Perceptual modification of sensitivity (d'): Modifying temporal resolution by the consistency of the spatial configuration

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The major question in this study was whether perceptual modifications are basic alterations in a sensory system or changes in the S's criterion. Four Ss were given prolonged training with a particular two-lined stimulus, deciding whether the stimulus had been presented in one continuous presentation or in two successive presentations with a temporal gap. The results confirmed the hypothesis, generated from modifications in visual cells, that the S's sensitivity (d') to a two-lined stimulus could be disrupted by the presentation of one original line with a new line. In contrast, two entirely new lines had little effect on the S's sensitivity. A discussion of the results also indicated that temporal resolution must be a plastic process which depends on the consistency of the spatial configuration as well as temporal parameters.

The purpose of the study was to determine if experience can modify the detectability of a stimulus in a simple perceptual discrimination. Psychophysical experiments investigating perceptual modifications have had three long-standing problems: (1) finding an appropriate response variable, (2) finding a measure of threshold or sensitivity that is not affected by the S's attitude, and (3) finding an independent variable that will produce a change in sensitivity.

The most satisfactory solution to the first two problems has been to use a signal detection method instead of a classical threshold method (Swets, 1961; Swets, Tanner, & Birdsall, 1961). Expressed in signal detection terminology, an alteration in a sensory system should change either the signal or noise distribution and result in a change in the S's sensitivity (d'). If, on the other hand, the experimental manipulations believed to produce a perceptual modification alter the S's strategy for detecting the signal, then the S's criterion (L) should change instead of sensitivity.

The problem is finding an independent variable that will produce a change in sensitivity. In the last few years, evidence has been found that there are cells in the visual system that will modify their response, if environmental variables are

manipulated. Therefore, it seemed logical to attempt to modify a simple visual discrimination by an environmental manipulation that was analogous to the kind of environmental manipulations which have been shown to change the response of visual cells.

For example, recent studies have shown that early visual experience is capable of modifying single cells in the visual system (Hubel & Wiesel, 1965; Hirsch & Spinelli, 1970, 1971; Blakemore & Cooper, 1970; Shlaer, 1971). These studies have shown that early visual experience can modify the cellular organization believed responsible for binocular vision, orientation, and probably other functions. One question is how much plasticity remains beyond the few-month "critical period" in which total visual deprivation causes physiological deficits. Morrell (1961) demonstrated in adult cats that the sensitivity and response pattern to a specific stimulus can be modified by previous inputs. Chow, Lindsley, and Gollender (1968), investigating binocular and dichoptic lateral geniculate neurons in adult cats, found that the latency of a response as well as pattern was in part a function of previous experience. Morrell (1967) found response modifications in 102 "polymodal" cells out of 890 cells explored in Visual Area 19. Horn and Hill (1969) and Spinelli (1970) found receptive field modifications after prolonged bodily tilt.

It is noteworthy that none of the unit modifications were produced by pairing two stimuli in the same receptor area. Morrell's (1967) examples were either "polymodal" or binocular modifications. Similarly, Chow, Lindsley, and Gollender's (1968) and Chow and Lindsley's

(1969) geniculate modifications were produced by pairing ipsilateral and contralateral stimuli.

The physiological evidence suggests that the effect of pairing two stimuli, at least from different receptor areas, was to produce a modification in some cells. The modification was a change in the unique response to one of the paired stimuli after an interpolated pairing experience. The Ss in the present experiment were given prolonged training with a particular two-lined stimulus, deciding whether the stimulus had been presented in one continuous presentation or in two successive presentations with a temporal gap. The task was constant throughout the experiment to avoid confounding environmental and task variables. If the repeated presentation of these particular two lines together contributed to the S's performance, then it is hypothesized that interpolating one original line with a new line would disrupt the pairing of the two original lines and the S's sensitivity to the original stimulus. However, two entirely new lines interpolated would be expected to have little effect on the sensitivity to the original stimulus. In addition, if the pairing experience requires different receptor areas to produce a modification, then dichoptic pairing of the two lines should produce an effect, and monocular pairing should produce no effect.

METHOD

Subjects

Four graduate students at the University of Waterloo each served for 45 sessions. Each session lasted for approximately 25 min. Two of the Ss had normal uncorrected vision, the third, P.T., was slightly myopic, and the fourth, M.G., had contact lenses. Monocular S J.G. was presented the stimuli in the left eye, monocular S M.G. in the right eye, and A.G. and P.T. were presented the stimuli dichoptically.

