Perceptual differentiation of sequential visual patterns*

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Two experiments examined the ability to perceive a difference between two sequentially presented visual patterns. An otherwise undetectable camouflaged target form was made visible by the sequential presentation of two random-contoured patterns that were identical except for the presence of the camouflaged form in one of the patterns. Experiment 1 found that form identifications became less accurate as a function of the luminance and contours of an intervening stimulus pattern and as a function of the ISI, falling to nearly a chance level by only 30 msec. Experiment 2 illustrated contrasts in stimulus conditions and in temporal characteristics of the differentiation and the integration of sequential visual patterns. Differentiation apparently differs from integration in the following respects: (1) it requires the sequential presentation of correlated patterns, in contrast to the uncorrelated patterns that produce masking when integrated; (2) it has a maximal effect with sequential presentation at ISI = 0 rather than with simultaneous presentation; and (3) it operates over a shorter range of ISI than does integration.

The temporal characteristics of visual form perception have been widely studied in recent years in order to obtain information about the contour coding processes of the visual system. Most investigations have indicated that the visual system integrates stimulation over intervals of about 100 msec. Sequentially presented patterns thus tend to summate into a single percept (Eriksen & Eriksen, 1971). But in contrast with these results, some studies of apparent motion and depth seem to indicate that the visual system is able to obtain information from changes or differences between sequential patterns (Anstis, 1970; Engel, 1966; Julesz, 1971; Kaplan, 1969). Little experimental attention has, however, been given to the apparent discrepancy in these findings.

Two major experimental paradigms have characterized research that points to temporal integration by the visual system. The most extensively investigated paradigm employs metacontrast or backward masking in which a second stimulus retroactively interferes with the perception of a previously presented stimulus (see Kahneman, 1968). Most attempts to explain backward and forward masking postulate that the visual system retains an iconic representation of the initial stimulus which persists over a longer interval than the actual physical stimulation. The visual system is presumably still responding to the

initial stimulus when it receives the second stimulus, and the two neural responses are thereby combined. Such explanations of masking in terms of temporal integration are compatible with the results of a second experimental paradigm, in which the S must fuse two sequentially presented partial forms in order to identify a unitary pattern formed by their additive combination (Eriksen & Collins, 1967). In both experimental paradigms, the integration of the two stimuli decreases as the ISI increases, asymptoting somewhere in the range of 100-350 msec, depending on various physical and informational characteristics of the target stimulus. In the former paradigm, integration of the two stimuli interferes with recognition of an individual stimulus, and in the second paradigm, integration enhances the recognition of a pattern formed from the combination of the two stimuli.

In contrast, the present experiments examined performance that depended upon another kind of stimulus information that can be provided by two sequential visual patterns—the difference between the two patterns. Suggestions that the visual system is capable of utilizing such information have come mainly from studies of apparent motion (Anstis, 1970; Gibson, 1968; Julesz, 1971) and apparent depth (Julesz, 1971; Kaplan, 1969), in which the task-relevant information is provided by changes in sequentially presented stimuli. Such phenomena would seem to reflect very important capabilities of the visual system, but little evidence is available on the limiting conditions under which these capabilities can be manifest. Nor is there an explanation for the apparent discrepancy of these

demonstrations with the many demonstrations of temporal integration of visual stimulation.

The purpose of the present experiments is (1) to demonstrate that the visual system is capable of utilizing information from a difference between two sequentially presented patterns as a basis for the perception of form, (2) to examine the ISIs and intervening stimulus conditions under which such changes in stimulation can be perceived, and (3) to illustrate some distinctions in the stimulus conditions for obtaining the differentiation vs the integration of sequentially presented visual patterns.

EXPERIMENT 1

The basic strategy for demonstrating the perception of a difference in sequential patterns was to construct stimulus displays such that cues for detecting a target form were provided only by the difference between two patterns rather than by either single pattern or by the additive combination of the two. This was accomplished by camouflaging a target form against a background of random contours. Two sequentially presented displays were identical, except in a small area containing the target form; that is, one display contained the form and the other did not. The basic experimental technique is illustrated in Fig. 1. In contrast to other experiments on masking or temporal integration, the simultaneous presentation of both stimulus displays provided little or no information for detecting the target form. The validity of this assumption was evident in pilot work and is verified more rigorously in Experiment 2.

