is 45 dB. The masking level is marked for each point on the curves.
4. For subject I.H., the lag click threshold is lower at all noise sensation levels for the 45 dB sensation level clicks. This is not consistently found for subject H.A. and several reversals may be observed. (Contrast Figs. 11 and 12).

5. Although subjects were equated for click and for noise sensation levels, it may be noted that markedly different $\Delta t_c$'s are obtained even for the control condition (-20 dB noise sensation level). What does not appear in the figures is the ordering of the curves, across subjects, is inversely related to the level of absolute click threshold. In other words, those subjects requiring least click acoustic energy at absolute threshold are also the subjects who require the least temporal separation ($\Delta t_2$) between dichotic clicks for the lag click threshold. The meaning of this observation is not evident.

In summary, the effects of background noise on the lag click threshold do not follow predictions made on the basis of signal-to-noise ratios. In fact, for noise sensation levels of 30 dB and less, the effects are directly opposite to such predictions. In addition there is the odd finding of a minimal lag click threshold at a specific noise sensation level, namely 30 dB.

Experiment E: Binaural Filtered Noise

An analysis of the spectral composition of the clicks (Fig. 6) had indicated that the click which was used in Experiment D (500 microseconds decay time) was a complex acoustic event having energy both in the high- and in the low-frequency range. The results of Experiment C had indicated that either filtering the clicks or manipulating the decay time altered $\Delta t_c$. In a search for a mechanism to account for the results for the paradoxical effects of noise on $\Delta t_c$, and as a possible means of elucidating the effect of stimulus spectrum, the influence on $\Delta t_2$ of the manipulation of the spectral content of the background noise was considered to be the next most logical experimental step.

The method of limits was employed to gather data. Five bands of noise were used for one subject and four bands of noise were used for the other subject. These bands were 125-1000 cps, 250-2000 cps, 375-3000 cps, 500-4000 cps, and 1000-8000 cps. The fact that noise bands as wide as 3 octaves were chosen was necessitated by an equipment limitation which did not allow a sufficient intensity range (50 dB SL) for narrower bands of noise. The clicks were 35 dB SL, and all noise bands were equated for monaural sensation level. Noise was on continuously and a pair of dichotic clicks was presented every 5 seconds.

In Fig. 13, the average $\Delta t$ for the lag click threshold is plotted on the ordinate, and the noise level is plotted on the abscissa, with the spectral content of the noise as parameter. The control level, -20 dB SL refers to a setting of the attenuator 20 dB below the attenuator setting for the noise band having the lowest threshold. For example, if for a given subject, the lowest threshold was obtained for the 500-4000 cps band at an attenuator setting of 80 dB, then for the control level the attenuators were set at 100 dB. However, for all other points on the abscissa, sensation level refers to decibels above the threshold for each noise band determined separately.
Fig. 13 The average \( \Delta t \) for the detection of the lag click is plotted on the ordinate. The sensation level of the background noise is plotted on the abscissa. The parameter is the spectral content of the bands of noise. Data for I. H. is plotted in the upper curves; data for H. A. is plotted in the lower curves.
The $\Delta t_2$ for the control level represents an average of 60 threshold crossings, whereas the $\Delta t_2$ for all other points is an average of 20 threshold crossings. The variability around the average $\Delta t_2$ at the control level is shown in Fig. 13, as ± one standard deviation around that point.

The results may be summarized as follows:

1. For the two low-frequency bands of noise, 125-1000 cps and 250-2000 cps, $\Delta t_2$ decreased as noise sensation level was increased up to 50 dB, the highest noise sensation level used. For the other three bands of noise (750-2000 cps, 500-4000 cps, and 1000-8000 cps), the minimal $\Delta t_2$ was found at a lower noise sensation level. The specific values of noise level at which two minimal $\Delta t_2$ was found is the same for both subjects for the 500-4000 cps band of noise (20 dB) but is different for the 1000-8000 cps band of noise (20 dB for subject I.H. and 30 dB for subject I.A.).

These trends are somewhat sharper for subject I.A. than for subject I.H. The difference between subjects may be referred to the difference in variability between the two subjects. The variability around each $\Delta t_2$ for subject I.A., as indicated by one standard deviation, never exceeded 150 microseconds at any point. For subject I.H. the standard deviations were at least twice as large, and often three times as large, as the standard deviations for subject I.A.

2. Above the minimal point, the steepness of the slope for $\Delta t_2$ as a function of noise sensation level is greater for the 1000-8000 cps band of noise than for the other noise bands.

