Notes and Comment

Dichotic temporal interactions: Nonmonotonic discrimination function

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When one of a pair of equally intense dichotically presented auditory transients (clicks) leads the other in time (Δt), a listener first reports a fused "image" lateralized toward the leading ear ($20 \mu\text{sec} \leq \Delta t \leq 1.0 \text{ msec}$). As Δt extends from 2 to 6 msec, the fused auditory image breaks up and the lead click is perceived as louder ($2.0 \leq \Delta t \leq 6.0 \text{ msec}$). With $6.0 \leq \Delta t \leq 10\text{-}15 \text{ msec}$, the two clicks are perceived as equal in loudness and judgments of their order are at chance. With $\Delta t \geq 15\text{-}20 \text{ msec}$, judgments of the temporal order can be made (Babkoff, 1975; Babkoff & Sutton, 1963, 1966; Babkoff, Sutton, & Barris, 1973; David, Guttman, & Van Bergeijk, 1959; Hirsh, 1959; Hirsh & Sherrick, 1961; Sternberg & Knoll, 1973).

Recently, I (Babkoff, 1975) reported the results of a systematic study of two of these phenomena. A subject listened to a dichotic pair of clicks at a Δt which varied between 2 and 128 msec. On each trial, his task was to report at which ear he heard two fused clicks ($2 \leq \Delta t \leq 4 \text{ msec}$) or the first of the two dichotic clicks ($\Delta t > 4 \text{ msec}$). Discrimination level was found to be a nonmonotonic function of Δt , consisting of a left segment, which decreases as Δt increases from 2 to 8-12 msec, and a right segment, which increases as Δt increases from 12 to 128 msec. Analyses indicated that the discrimination function consisted of two separate curves intercepting near 10 msec; the left curve reflects the breakup of the fused dichotic click. The right curve, which increased with increasing Δt , was assumed to reflect judgment of auditory temporal order.

The method used (Babkoff, 1975) was a variation of the two-alternative forced choice with an accuracy indicator (known to E) but lacking a comparison. Within a block of 20 trials, Δt was constant, but it was randomized from block to block. It was argued that keeping Δt constant within a block of trials made it easier for the subject to learn to identify the relevant cue and thus maximize performance. This is especially important in a task like dichotic temporal discrimination, since the variety of cues may serve to

confuse the subject and decrease discrimination. However, one of the difficulties with such a design is that subjects can arbitrarily select one cue within a given block and ignore others (Babkoff, 1975; Kietzman & Sutton, 1968). It is also not clear what is the appropriate signal detection model to apply to such a design to obtain a relatively response-bias-free measure of discrimination (d'). This may be an important factor because of the issue of "cue selection" noted above.

The present communication is a report of an experiment designed to utilize the same maximization of cue learning, i.e., block presentation of a fixed Δt but with an experimental paradigm which yields a d' discrimination index, e.g., an AX design (described below). If the data generated by such a paradigm show the same type of nonmonotonicity, this result will be further validation for concluding that the dichotic temporal discrimination function is V-shaped.

METHOD

The interval between the dichotic clicks (Δt) was varied from 2 to 128 msec. All Δt s were generated by a crystal-controlled timer (local design), calibrated and monitored by a Systron Donner counter timer, Model 1034 (Babkoff et al., 1973). Error did not exceed .05%. Intertrial intervals were 10 sec.

The transient stimuli were generated as square waves and shaped as negative-going pulses with an exponential return to base with a time constant of .1 msec. The negative-going exponential pulses were transduced as clicks by a set of Sharpe HL-10 circumaural earphones. Pictures of such transduced clicks are shown elsewhere (Babkoff & Sutton, 1966).

The subject was seated in a booth facing a panel with a warning light, a feedback light, and two response keys. A trial was signaled by the onset of a warning light and consisted of two presentation intervals, constituting an AX design. In the first interval (A), a single pair of dichotic clicks was presented with either (a) the first click to the right ear and the second click to the left ear (R- Δt -L) or (b) the opposite sequence (L- Δt -R). The second interval (X) contained either (c) a pair of clicks with the same sequence as in the first interval ("same") or (d) a sequence opposite to that in the first interval ("different"). On every trial (within a given block of trials), the Δt separating the clicks in the second interval was always the same as in the first interval, whether the sequence of stimulus presentation was the same (e.g., first interval, R- Δt -L; second interval, R- Δt -L) or different (e.g., first interval, R- Δt -L; second interval, L- Δt -R). Δt was constant within a block of 20 trials, but randomized across blocks of trials. All AX permutations were randomized within each block of trials. Subjects were instructed to listen to the first interval and compare the second interval to the first, then to respond by depressing the key marked "same" if the click pair in the second interval was the same as in the first, or to depress the key marked "different" if the click pair in the second interval was different from that in the first. The subjects received feedback after each trial as to the correctness of the response. The subjects were trained for three sessions on all of

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the Δt s (2, 4, 6, 8, 12, 16, 24, 48, 64, and 128 msec) subsequently used in the experiment.