Method

Stimuli. Stimulus displays were binocularly presented in an Iconix three-field tachistoscope (Model 6135). The two stimulus fields were illuminated at 6 fL (measured with a Spectra Spot Photometer), and the pre- and postexposure fields were dark (.02 fL). The displays were glossy photographic prints of a randomly textured shading material (Formatt 7086). The displays subtended a visual area of 6.5 deg square. The camouflaged target form (see Fig. 1) subtended about 0.8 deg and was positioned 1 deg off center to the right or left and .35 deg above the center of the second display.

The target form was presented in one of three alternative orientations—obtained by rotating the form shown in Fig. 1 about its center in steps of 120 deg—in either the right or left positions. There were thus six alternative target forms to be identified. Identifying the orientation

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FIRST STIMULUS

SECOND STIMULUS

Fig. 1. Schematic illustration of stimulus displays used in Experiment 1.

of the camouflaged target form was, under the best conditions, a moderately difficult task in shape discrimination. Identifying the position of the form, however, was a very easy detection task, dependent upon a minimal amount of perceptual information. Orientations were often confused even when the position of the form was clearly detectable.

The first and second stimulus patterns were both presented for 300 msec and were temporally separated by a variable ISI of 0, 10, 20, or 30 msec. One of four alternative intervening stimulus conditions prevailed during the ISI: (1) the same dark (.02 fL) field as in the pre- and postexposure conditions, (2) a homogeneous gray field (5.5 fL) at about the same luminance as the stimulus patterns, (3) a homogeneous bright field (9 fL), or (4) a different set of contours at the same luminance and photographed from the same random shading material as the other two stimulus patterns.

Procedure. Each S served in four experimental sessions. Within each experimental session, the intervening stimulus condition was held constant and the four ISIs were varied across trial blocks within the session, with a particular ISI in effect for a block of 12 presentations. The ordering of both the ISIs and the intervening conditions

was counterbalanced across Ss.

Each session consisted of 96 presentations, 24 under each of the four ISIs, plus 12 practice trials. The Ss were self-paced and required about 20 min to complete each session. The stimulus sequence was initiated by the S with a hand-held button. The S was required to identify both the orientation and the position of the partial circle, with one of six alternative responses. During the 12 practice trials, which began each session, the stimuli were presented with an ISI of 0 msec. During practice, S responded as in the actual data collection phase, except that he received feedback and was allowed to view the same stimulus sequence until he was confident that he saw the correct orientation and position. No feedback was given during the remaining trials, but after each block of 12 trials, the S was told the total number of correct responses for that block.

Subjects. The authors, two graduate students in psychology, and two undergraduates at Vanderbilt University served as Ss. The undergraduates were paid volunteers. All Ss had normal or corrected to normal vision.

Results

The percentage of trials on which

both the orientation and position of the target form were correctly identified and the percentage of trials on which the position was correctly identified are given in Fig. 2 for each ISI and intervening stimulus condition. The identification of the orientation reflects the extent of the perceptual information about the shape of the target forms, whereas the position identification reflects the mere detection of a change in the stimulus pattern. As may be seen, increases in ISI produced large decrements in the accuracy not only of the orientation identifications, but even in detection of the position of the form. The extent of the decrements depended also upon the intervening stimulus condition.

Analyses of variance were performed separately on the number of errors in identifying both orientation and position and in detecting the position of the form. For the orientation identifications, there was a large effect due to ISI, $F(3/15) = 144.3$, $p < .001$. The variation in intervening stimuli also produced a significant main effect, $F(3/15) = 18.1$, $p < .001$, as did the interaction between ISI and intervening stimulus, $F(9/45) = 6.0$, $p < .001$. Similar results were obtained for the position identifications: Again, the ISI and intervening stimuli both affected

performance, $F(3/15) = 52.8$ and $F(3/15) = 15.1$, $p < .001$, respectively; the interaction between the two variables was also significant, $F(9/45) = 4.5$, $p < .001$.