It therefore appears that the finding of a minimal $\Delta t_2$ at a noise sensation level of 30 dB for all three subjects in Experiment D, was related to the broad band of noise used (125-8000 cps). It can be seen from this experiment that with narrower bands of noise the minimal $\Delta t_2$ is related to the spectral composition of the noise band. These results (a decrease in $\Delta t_2$ with an increase in the level of low-frequency noise bands and an increase in $\Delta t_2$ with an increase in level of high-frequency noise bands) are also consistent with the results obtained by manipulating click spectral composition (Experiment C above). In both cases a decrease in low-frequency composition of the clicks, obtained either by filtering the click directly or by presenting a low-frequency background noise, resulted in a decrease in $\Delta t_2$. The congruity of results for different types of experimental manipulation is discussed in greater detail below.

**Experiment F: Monaural Broad-Band Noise**

In Experiment B, the lag click threshold was shown to be related to the amount and direction of interaural intensity asymmetry of a pair of clicks. To restate, an interaural intensity asymmetry favoring the lead click was found to increase $\Delta t_2$, whereas an interaural intensity asymmetry favoring the lag click was found to decrease $\Delta t_2$. In the present experiment the clicks at the two ears are maintained at the same intensity level and background noise presented to one of the ears is used to produce asymmetry in signal-to-noise ratio. The question that is explored, therefore, is whether monaurally presented background noise is equivalent to decreasing the click sensation level.
at that ear. Given the results of Experiments D and E, it may be inferred that such equivalence will not be found.

The method of constant stimuli was employed to gather data on two subjects. As in Experiment D, a broad-band (125-8000 cps) noise was used, and the click level was maintained at 35 dB SL. Clicks were presented dichotically and noise was presented monaurally. Each Δt was presented 30 times. Both subjects were tested with noise presented to the lead ear alone, while only subject H.A. was tested with noise presented to the lag ear alone.

Results are plotted for the two subjects separately as percent report of two clicks as a function of the Δt separating the dichotic clicks with noise level as parameter (Figures 14 and 15). The control curves from Experiment D, i.e., the -20 dB curves, are also shown. By comparison with the control level, monaural noise to the lead ear gives a clear displacement of Δt2 in the direction of longer Δt’s for subject H.A. (Fig. 14) while for subject E.M. (Fig. 15) the displacement is very slight, but in the same direction. On the other hand, when only a 10 dB SL noise was presented to the lag ear alone (Subject H.A. Fig. 14) there was a very large displacement of the curve toward longer Δt’s. In contrast to binaurally presented noise, which reduced Δt2, monaural noise tended to increase Δt2. The increase appeared to be much greater for noise presented to the lag ear alone.

When compared with the results obtained with intensity asymmetry (Experiment E) the effect of monaural noise is seen to be much different. Whereas the direction of interaural intensity asymmetry produces the opposite effects on Δt2, monaural noise increases Δt2 whether presented to the lead or lag ear. Furthermore, the magnitude of the effect of noise presented to the lag ear appears much greater than noise presented to the lead ear.

Experiment C: Monaural Filtered Noise

The results of Experiment E had shown that the spectral content of the noise bands presented binaurally was an important factor in determining the lag click threshold. Having found in Experiment F that a broad-band noise presented monaurally resulted in an increase in the lag click threshold, the question arose as to whether the spectral content of monaural noise was also an important factor affecting the lag click threshold. Accordingly, this experiment was designed to study the effect on the lag click threshold of monaural presentation of one-octave wide low- or high-frequency bands of noise.

The method of limits was employed. Clicks were presented dichotically at 35 dB SL, and noise was presented either to the lead ear alone, the lag ear alone, or both ears. The low-frequency band of noise extended from 375 to 750 cps, and the high-frequency band of noise extended from 3000 to 6000 cps.

15Subsequent to the experiments using three-octave-wide bands of noise (Experiment E), the equipment was modified to increase the amplification of the noise channels which permitted the use of one-octave-wide bands of noise over a sufficient range of intensities.
Fig. 14 Percent report of two clicks is plotted on the ordinate. The temporal interval separating the dichotic clicks is plotted on the abscissa. The parameter of the curves is the ear (lead or lag) to which the broad-band background noise is presented. (Subject: H. A.)