Monaural thresholds of each subject were measured before the experiment by the method of limits and monitored throughout the experiment. Since no large changes in threshold were recorded, these estimates were maintained throughout. Stimulus intensity at each ear was set to 32 dB re monaural threshold. Each subject was tested over five sessions. A session consisted of the randomized presentation of 10 blocks of 20 trials (1 block at each Δt).

RESULTS

The data were initially analyzed by a two-way analysis of variance with repeated measurements (Δt and the sequence of blocks of trials). The results indicate that only one of the variables, Δt , is significant in determining dichotic temporal discrimination level ($F = 9.25$, $p \leq .001$). There is no effect of the sequence of the blocks of trials on discrimination ($F = 2.0$, $p > .25$), nor is there any significant interaction involving the sequence of blocks of trials and Δt ($F = .17$).

The cumulative data (over the five sessions) are plotted, in Figure 1, separately for each subject, as percent correct discrimination on the ordinate and as a function of Δt in logarithmic units on the abscissa.

These data indicate that subjects may differ in absolute discrimination level; however, the overall form of the function as well as the anchor points of 2 msec on the left segment and 128 msec on the right segment are the same for the three subjects. The discrimination curve is a nonmonotonic U- or V-shaped function.

In the AX design, the subject must decide whether the two dichotic click pairs in the two intervals of a

Figure 1. Percent discrimination is plotted on the ordinate as a function of the dichotic temporal interval (Δt) separating the stimuli on a logarithmic abscissa. Data are plotted for each of the three subjects separately.

Figure 2. d' is plotted on the ordinate as a function of the dichotic temporal interval (Δt) separating the stimuli on a logarithmic abscissa. Data are plotted for each of the three subjects separately.

trial are the same or different. The assumption is made that the subject bases his decision on the absolute differences between his perceptions in the two intervals ($A - X$) and responds "same" if the difference is smaller than the criterion and "different" if the difference is larger than the criterion (Kaplan, Macmillan, & Creelman, 1978). The data can, therefore, be transformed to hits and false alarms according to these decision rules as developed by Kaplan et al. (1978). For the purposes of this analysis, all of the data for R- Δt -L, followed by R- Δt -L and L- Δt -R, followed by L- Δt -R were analyzed together as the "same" condition, while the data for R- Δt -L, followed by L- Δt -R and L- Δt -R, followed by R- Δt -L, were analyzed together as the "different" condition. The data were transformed to the tabulated d' s for an AX design (Kaplan et al., 1978) and are plotted for each subject separately in Figure 2.

The data plotted in Figure 2 have the same general form as the data plotted in Figure 1, a U- or V-shaped function relating d' on the ordinate to Δt in milliseconds on a logarithmic abscissa. Individual differences are expressed in terms of the d' levels. For all three subjects, d' is very large for $\Delta t = 2$ msec and 128 msec, the two anchor points. For the other Δt values, $1.0 \leq d' \leq 4.7$ at $\Delta t = 4$ msec and $1.35 \leq d' \leq 3.3$ at $\Delta t = 64$ msec. For $8 \leq \Delta t \leq 48$ msec, $0 \leq d' \leq 1.0$.

The d' data were analyzed by a one-way analysis of variance with repeated measurements. The results indicate that d' changes significantly as a function of Δt ($F = 6.7986$, $p \leq .002$).

DISCUSSION

The data are complementary to those presented previously (Babkoff, 1975) in further indicating that dichotic temporal discrimination of pairs of clicks is nonmonotonic when Δt varies between 2 to 128 msec with anchor points of high-level discrimination at the shortest and at the longest Δt s.

Several additional conclusions may be added based on the present report. First, a change in methodology, from a design requiring the subject to respond to each pair of dichotic clicks as to the direction of the fused click ($2 \text{ msec} \leq \Delta t \leq 4 \text{ msec}$) or to the order of the click presentation to a design requiring the subject to compare the second pair of dichotic clicks to the first pair and respond whether the two pairs are the same or different (AX design) does not change the basic form of the discrimination function. It may be noted that, in both the first report and in this report, the design maximized the subjects' use of cues for each Δt , by maintaining Δt constant within a block of trials. Second, the use of a relatively response-bias-free measure (d') yields essentially the same form of the discrimination function. Third, for subjects even slightly trained (three sessions) prior to the experiment, there is no effect of the sequence of blocks of trials on the discrimination level or on the form of the function (no significant Δt by Block Sequence interaction).

These data thus lend further support to the conclusions reached in the earlier paper, that the temporal-discrimination/dichotic-interval function within this time range is bisegmented, with one segment decreasing with increases in the short Δt range and the sec-

ond segment increasing with increases in the longer Δt range. The overall framework within which these data may be considered was discussed in the earlier paper (Babkoff, 1975).

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