Discussion

The results of this experiment indicate that the visual system is able to obtain information about a difference or change in the contours of two sequentially presented patterns. The perceptual information obtained from this change has sufficient spatial detail to enable the discrimination among very similar shapes. The accuracy of detecting and of identifying the shape of this difference in sequential patterns was found to decrease sharply over brief ISIs and to decrease with increases in the luminance and contours of the intervening stimulation.

The influence of the various intervening fields upon performance is compatible with the results of numerous backward masking experiments. The ordering of the effects due to the dark, gray, and light intervening stimuli would be predicted from hypotheses about luminance summation between successive stimuli (Eriksen, 1966). A reduction in the black/white contrast of either the first or second stimulus pattern would be produced as a function of the summation of intervening luminances with the contours in the stimulus pattern. In addition to the luminance summation effects, the occurrence of contours in the intervening stimulation appears also to interfere with perception of the change in contours between the other two stimulus patterns. This interference is similar to the masking effects observed when unrelated contours are presented in regions adjacent to the target form (Eriksen & Collins, 1965; Uttal, 1969).

Two interesting discrepancies with the literature on masking were, however, obtained in the present experiment: First, the ability of the visual system to utilize information about the difference between sequential stimulus patterns suggests the operation of processes quite different from the temporal integration that is indicated by the studies of masking and fusion of dot patterns. Second, the interaction between the two successive stimulus patterns was maintained over much briefer durations of ISI than have been obtained in most masking studies.

The form identification obtained in this experiment might seem explainable in terms of temporal integration rather than differentiation: Since the two sequential patterns were identical in every region except that of the target form, the superposition of

Fig. 2. Percentage of correct identifications in Experiment 1 as a function of ISI and intervening stimulus condition. The left graph gives the accuracy for identifying both orientation and position of the target form, and the right graph gives the accuracy for simply detecting the position of the target form.

the two patterns, via an integrative process, might be expected to yield the same set of contours as in the individual displays in every region except that of the target form, where the contours would be more dense. On this hypothesis, the best performance would be predicted for the simultaneous presentation of the two stimulus patterns, where no "difference" in the patterns could be defined. Informal observations in pilot work for this experiment indicated that, on the contrary, performance was very poor with simultaneous presentation of the two patterns. These observations are confirmed in Experiment 2.

EXPERIMENT 2

Several readers of an earlier report of Experiment 1 were uncertain and skeptical about our claims for a basic distinction between integration and differentiation processes in vision. Experiment 2 was motivated by their comments.

The objective of Experiment 2 was to provide a more direct operational basis for the conclusions that (1) integration and differentiation are two fundamentally distinct phenomena in visual perception that depend upon different stimulus conditions, and that (2) the time parameters for the two phenomena are different. The general strategy was to minimize differences in the stimulus conditions for producing the two phenomena.

The specific approach was to add cues to the target form so that it was less well camouflaged and now

detectable when presented in a single display. Backward masking of these added cues was produced by the presentation of a second pattern containing random contours that were uncorrelated with those in the first pattern. When these two patterns were superimposed (either by the E or by integrative processes in the S's visual system), the clarity of the additional contour cues in the target form was reduced by the overlapping and adjacent contours of the uncorrelated second pattern. This arrangement corresponds to the familiar backward-masking paradigm. Accordingly, the accuracy in identifying the target form should be lowest when the two patterns are presented simultaneously and should improve as the ISI increases.