Apparatus

The apparatus consisted of a six-field tachistoscope (Scientific Prototype), two three-channel timers (Model GB), an event recorder (Esterline Angus Model A), and a tape drive. The apparatus was wired so that when the S pressed the advance toggle switch, the programming tape advanced one trial, the event recorder advanced, Channel 1 on the event recorder marked the trial, and Channel 2 marked the binary event presented. When the S pressed the start switch, the preprogrammed stimulus was presented after a delay of 1.5 sec and the S responded by pressing either the switch labeled 1 or

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Fig. 1. Illustration of two-lined Stimulus A, Stimulus B with no lines in common with Stimulus A, and Stimulus C with one line in common and one different.

the switch labeled 2, which were connected to Channels 3 and 4. The S counted trials by checking off the trial number.

Stimulus

In the monocular condition, the S looked through a 1-mm artificial pupil and fixated a point on a continuous background of 10 fL, as measured by a Prichard Photometer (Model 1970-PR). In the dichoptic condition, the S fused the fixation points. The stimuli were cutouts superimposed on the background. The luminance of the stimulus plus background was 15 fL. Each stimulus was formed by two lines, 1 deg 24 min x 16.4 min, joined to form an angle of 27 deg. In the dichoptic condition, the two lines were fused to form an angle of 27 deg. The stimulus occurred in one of three possible orientations (Fig. 1). The horizontal and vertical lines in the dichoptic condition were presented to the left eye, and the other lines were presented to the right eye.

Procedure

The S's task was a binary signal detection. On 50% of the trials, the stimulus was presented in one 200-msec exposure. On the remaining 50% of the trials, the 200-msec exposure was preceded by a 20-msec exposure of the same stimulus. On all trials, the 1.5-sec delay between the start of the trial and stimulus onset was constant. The S's task was to decide whether the stimulus had been presented in one continuous presentation or in two successive presentations with a temporal gap.

The first five 160-trial sessions were designed to determine an interstimulus interval (ISI) which would stabilize the S between perfect and chance performance. On the first day, the ISI was changed every 20 trials in a descending then ascending series. On the second day, the beginning ISI was chosen according to the S's performance on the previous day. The initial ISI was the one that produced a d' closest to unity on the previous day.

On Days 3, 4, and 5, the same procedure determined the beginning ISI from the previous day's performance. After the first 5 days, the ISI was fixed at the interval which produced a d' closest to unity. The Ss' ISIs were: A.G., 27 msec; P.T., 15 msec; M.G., 16 msec; and J.G., 26 msec.

Stimulus A, the same stimulus presented in the previous five sessions, was presented for 15 more sessions for each S at his fixed ISI. The purpose of these sessions was to determine the variability of d' and the S's criterion (L).

In the next five sessions, M.G. in the monocular condition and A.G. in the dichoptic condition were presented with Stimulus B. J.G. and P.T. were presented Stimulus C during these sessions. Stimulus A was presented on the next 10 sessions for all Ss. On Sessions 36-40, Ss who were presented Stimulus B, previously, were now presented Stimulus C, and vice versa. Stimulus A was then presented again for five sessions to all Ss.

Several irregularities occurred during the experiment. A.G., after 12 sessions, noted that he was listening to clicks from a relay. Since the clicks were uncorrelated with the task, any hypothesis would be misleading; therefore the E had A.G. wear ear plugs and listen to continuous white noise for the remaining sessions. J.G. was asked about the clicks and he reported that he did not listen to them; since he had already passed the 21st session, he was allowed to proceed without ear plugs. The remaining two Ss had ear plugs and continuous white noise for all sessions.

The second irregularity was a 2-week break at Christmas. The break occurred between Sessions 30 and 31 for Ss A.G., J.G., and P.T., in the

Fig. 2. Changes in sensitivity to Stimulus A during control sessions (6-20) and after five interpolated sessions (21-25 or 36-40) of either Stimulus B with no lines in common with Stimulus A or Stimulus C with one line in common and one different. Interpolated sessions of Stimuli B and C were omitted, and the stimulus presented is indicated above Sessions 26 and 41.

middle of the 10 sessions of Stimulus A. M.G. had no break during her 45 sessions.

