Fragmentation and identifiability of repeatedly presented brief visual stimuli*

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Ss were given repeated brief presentations of geometric forms and drew what they thought they saw. The stimulus patterns were presented tachistoscopically for as many repetitions as necessary for correct identification. The nature and sequential properties of pattern fragments reported prior to correct identification were examined. The first fragments to be reported were generally straight line elements of the stimulus patterns. With repeated presentations, more features were gradually reported until the complete figure was correctly identified. The pattern of construction appeared similar to patterns of fragmentation found in research on stabilized retinal images, prolonged afterimages, and conditions of steady fixation. Implications of these findings for theories of pattern information processing were discussed.

When an image is artificially stabilized on the retina, it is often found that the pattern fades and regenerates in a nonrandom fashion (e.g., Pritchard, 1961). For example, when a pattern such as a square is presented in stabilized form, single line elements or two parallel lines often fade and regenerate as units. Similar fragmentation effects have been found for other procedures, such as viewing prolonged afterimages or prolonged steady fixation (MacKinnon, Forde, & Piggins, 1969). Evans (1968) presented geometric patterns tachistoscopically for brief durations and required his Ss to draw what they observed. A single pattern was presented for as many repetitions as were necessary to correctly reproduce the stimulus for five successive presentations. He found that the fragments of patterns reported prior to recognition of the complete pattern closely resembled the manner in which units of stabilized images fade and regenerate.

Other investigators have studied the effects of repeated brief exposures to other kinds of visual stimuli. For example, Haber and Hershenson (1965) presented Ss with English words for 25 exposures while holding duration and illumination constant. It was reported that, on the first few trials, only parts or letters of the words were seen and that after several presentations the entire word would be correctly reported. According to Haber and Hershenson (1965), "repeated exposures of a word at a constant duration does contribute to the growth of the phenomenal experience of the word [p. 45]." Haber (1969) reviews several studies showing that this repetition effect also holds when meaningless words were used as stimuli and when Ss had prior knowledge of the words to be presented.

Haber's studies have not examined in a systematic fashion what Ss see prior to the correct report of the

stimulus presented. Furthermore, Evans (1968) reported only the relative frequencies of pattern fragments reported by his Ss. The present study was, thus, designed to examine the repetition effect in further detail. A detailed examination of the nature of fragmentation when Ss are repeatedly presented with brief visual stimuli will reveal if the pattern of feature extraction shows systematic organization which leads to the final percept. Specifically, the present study investigated the manner in which pattern information is processed in terms of sequential fragmentation as well as the growth function of the final percept.

METHOD

Subjects

The Ss were 60 undergraduates enrolled in general psychology classes at Kansas State University.

Stimuli

The stimulus patterns consisted of a square, triangle, triangle and circle, and an HB monogram. These stimuli were similar to those used by Pritchard (1961) and are shown in Fig. 1. The tachistoscopic field of view subtended a visual angle of 5 deg vertically and 8 deg horizontally. Each stimulus pattern was drawn in black ink on white backgrounds and subtended a visual angle of 2 deg along its largest dimension; the width of the lines of the patterns subtended 2 min of visual angle.

The stimuli were individually presented in one channel of an Iconix 6131 three-channel tachistoscope. The reflectance at the eyepiece was 43 mL for each channel. A homogeneous preexposure field containing a fixation point was presented in the second channel of the tachistoscope. The fixation point was centered in the preexposure field and coincided with the center of the stimulus pattern in the other channel. A homogeneous white postexposure field was presented in the third channel.

Procedure

The preexposure field was on at the beginning of each trial. Each S initiated the presentation of a stimulus pattern by means of a hand switch which triggered the stimulus channel of the tachistoscope. When triggered, the preexposure field went off and was immediately followed by the stimulus field. Upon termination of the stimulus field, the postexposure field

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Fig. 1. Relative frequencies of occurrence of main fragments for each stimulus pattern. These frequencies are listed in mean rank order of occurrence.

immediately followed for 500 msec. During this period, S removed his head from the tachistoscope and recorded his response. The preexposure field then came back on until S initiated a new trial.