The differentiation phenomenon can be produced by the same method as in Experiment 1—by the sequential presentation of a second pattern in which the contours are perfectly correlated with those in the first pattern except in the small region occupied by the target form. Insofar as the differentiation phenomenon depends upon the sequential presentation of these two correlated patterns, performance should be best when the ISI equals 0 and should be poorer at longer ISIs and poorer with simultaneous presentation of the two patterns. Additionally, if the differentiation does indeed diminish with ISI more rapidly than does the integration of the two patterns, then there should be some range of ISI values at which masking should occur with the correlated second pattern,

Fig. 3. Percentage of correct identifications of both orientation and position of the target form for each experimental condition in Experiment 2.

and performance should fall to the same level as with the uncorrelated masking pattern, below the level of performance with a single display. That is, both differentiation and integration (masking) should be obtainable with the same set of stimulus displays but at different ISI values—differentiation at very short ISIs and integration at longer ISIs.

These predictions were confirmed.

Method

Stimuli. The stimulus displays were very similar to those used in Experiment 1, shown in Fig. 1. The two main modifications pertained to the addition of cues to make the position and orientation of the target form discernible in a single display and to the use of a second display (without the target form) that was either *correlated* or *uncorrelated* with the first display. Cues to the position and orientation of the target form were produced by the addition of 20 black spots (Paratype No. 55068), approximately 1 min of visual angle, around the perimeter of the target form in the photograph. For the condition in which the contours in the second pattern were uncorrelated with those in the first, another copy of the same photograph used in the correlated-patterns condition was simply rotated 180 deg.

Additional modifications in the stimulus conditions of Experiment 1 were as follows: (1) The target form always appeared in the first rather than in the second display. (2) The ISIs were simultaneous, 0, 20, or 100 msec. (3) The exposure durations for each stimulus pattern were reduced

to 40 msec for three of the Ss (H.B., L.B., K.D.) and 70 msec for another S (J.L.). Adjustment of the exposure durations was necessary in order to obtain moderately accurate identifications when the single display containing the target form was presented by itself and at the same time obtain a high error rate when the uncorrelated masking pattern was presented simultaneously with the target form. (4) Luminance of the first and second stimulus patterns was 3 fL, and luminance of the pre-, post-, and interstimulus field was .05 fL. (5) The visual area subtended by the stimulus displays was 5.9 deg square; the size of the target form was .85 deg (but with the same shape as in Experiment 1 and Fig. 1); and the target form was positioned 1.2 deg off center to the right or left and .35 deg above the center of the first display.

Other details of the stimuli and apparatus matched those of Experiment 1.

Procedure. There were nine experimental conditions: (1) a single-pattern condition, in which the first display containing the target form was presented by itself, (2) four correlated-patterns conditions, in which the second pattern was identical to the first (except in the area of the target form) and was presented simultaneously with the first pattern or after an ISI of 0, 20, or 100 msec; and (3) four uncorrelated-patterns conditions, in which the contours of the second pattern were uncorrelated with those of the first and were presented at each of the four ISIs.

All nine conditions were studied in each session. A block of 18

consecutive trials was devoted to each condition. Thus, there were 162 experimental trials in each session; these were preceded by 18 practice trials under the single-pattern condition. About 45 min were required to complete a session. During the practice trials, feedback was provided after each trial and S was permitted to view each display as many times as he wished. During the experiment proper, feedback was given at the end of each block of trials. Each of four Ss served for three sessions. The order of the nine experimental conditions within each session was counterbalanced over sessions and Ss for three of the Ss; two of the Ss received the same ordering of conditions.

Other details of the procedure repeated those of Experiment 1.

Subjects. The authors, one graduate student and one undergraduate student in psychology at Vanderbilt University, served as Ss. All had served in Experiment 1.

Results

The average percentage of correct identifications of both orientation and position for each of the nine conditions is shown in Fig. 3; the data for each individual S is given in Table 1. The percentage of trials on which each individual S correctly detected the position of the target form is given in Table 2.

The basic results portrayed in these data are the following: (1) Identification accuracy was greater in the single-pattern condition than in any of the uncorrelated-patterns conditions, implying that backward masking was produced by the uncorrelated second pattern. (2) The single-pattern condition produced greater accuracy than the correlated-patterns conditions, except at an ISI of zero, where the correlated pattern yielded slightly better performance. (3) When the two patterns were uncorrelated, identification accuracy increased with the ISI (up to 20 msec). (4) When the two sequential patterns were correlated, identification accuracy was greatest at an ISI of zero and was lowest when the two patterns were presented simultaneously. (5) The correlated and uncorrelated patterns yielded reliably different performance only at the zero ISI, there being a large superiority with the correlated patterns at that point but little or no difference at any other ISI. (6) There was little or no difference in identification accuracy for ISIs of 20 and 100 msec.