Fig. 15 Percent report of two clicks is plotted on the ordinate. The temporal interval separating the dichotic clicks is plotted on the abscissa. The parameter of the curves is the level of broad-band background noise presented to the lead ear. (Subject: E. M.)
Both noise bands were equated for monaural sensation level. Noise was presented continuously and a pair of dichotic clicks was presented every 5 seconds.

Results are shown for noise presented to the lead ear alone for two subjects in Fig. 16 and for noise presented to the lead ear, the lag ear and to both ears for one subject in Fig. 17. The control level, -20 dB SL, refers to a setting of the attenuator 20 dB below the threshold setting for the 3000-6000 cps noise band. The attenuator setting threshold for this band was lower than that for the 375-750 cps band of noise. However, for all other points on the abscissa, sensation level refers to decibels above the threshold for each band determined separately. Results presented in Fig. 16 are based on 30 threshold crossings per point, and the results presented in Fig. 17 are based on 60 threshold crossings for the control level and 20 threshold crossings for the other values.

When narrow-band high-frequency noise is presented to the lead ear, the lag click threshold increases with increasing noise level whereas when narrow-band low-frequency noise is presented to the lead ear, the lag click threshold decreases with increasing noise level (Figs. 16 and 17). However, when the noise is presented to the lag ear alone there is a dramatic increase in the lag click threshold which is particularly marked for high-frequency noise (Fig. 17). As distinguished from broader bands of noise (Experiment F), a one octave-wide high-frequency band of noise presented to both ears results in a slight increase in the lag click threshold. However a low-frequency one-octave band of noise presented to both ears yields results which are consistent with the broad-band findings in producing a decrease in the lag click threshold (Fig. 17). Thus, results for one octave-wide bands of noise to the lead ear alone or to both ears are essentially similar; high-frequency noise increases the lag click threshold while low-frequency noise decreases the lag click threshold. The effect of noise to the lag ear alone is, however, quite different; first in that both low- and high-frequency noise result in an increase in the lag click threshold and second, in that there is a very marked increase in the lag click threshold with high-frequency noise.

DISCUSSION

The essential findings of this study may be summarized as follows: The temporal interval between dichotic clicks necessary for the detection of the lag click has been shown to be related to the sensation level of the clicks, the interaural intensity asymmetry, the spectral composition of the clicks and the over-all level and spectral characteristics of the background noise. As had been shown in previous studies (Guttman, Teas, T0), the present experiment indicated that an increase in the sensation level of the clicks results in a decrease in the lag click threshold. An interaural intensity asymmetry favoring the lead click was shown to result in an increase in $\Delta t_2$, while an interaural intensity asymmetry favoring the lag click was shown to result in a decrease in $\Delta t_2$. A manipulation of the click spectrum to reduce low-frequency components of a pair of dichotic clicks results in a decrease in $\Delta t_2$.

Low sensation levels of broad-band background noise decrease $\Delta t_2$, an
Fig. 16 The average temporal interval ($\Delta t$) for the detection of the lag click is plotted on the ordinate. The sensation level of the background noise is plotted on the abscissa. The parameter is the spectral content of the noise presented to the lead ear. Data is plotted for two subjects.

Fig. 17 The average temporal interval ($\Delta t$) for the detection of the lag click is plotted on the ordinate. The sensation level of the background noise is plotted on the abscissa. The curve has been broken into three parts; each part depicting data for a different type of noise presentation; to both ears, to the lead ear, and to the lag ear. The parameter is the spectral content of the background noise. Data is presented for one subject.
effect not predictable from signal-to-noise considerations. Low-frequency bands of noise presented either binaurally or to the lead ear result in a decrease in $\Delta t_2$, while either low- or high-frequency bands of noise presented to the lag ear result in an increase in $\Delta t_2$.

In discussing the results of Experiment C, we had concluded that since both spectral differences and sound pressure versus time differences could be invoked to explain the fact that shorter $\Delta t_2$'s are obtained for high-frequency clicks than for low-frequency clicks, no discrimination could be made on the basis of the data between the two hypotheses.

The results of Experiments E and G indicate, however, that even when no direct manipulation of the click duration or spectrum is performed and only the spectral composition of the background noise is altered, low-frequency noise decreases the lag-click threshold, while high-frequency noise increases the lag-click threshold. Thus, an operation which reduces or masks low-frequency components of the clicks indirectly (by a background noise) decreases the lag click threshold, while an operation which reduces or masks high-frequency components of the clicks indirectly (by background noise) increases the lag click threshold. It seems reasonable to argue on the basis of these results that if the spectral composition of the background noise affects $\Delta t_2$ in a manner consistent with a direct manipulation of click spectrum that it is click spectrum differences rather than just sound pressure versus time (i.e. dead-time) differences between the high- and low-frequency clicks which determines $\Delta t_2$.

