Violations of visual simultaneity¹

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We present the result of two experiments that demonstrate an ability on the part of Os to detect asynchronies in visual stimuli within the range of 0-100 msec. Such results are additional examples of an ability on the part of the human O to use information about temporal order to a precision beyond the usual results of visual "simultaneity" experiments. Thus the conventional notions of simultaneity and its corollary, the psychological moment, may be reflections of psychophysical technique rather than the biological function of sensory systems.

A problem of continued interest to students of visual perception concerns the preservation of information about the relative temporal order or simultaneity of two sequential visual stimuli. In some of the recent studies concerned with simultaneity (e.g., Lichtenstein, 1961; Fraisse, 1966), the psychophysical method asks directly of the S, "Are the two (or more) stimuli simultaneous?" Typically, the results of experimental questions posed in this manner indicate that when two stimuli are separated by an interval of less than about 100 msec, Ss answer this question affirmatively.

However, in auditory experiments (cf. Piéron, 1952), two stimuli are reported to be simultaneous when they are separated by about 20 msec. Nevertheless, Ss can, in other contexts, respond differentially to stimulus patterns in which the asynchrony is measured in fractions of a microsecond. Auditory localization data suggests temporal discriminations of the order of a few microseconds and recent experiments (cf. Pollack, 1968) show nanosecond sensitivities to pulse interval jitter.

Therefore, it seems that an alternative form of the question asked in successive visual-stimulation experiments might also permit differential responses as a function of stimulus intervals, even at intervals at which stimuli are reported to be concurrent with the simultaneity question. Ss would be, in effect, allowed to use all of the information contained in the stimulus pattern, rather than being limited to those codes underlying only apparent simultaneity. In fact, many other experimental paradigms do exactly this. Studies in visual masking, short-term visual

storage, apparent movement, and other empirical results all show that there is sensitivity to stimulus interval to a degree not suggested by the answers to the simultaneity question.

Recently, our laboratory has been working with a pattern-recognition problem, using a masking stimulus called dynamic visual noise (DVN) (see Uttal, 1969a, b, c). DVN is a series of temporally distributed dots plotted on a CRT randomly in space but at regular temporal intervals. DVN can be used as a mask for character-recognition studies by overlapping the space in which the character formed from similar dots is presented. In this way, character recognition can be used as an assay technique to determine the effects of varying densities of DVN and various temporal relations between the character and the DVN. In one of our earlier studies (Uttal, 1969a), for example, a very substantial difference in character-recognition scores was obtained when the character was embedded in both leading and trailing DVN (a recognition score of 12%) compared to either leading or trailing DVN alone (a recognition score of 50%).

This result suggested that the S is not dealing with the masking dots and the character dots in the manner that would be predicted by a simplistic notion of simultaneity. Rather, some behavioral measure, sensitive to the small differences in synchrony of the two stimuli can be elicited from the S. In the present study, we first track the change in recognition scores as the character is moved from a region outside the period of the DVN into the body of the DVN in both the leading and trailing direction and show that there is a substantial differential effect throughout this transition zone. We then use a static dot pattern, in which all of the masking dots are presented in less than 3.2 msec, to further demonstrate continuous perceptual discrimination within intervals of less than 100 msec. The purpose of these demonstrations is to emphasize the fact that "simultaneity" in visual perception can be considered more realistically as an operationally defined constraint of a particular psychophysical method, rather than as a fundamental biological limitation. Such a point of view also helps us to appreciate the

often-overlooked fact that information about a given stimulus dimension need not be represented in exactly the same dimension at various levels of the nervous system.

METHOD

Subjects

Each point plotted in the data figures represents the pooled results of six to eight Ss for each condition. All Ss had participated in several experiments of similar design and should be considered to be highly trained Os. In some instances these Ss were performing at the 50% character-recognition level in experimental conditions in which naive Os could not do better than chance. Performance levels of 98% correct character identification were typical when the Ss made the transition from training trials with no masking to the experiment itself. All Ss had normal vision, although in some cases with correction.