Statistical corroboration of the preceding statements was obtained by using the normal approximation to the

Table 1
Percentage of Correct Form Identifications for Each S and Condition in Experiment 2

Combination of Patterns	ISI	Ss				Average
		HB	LB	KD	JL	
Single		78	80	93	96	87
Correlated	Simult.	48	26	33	28	34
Correlated	0	89	91	91	96	92
Correlated	20	69	78	91	69	76
Correlated	100	70	76	94	74	79
Uncorrelated	Simult.	30	24	44	22	30
Uncorrelated	0	65	46	80	48	60
Uncorrelated	20	61	70	94	72	75
Uncorrelated	100	69	70	85	78	75

Table 2
Percentage of Correct Detections of the Position of the Target Form for Each S and Condition in Experiment 2

Combination of Patterns	ISI	Ss				Average
		HB	LB	KD	JL	
Single		94	85	98	96	94
Correlated	Simult.	72	56	61	59	62
Correlated	0	100	100	98	100	100
Correlated	20	91	91	98	93	93
Correlated	100	85	85	100	89	90
Uncorrelated	Simult.	65	50	70	65	63
Uncorrelated	0	89	80	91	91	88
Uncorrelated	20	81	81	96	94	88
Uncorrelated	100	85	81	94	89	88

Table 3
Statistical Significance of the Difference in Percentage of Correct Identifications for All Pairs of Conditions in Experiment 2

	Correlated				Uncorrelated			
	Sim	0	20	100	Sim	0	20	100
Single	**	*	**	*	**	**	**	**
Cor-Sim		**	**	*		**	**	**
Cor-0			**	**		**	**	**
Cor-20						**		
Cor-100					*	**		
Unc-Sim						**	**	**
Unc-0							*	**
Unc-20								

* $p < .05$ (one-tailed test)

** $p < .01$ (one-tailed test)

binomial distribution to compare the total number of correct identifications (of both orientation and position) for each pair of conditions. The results are given in Table 3. No statistical analysis was made on the accuracy of detecting the position of the form, due to the small numbers of these errors in most conditions.

The principal point in these results pertains to the performance that occurred in the correlated-patterns conditions: Form identification was very accurate when the two correlated patterns immediately followed one another at an ISI of zero, but fell to the same level as with the uncorrelated masking pattern at other ISIs.

DISCUSSION

Experiment 2 serves to contrast some of the necessary and sufficient conditions for obtaining the

differentiation vs the integration of sequential visual patterns. The basic requirement for producing the differentiation process seems to be that the two sequential patterns be sufficiently correlated (perhaps identical) in some areas so that a difference in the patterns in other areas can be identified. The use of masking paradigms to study temporal characteristics of visual perception has typically precluded the construction of stimulus patterns with this characteristic.

A second requirement pertains to the ISI separating the sequential patterns: Not only does the differentiation require sequential rather than simultaneously presented patterns, but the enhancement produced by differentiation seems to be obtainable at shorter ISI values than does the masking produced by

integration. A distinction in the temporal parameters of the two processes is clearly indicated by the drop in performance when the ISI between the target and the correlated second pattern was increased from 0 to 20 msec. At 0 msec, ISI performance was slightly better than in the single pattern condition, reflecting the differentiation process; but at 20 msec, ISI performance dropped below the single pattern condition to the same level as with the uncorrelated second pattern, reflecting masking by the integration process. Thus, two different processes seem to have been tapped by merely changing the ISI between the target and correlated second pattern. This would imply that the effectiveness of the differentiation process decreases over time at a faster rate than does that of the integration process.