RESULTS

Sensitivity Changes in Stimulus A

Figure 2 shows each S's changes in sensitivity (d') to Stimulus A over sessions. The mean and 95% confidence limits for the t distribution were calculated from Sessions 6-20 and plotted for each S as a control reference for all experimental sessions. The order of Stimuli B and C in Sessions 21-25 and 36-40 was counterbalanced. Since Sessions 21-25 and 36-40 were omitted from Fig. 2, the stimulus presented on Sessions 21-25 is indicated in the upper left corner above Session 26 and the stimulus presented on Sessions 36-40 is indicated above Session 41. The null hypothesis was that the interpolation of Stimuli B and C would produce no difference in the sensitivity to Stimulus A compared to control Sessions 6-20. The experimental prediction from the physiological evidence was that Stimulus B composed of two lines entirely different from Stimulus A would produce no change in the S's sensitivity to Stimulus A. Stimulus C, with one line in common with Stimulus A and one different, was expected to disrupt the S's sensitivity to Stimulus A, if the repeated presentation of these particular lines together contributed to the S's sensitivity. The Ss' performance suggests (Fig. 2) that five interpolated sessions with Stimulus B had no appreciable effect on the sensitivity to the pretrained Stimulus A. Using a two-tailed t test and Sessions 6-20 to obtain the error term, the sensitivity to Stimulus A was significantly (A.G., $p < .01$; P.T., $p < .01$; M.G., $p < .01$; J.G., $p < .05$) reduced on the session immediately following Stimulus C and markedly affected on the next 160-trial session (A.G., $p = .30$; P.T., $p < .05$; M.G., $p < .05$; J.G., $p < .05$).

Criterion Changes in Stimulus A

The likelihood (L) ratios were transformed into an equal interval scale by dividing the smaller ordinate into the larger and calling the SN ordinate divided by the N ordinate positive and the inverse negative. The zero origin was set at a likelihood ratio of 1 (SN and N ordinates equal). Figure 3 plots the criterion mean, the criterion variance, and the aftereffect of interpolating Stimuli B and C. The affect of Stimulus B on the S's criterion (L) was unsystematic. Interpolation of Stimulus C had a slight, but insignificant tendency to suppress the S's criterion. There were no significant points in common with

Fig. 3. Changes in criterion for Stimulus A during control sessions (6-20) and after five interpolated sessions (21-25 or 36-40) of either Stimulus B with no lines in common with Stimulus A or Stimulus C with one line in common and one different. Interpolated sessions of Stimuli B and C were omitted, and the stimulus presented is indicated above Sessions 26 and 41.

any two Ss; therefore, in general, interpolating Stimuli B and C produced no significant systematic effect on criterion.

Relationship Between d' and L in Stimulus A

None of the significant changes in d' and L coincided on any experimental session for any S. One session (J.G., No. 14) in the control series showed a significant ($p < .05$) change in both d' and L . There were, however, significant ($p < .05$) correlations between the measure of criterion and sensitivity during both the experimental and control series in two of the four Ss. The finding of a significant relationship between the measure of sensitivity and criterion appears to violate signal detection's assumption of independent processes. However, by using one simple assumption, it is possible to predict this relationship by sources which normally occur in signal detection experiments and which do not violate the assumption of independent processes (Tyson, 1971).

Comparison of Monocular and Dichoptic Ss

If the pairing experience requires different receptor areas to produce a modification, then dichoptic pairing of

the two lines should produce an effect and monocular pairing should produce no effect. The monocular Ss (M.G. and J.G.) were indistinguishable from the dichoptic Ss in terms of changes in sensitivity or criterion during the control and experimental sessions.

Sensitivity and Criterion Changes in Stimuli B and C

Using a two-tailed t test, the difference in sensitivity to Stimuli B and C was compared, but it was found to be insignificant ($p > .05$) for all four Ss. There was a tendency for sensitivity and, to a lesser degree, criterion to increase over sessions for both stimuli. The significance of these changes in Stimuli B and C, however, cannot be assessed with this design.