Apparatus

A complete description of the experimental apparatus is given in an earlier paper (Uttal, 1969a). Briefly, the entire experiment, including stimulus selection and presentation, as well as response acquisition and analysis, was under the control of a medium-sized digital computer (a Digital Equipment Corporation PDP-9). Alphabetic characters, composed of dots, were presented in about a third of 1 msec on the face of a CRT, with an ultrashort persistence P15 phosphor. The masking patterns, consisting of randomly positioned dots, were plotted over an area slightly larger than that defining the limits of the character size. Specifically, the character subtended a visual angle of 4 x 3 deg, while the noise was plotted in a region of about 9 x 6 deg. The S viewed the CRT binocularly at a distance of 14 in. His head was guided into position by a forehead bar, but no attempt was made to constrain head movement. Because of the small differences between the characters D, O, and Q, O and Q were not included in the experimental alphabet set.

General Procedure

During each daily session, the values of the independent variable defining the temporal relation between the character and the masking dots were kept constant,

EXPERIMENT 1

Fig. 1. This figure schematically presents the experimental paradigm used in the two parts of Experiment 1. The numerals indicate the position of the character in time relative to the masking burst, the time course of which is indicated by the horizontal line. Negative values are for characters which are more or less embedded in the DVN.

but the characters were presented in a random order defined by a multiplicative algorithm evaluated by the computer before each trial. The sequence of trials was self-paced by the S. After each trial, a ready signal was presented at the top of the CRT screen. When the S felt ready, he depressed a hand-held pushbutton that released, after a 1-sec delay, the sequence of character and masking selected for that day. The S reported the character he saw over an intercom system to a transcriber, who entered it into the computer through a typewriter-like keyboard. If a mistake had been made, the transcriber fed back the name of the correct character to the S.

Each S ran for ½ h in a light-tight and soundproof booth and then exchanged places with the transcriber for the second ½ h. Response information was acquired on the magnetic-tape unit of the computer and, at the end of each day, was immediately analyzed into both individual and group summaries by appropriate analysis routines. The temporal relationship between the presentation of the character and the presentation of the masking patterns was the specific independent variable used in the two experiments.

Experiment 1

The specific purpose of this experiment was to determine the nature of the transition between the recognition scores obtained when the character was at the beginning or end of a temporally dispersed burst of DVN and when it was embedded in the DVN. The experiment consisted of two parts, each of which measured the effect of varying the temporal position of the character relative to the DVN. In both cases, on each sequential day, the character

was moved further from the original position, in which it was leading the DVN by a 100-msec delay, closer to the DVN until it ultimately moved into it. This process continued until recognition scores were reduced to the same low level as obtained when the character was centered in the DVN. In the first part of the experiment, the character was moved from a leading position relative to the DVN into the DVN, while in the second part, the character moved from a trailing position into the DVN.

The meaning of the intervals defining the position of the character relative to the DVN varied depending upon which part of the experiment was under discussion. When the character was outside the noise in either a leading or a trailing condition, the position of the character was defined by the interval between the character and the edge of the DVN. Empty intervals of 100, 50, 30, and 0 msec were used in this situation.

When the character entered the DVN, the interval defining its position no longer represented an empty period between the character and the DVN, but rather was an indicator of how many milliseconds "deep" into the DVN the character was positioned. Figure 1 depicts the timing relations of the character and the DVN in the two parts of Experiment 1. The DVN level used throughout this experiment was 1 msec, i.e., the sequential dots of the DVN were plotted at 1-msec intervals during the time the DVN burst was on. The total burst length for all conditions of this experiment was 1 sec.

Experiment 2

Because the distributed characteristics of DVN place some of the dots in regions in

which they would have lesser masking effects and some in regions in which the same number of dots would have greater effects, it is clear that Experiment 1 confounds a number of different effects by mixing different levels of effectiveness for dots presented at different positions in the interval. Experiment 2 was, therefore, executed in such a way that all of the masking dots were placed at a constant interval from the dots of the character. This was done by reprogramming the computer to present 100 dots of DVN in as brief a time as possible, but at controlled delays following the character. The computer used in this experiment allowed us to plot the 100 dots in 3.2 msec. Experiment 2 was performed only in this backward-masking condition. Intervals between the character and the burst of masking dots of 100, 75, 50, 40, 30, 20, 10, and 0 msec were used. Character recognition was measured as described above.