The masking produced in this experiment by the uncorrelated second pattern appears to differ in some respects from the results that have typically been reported (e.g., Eriksen, 1966; Eriksen & Collins, 1965; Spencer & Shuntich, 1970). One discrepancy with previous results is in the lack of change in performance between the 20- and 100-msec ISIs, even though performance had not yet asymptoted to the level of the single-pattern condition by 100 msec. One possible basis for this discrepancy might derive from the use of dense, randomly contoured patterns in which a target form is constructed from a subset of these randomly distributed contours. This speculation is consistent with the fact that Uttal (e.g., 1969) has often obtained large changes in performance over brief ISIs in his work with densely dotted displays. Much remains to be learned, however, about the effect of the spatial distribution of contours on the temporal characteristics of visual form perception. Spatial factors can well be expected to affect the temporal characteristics of both the integration and differentiation of sequential visual patterns. These two phenomena are indeed but two characteristics of the general capability of the visual system for processing spatial and temporal patterns of stimulation.

The very poor performance obtained when the correlated patterns were simultaneously presented seems surprising: If the two nearly identical patterns were superimposed, then the area occupied by the target form should be at least partially visible as a set of denser contours. But this did not occur, since performance was very similar for both correlated and uncorrelated patterns under the simultaneous condition. The explanation seems to be that the two

correlated patterns were not precisely superimposed in the simultaneous condition, due to slight misalignments in the optical system. On the other hand, the very accurate performance in the zero ISI condition seems to imply that the two patterns have now been correctly aligned by the S's visual system. This phenomenon suggests the operation of autocorrelational processes that can match two misaligned patterns presented at successive points in time.

GENERAL CONCLUSIONS

The chief objective of this study is to document the ability of the visual system to obtain information from a difference in sequentially presented visual patterns.

The integration of temporally distributed visual stimulation has often been considered a pervasive characteristic of visual perception (e.g., Eriksen & Eriksen, 1971). The contribution of the present study is to show that the integrative interaction of sequentially presented stimuli is dependent upon the existence of specific properties of the stimulus patterns, viz, little or no correlation between the contours of two or more discrete stimulus patterns. When the temporal sequence of contours describes a systematic pattern of changing contours, then the visual system can often exhibit a capability for encoding the pattern of change that far surpasses the limitations in temporal resolution that are suggested by research on masking.

The ability of Ss in the present experiments to obtain perceptual information about a difference in two sequential patterns indicates the operation of a subtractive or correlational process that serves to identify areas of identity and of change. Such a process would seem to function in a manner quite similar to the binocular fusional processes that have been indicated in Julesz's (cf. 1971) experiments with stereograms composed of randomly distributed contours. One easily wonders whether the two phenomena might be based on

operation by the same neural processes. Interestingly, Julesz and White (1969) have demonstrated that stereoscopic depth perception can occur when the two monocular portions of a random-dot stereogram are temporally separated by intervals of 50 msec or less. (Procedural differences between their experiment and ours unfortunately prevent a close comparison of the temporal characteristics of the two phenomena.) But the binocular processes also utilize the information in lateral displacement to measure the relative depth of two segments of a binocularly fused pattern; analogously, the differentiation process indicated in the present experiment might be capable of utilizing lateral shifts to measure movement of the patterns. Anstis (1970) has, in fact, suggested that the two perceptual achievements are based on very similar processes for subtracting and shifting two inputs in order to minimize their differences. We are currently studying this possibility in more detail.

The stimulus displays employed in these experiments—providing perceptual information by a difference in two sequential patterns of dense and randomly distributed contours—represent only one class of many alternative patterns of stimulation changing in space and time. The general domain of inquiry concerns the visual processing for this entire set of spatiotemporal patterns rather than only masking or integration or the differentiation reported here. Questions naturally arise about the ability to perceive other spatiotemporal patterns. Demonstrations of the perception of projective transformations of objects moving in three-dimensional space (Green, 1961; Hershberger & Urban, 1970), of depth produced by a differential rate of change in texture at an edge (Kaplan, 1969), and of stereopsis produced by binocular disparities of motion (Enright, 1970) all give evidence of an exquisite sensitivity to coherent patterns of spatiotemporal change.

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