DISCUSSION

The results demonstrate that the S's ability to detect the difference between one and two presentations of a two-lined stimulus can be changed by interpolating a stimulus with one common and one different line. At first glance, the obvious difference between the trials on which the stimulus had been presented once and twice was the presence or absence of the 20-msec stimulus. The basis for discrimination would then be the detectability of the 20-msec stimulus,

Fig. 4. Changes in sensitivity and criterion for Stimulus A during the 200-msec vs 220-msec sessions and the 200-msec vs 240-msec sessions.

and, therefore, changes in sensitivity reflect changes in the S's ability to detect the presence or absence of the 20-msec stimulus. Classically, the detectability of a stimulus depends on the total light energy entering the eye when the duration is short (Bloch's law) and the area is small (Ricco's law). When the energy input and adaptative state of the eye (Barlow, 1958) are measured in the present experiment, the results indicate that the 20-msec stimulus would always be easily detected, and, therefore, the presence or absence of the 20-msec stimulus could not be the basis for discrimination.

The Ss' relative inability to detect the presence of the 20-msec stimulus must then reflect an interaction between the physically separated 20-msec and 200-msec pulses. Somehow, interpolating a similar stimulus with one common and one different line changed the interaction between these flashes.

Since at least 1915, Es investigating the interactions between flashes have interpreted their results in terms of temporal resolution (Dunlap, 1915). Temporal resolution is the minimal time interval between two pulses which allows them to be perceived as successive and not simultaneous. Unfortunately, two-pulse forced-choice methods, like those used in the present experiment, cannot always be related to temporal resolution, as Kietzman and Sutton (1968) have demonstrated effectively

with stimulus manipulations and cue reports.

With Kietzman and Sutton's (1968) precautions in mind, the basis for discrimination in the present experiment will have to be determined before the results can be interpreted in terms of temporal resolution. First, the S's task was to report whether the stimulus had been presented once or twice, like the single stimulus method, but there is no guarantee that the instructions were followed. In fact, the one- and two-pulse conditions differed not only in total duration, but also in total energy. Second, the Ss were asked what cue they had used and reported unanimously that they had used a "flicker" as the distinctive feature of doubleness, which adds some introspective support to the temporal resolution hypothesis. To establish that the interruption was the basis for discrimination, two Ss (J.G. and P.T.) each served for 10 more sessions. Half of the sessions required a 200-msec vs 220-msec discrimination and the other half required a 200-msec vs 240-msec discrimination. The order was random, and only one S, P.T., knew the purpose of the experiment. The null hypothesis was that if the energy difference was the basis for the discrimination, then performance on the 200-msec vs 220-msec sessions should equal the control in the previous experiment. The second null hypothesis was that if the total duration and energy difference cues combined as the basis

for discrimination, then performance on the 200-msec vs 240-msec sessions should be at least equal to the control sessions.

The results in Fig. 4 show that performance for both the 220-msec and 240-msec conditions was near chance and in no case close enough to the control sessions to have been produced by chance at the .01 level, using a two-tailed t test. The S's criterion, on the other hand, was significantly ($p < .05$) different from the control only once (Fig. 4). The two null hypotheses must be rejected, and the conclusion is reached that the energy or duration cues alone or in combination cannot account for the present results.

There is always the possibility in discrimination tasks, no matter how many cues are eliminated, that the S may be using unforeseen cues. If the S was not using the same cue throughout the present experiment, then the results could be interpreted in terms of shifting from one cue to another. For example, assume that the S was using one cue during the control presentation of Stimulus A and, when exposed to Stimulus B or C, shifted to a new cue. When Stimulus A was presented again, the cue shift may have interfered with the detectability of Stimulus A. The possibility is real, but is the cue?

If no unforeseen cues allowed the S to discriminate between one continuous presentation and two successive presentations, then in support of the introspective evidence, it appears that temporal resolution was the basis for discrimination in the present experiment. Interpolating a stimulus with one common and one different component changed the interaction between the 20-msec and the 200-msec flashes and resulted in a change in the S's temporal resolution. Temporal resolution must, therefore, be a plastic process which depends on the consistency of the spatial configuration as well as on temporal parameters. Somehow, presenting the visual system with a constant spatial stimulus allows the system to resolve fine temporal differences which are imperceptible when the spatial consistency is interrupted. The mechanism underlying the interaction between the 20-msec and the 200-msec pulses must have the ability to store, in some form, information about the spatial configuration of the stimulus.

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