RESULTS

The results of both parts of Experiment 1 are plotted together in Fig. 2 to emphasize the similarities between forward- and backward-masking effects. The data points plotted within the limits of the two dashed lines are for those positions of the character inside the burst of DVN. The dotted-and-dashed line indicates the division between the results of the two parts of the experiment. Data outside the two dashed lines indicate character positions outside the noise burst.

The first result to be noticed is that the character-recognition scores, the dependent variable, decrease continuously the closer the character is to the DVN, and continue to decrease as the character moves into the temporal region of the DVN. The data points for the character positions outside of the burst of DVN generally replicate the values obtained in earlier experiments. For those positions in which the character is embedded in the burst of DVN, the recognition scores continue to decrease as the character moves further into the DVN. Let us first consider those conditions in which the masking DVN is trailing the presentation of the character. When the interval between the character and the

Fig. 2. The results of the two parts of Experiment 1, plotted on the same graph to emphasize the symmetry of the effects of forward and backward masking. The numerals on the horizontal axis are the same as those in Fig. 1 and indicate the specific configuration of the stimuli as described there.

DVN is decreased so that the character enters trailing DVN, we are essentially adding leading DVN. Similarly, when the DVN was preceding the character and the character enters the DVN by a decrease in the interval between the DVN and the character, we are adding trailing DVN. The amount of additional impairment in character recognition is not equal in these two instances. Adding forward masking to trailing masking leads to a greater deficit and a reduction to chance levels more quickly. This is expected in accord with the previously noted result that forward masking with DVN is the more persistent and effective masking condition.

The size of the intervals at which the two curves arrive at the same recognition scores as that obtained with the character centered between one full second of leading and one full second of trailing DVN (a recognition score indicated by the horizontal dashed line) is also of some significance. The amounts of time in which additional dots are effective provide

estimates of the maximum integrating period of the persistence of this type of masking effect. For a character entering trailing noise, 50 msec of forward masking is sufficient to reduce the score to the value for a character centered in a 2-sec burst of DVN. For a character entering leading noise, however, 70 msec of trailing noise is required.

The results of Experiment 2 are shown in Fig. 3. It is clearly evident that within the entire range of intervals used, there is a continuously differential effect. Scores decline from nearly perfect recognition to 27% of the total number of trials. This particular recognition score is characteristic of the particular number of dots (100) used, and a family of curves would obtain if we had scanned the parameter of masking dot numerosity.

Both of these experiments clearly indicate an ability on the part of the S to respond differentially and continuously to stimuli separated by an interval of less than 100 msec. Thus, information about the asynchrony of the two stimuli is preserved in some manner even though they appear to be "simultaneous" to the S. The earlier estimates of visual simultaneity should be considered, therefore, to be methodological artifacts produced by an insufficiently vigorous psychophysical test.

DISCUSSION

There are two main issues of concern in a discussion of the results of these experiments. First we will consider the issue of simultaneity as it has been used in the older sense. Then we will consider the notion of simultaneity as it has been used in terms of the psychological moment or integrating period in some of the newer literature.