The results are consistent with the following set of generalizations. First, an over-all increase in click sensation level decreases the lag click threshold. Second, any operation which reduces the low-frequency components of the clicks at the lead ear or at both ears by either direct manipulation or by manipulation of background noise reduces the lag click threshold. Reducing the high-frequency components at the lead ear or at both ears by the same manipulations results in the reverse, an increase in lag click threshold. For the lag ear, reducing either the low- or the high-frequency components of the click by manipulating background noise increases the lag click threshold. Finally, an intensity asymmetry favoring the lead click increases the lag click threshold, while an intensity asymmetry favoring the lag click decreases the lag click threshold.

A model to interpret most of these results has been developed elsewhere. Since the model is not yet fully explored, it will not be presented in detail here. However, the main points may be sketched briefly.

1. The lead click exerts an inhibitory influence on the central representation of the lag click which is a function of both the time interval separating the clicks and their relative intensities. The lag click threshold represents the release of the lag click from the inhibitory influence of the lead click.

H. Babkoff, "The Effect of Background Noise on The Dichotic Temporal Interval Required for the Detection of the Lag Click." Doctoral Dissertation, Columbia University (1964)
2. The central representation of low-frequency components of the clicks is prolonged in time (i.e. firing is spread in time) whereas the central representation of high-frequency components of the clicks, involving greater synchrony of neural firing, is brief in time.

The notion of an inhibitory influence of the lead on the lag click which decays as a function of the temporal separation of the two clicks is postulated in models by Boring\(^7\) and Matzker\(^8\) and is supported by single unit recording in the superior olive by Galambos, Schwartzkopf and Rupert\(^9\) and by Moushegian, Rupert and Whitcomb\(^10\). The differential effect of stimulus frequency on the temporal spread of neural firing is supported by recording of \(N_1\) by Kemp, Coppée and Robinson\(^11\), Deatherage, Eldredge and Davis\(^12\) and by Teas, Eldredge and Davis\(^13\) and by single unit recording in the eighth nerve by Kiang, Watanabe, Thomas and Clark.\(^14\) In both these lines of work, the neural response to low-frequency stimuli is prolonged in time whereas responses to high-frequency stimuli is synchronized and brief in time.

According to the model briefly outlined, the differential effects of intensity asymmetry of the clicks that were reported above i.e. intensity asymmetry favoring the lead ear increases the lag click while intensity asymmetry favoring the lag ear decreases the lag click threshold (Section I, Experiment B), can thus be understood in terms of the relative numbers of inhibited versus excited neurons in the auditory pathway responding to the lag click at any given \(\Delta t\). At a given \(\Delta t\), a more intense lead click results in the inhibition of more neurons which might otherwise respond to the lag click, whereas at the same \(\Delta t\), a more intense lag click results in a relatively greater number of uninhibited neurons.


The decrease in the lag click threshold achieved by reducing the low-frequency components of the clicks (Section I, Experiment D) can be understood in terms of a decrease in the temporal spread of neural firing which results in a decreased inhibitory effect of the lead on the lag click. Similarly, the effects of low-frequency background noise in decreasing the lag click threshold (Section II, Experiments B and C) can be understood as the result of masking the low-frequency components of the clicks and a consequent decrease in the temporal spread of neural firing.

According to the principles outlined above, masking the low-frequency composition of the clicks should only be effective in decreasing the lag click threshold when noise is presented to the lead ear alone or to both ears, but should be ineffective when low-frequency noise is presented to the lag ear alone. The results of Experiment G (Section II) confirm this prediction.

The decrease in the lag click threshold resulting from low sensation level broad-band noise may be understood as due to a reduction in the temporal spread of neural firing resulting from the masking of low-frequency components of the clicks. At higher noise sensation levels, however, to the extent that the high-frequency components of the clicks are also masked, the lag click threshold is increased due to the reduction in the total number of neurons responding synchronously.

The effect of an overall increase in click sensation level in decreasing the lag click threshold and the effect of a broad-band or high-frequency noise of even low intensity level presented to the lag ear alone (Section II, Experiments C and D) in increasing the lag click threshold are not explainable in terms of the principles outlined above.