The older notion of simultaneity can have both a strong and a weak meaning. A weak definition would define the term operationally as the set of psychophysical responses to the question, "Did the two

stimuli occur at the same time?" A strong definition would imply that no behavioral discrimination is possible between two stimuli occurring within some minimum interval, because the information about order is actually lost somewhere in the nervous system. Yet, clearly, there is a large number of psychological phenomena that indicate that such information is not lost. Mayzner's study of sequential blanking (Mayzner, Tresselt, & Helfer, 1967) indicates that order information is very important at intervals as short as 20 msec, and that characters actually can inhibit each other selectively depending upon presentation order. The work of many investigators on backward and forward masking (as summarized by Weisstein, 1968, and by Kahneman, 1968) also show effects similar to the ones reported in this present paper that are characterized by continuous functional relationships between some dependent variable and an interval of less than 100 msec between the test and masking stimuli. The related work on apparent motion also shows a similar sort of discriminative response to brief intervals. It is even the case that Ss can learn to use alternative modes of increased discriminability without explicit instructions, as was noted and discussed by Thor (1968) in his comments on Robinson's (1967) work.³

Thus, while the weak notion of simultaneity may be acceptable, the strong definition certainly does not generally hold. Stimuli are "simultaneous" in Lichtenstein's (1961) and Fraisse's (1966) experiments only in the sense that the Es have not asked a sufficiently vigorous question and have thus set their Ss to use only part of the available information. In such situations as the present study and the forward- and backward-masking studies, the S is essentially freed from these constraints on the use of all available information and is able to perform as if the stimulus and mask were asynchronous. The biological information-processing limits of the organism are, therefore, not adequately tested by the "simultaneity" question while they are in these alternative paradigms.

The second major issue to be discussed in this paper concerns a problem that has

Fig. 3. The results of Experiment 2, showing the backward masking effects of a burst of 100 dots plotted as fast as possible (a 3.2-msec total duration of the masking burst) at various delays following the character.

been most clearly stated by Allport (1968). He points out that the notion of the psychological moment also has a weak and a strong formulation. The weak formulation revolves around the idea that perception is discontinuous, and that information is dealt with separately in sequential psychological moments. The stronger formulation of the notion of the psychological moment is what links the concept to the problem of perceptual simultaneity. Allport considers this stronger formulation to imply that information about order is lost in each of these psychological moments. In other words, two stimuli are perceptually simultaneous if they occur in the same moment. He makes the exceedingly important point that, almost without exception, all experiments that deal with the psychological moment do not discriminate between the two possible versions of this stronger formulation, namely, that the psychological moment is randomly placed with respect to the stimulus as opposed to the possibility that it is sliding along continuously in time. In the latter case, a given moment could, of course, be synchronized with any and every sequential stimulus event.

Because of the statistical nature of the way in which data in almost all related experiments (with the notable exception of Allport's ingenious study) have been collected, these data are consistent with either a sliding or a randomly positioned psychological moment, synchronized or unsynchronized to the stimulus event itself. But these experiments, in general, do not distinguish between the two. Insufficient consideration has been given in many of the cited experiments to the possibility that the moment is nothing more than the persistence, in some short-term visual store, of sequentially presented stimuli.

It is our contention that because of the special characteristics of the punctate stimuli used in both the masking noise and the test character, the effects we have measured are almost purely due to the confusion of the dots of the test character and the visual noise. There is little in the way of peripheral retinal mixing and little lateral inhibitory interaction possible at other levels of the nervous system. We thus are measuring a confusion type of phenomenon that directly reflects how thoroughly mixed the dots of the two stimuli are, or, in other words, the extent to which they are simultaneous. Thus, the discriminative abilities of our Ss indicate that stimuli are not simultaneous in the sense of Fraisse and Lichtenstein. Ss are able to separate the signal from the noise with continuously increasing efficiency as the interval between the two increases, as long as they are not forced by the psychophysical question to discard available information.

Consideration of the two possible artifacts—the limitation of full information utilization by the S through the psychophysical method and the fact that many experiments are ambiguous with regard to the distinction between a sliding period of integration and randomly placed stimulus-independent moments—suggests that some reconsideration of the nature of continuity and simultaneity in visual perception would be in order.

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NOTES

1. The research described in this report was supported in part by NSF Grant GB-6093.
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3. The same point has been made by J. Baron who rejected the notion of the psychological moment on the basis of ROC curves for order discrimination (Baron, J. Temporal ROC curves and the psychological moment, *Psychonomic Science*, 1969, 15, 299-300).

(Accepted for publication May 13, 1969.)