Each S was presented with only one stimulus pattern. The S was instructed to fixate on the dot in the tachistoscope and then press the button to trigger the presentation of the stimulus channel. The S was then instructed to draw what he saw. The Ss drew their responses in 2.5-cm square spaces, 50 of which were contained on one response sheet. Each response space subtended a visual angle of approximately 3 deg at S's viewing distance. The Ss were allowed to work at their own pace and generally made their responses within a period of 5-10 sec. They were told nothing regarding the nature of the pattern in the stimulus channel and were not told that the same stimulus was to be presented every trial.¹ It was emphasized that Ss were to report only what they saw. If they saw nothing, they were instructed to place a dot on the response sheet.

All stimuli were initially presented for a duration of 2 msec. The duration was increased by 1 msec if S reported that he saw nothing on any of the first 15 trials. If any feature was reported, the duration was held constant for 50 trials and then increased by 1 msec. The experiment was terminated when S correctly reproduced the stimulus pattern five trials in succession.

RESULTS

The four separate stimulus patterns were presented individually to four independent groups of Ss. Any given S was presented with repeated exposures of the same pattern until the pattern was correctly reported five trials in succession. A trial was defined as one exposure to the stimulus pattern. The Ss typically reported fragments of their pattern prior to correctly reproducing the entire pattern. A frequency count was made of all fragments reported for each pattern. Because some features were reported with relatively low frequencies, a criterion of 6 Ss out of the total 15 Ss exposed to each pattern had to report a fragment for it to be included in the frequency analysis. This procedure accounted for 82% of all fragments reported.² Figure 1 presents the relative frequencies of the fragments reported for each of the four patterns. The fragments listed in this figure

represent the total number of trials on which a given fragment, and only that fragment, was reported. Left and right single vertical line elements were pooled in this analysis. The fragments for each pattern are arranged on the horizontal axis of this figure in mean rank order of appearance. This rank order was determined by obtaining the rank order of appearance of each fragment for each S and then taking the mean of the rank orders across all Ss.

Single line elements were the first fragments to be reported for all patterns. With repeated exposures, additional elements were reported until the entire figure was correctly identified. With the HB and square, parallel lines tended to be reported with relatively high frequencies. The curved features of HB and triangle-circle patterns tended to be reported only after all straight line elements had been reported. The latter features to be reported for the HB figure tended to be in the forms of meaningful letter units (e.g., H and B, as indicated in Fig. 1). Fragments such as H and 3 that have been previously reported in the stabilized image literature (e.g., Pritchard, 1961) were also obtained in the present study, but with lower frequency.

A comparison was made of the relative frequency of vertical and horizontal straight line elements, regardless of whether the elements were reported alone or in conjunction with other elements. There are an equal number of vertical and horizontal straight line elements contained in the pattern of a square. Therefore, if both vertical and horizontal elements are equally recognizable, one would expect both kinds of elements to be reported equally often for the square. For the HB stimulus there are two vertical line elements and only one horizontal line element. Therefore, twice as many vertical elements would be expected if both kinds of fragments are equally recognizable for the HB figure. Instead, verticals were reported 5.2 times as often as horizontal for the square and 6.7 times as often for the HB figure. Chi-square tests performed on the frequencies

of vertical and horizontal elements indicated that vertical elements were reported with significantly greater frequency than chance expectancy ($p < .001$).

A similar analysis was used to compare the relative frequencies of reports of oblique and horizontal line elements in the triangle and triangle-circle patterns. Twice as many oblique elements as horizontals would be expected if both kinds of straight line elements are equally recognizable. Instead, only 1.1 times as many obliques as horizontal elements were reported for the triangle, indicating that horizontal features were reported more often than might be expected ($p < .001$). On the other hand, oblique line elements were reported 6.8 times as often as horizontals for the triangle-circle pattern, indicating that oblique line elements were more salient features for this pattern ($p < .001$).

In a further analysis, the frequency of reporting pattern elements falling to the left of the fixation point was compared with the frequency of features falling to the right of the fixation point. These frequencies were determined from Ss' protocols. For oblique line elements and angles, the direction of the elements could easily be determined by the slant of the oblique lines or the direction of the angle. However, the location of vertical and horizontal straight line elements had to be judged from the position of the element relative to the center of the space in which Ss made their responses. Left vertical line elements were reported 33 times as often as right line elements for the square. Left oblique sides were reported 3.1 times as often as right obliques for the triangle and 5.2 times as often for the triangle-circle. A similar analysis of left and right acute angles indicated that left acute angles were reported 3.5 times as often as right acute angles for the triangle and 11.4 times as often for the triangle-circle. Because there were equal numbers on left and right elements for the above comparisons, an equal number would be expected to be reported by chance. Chi-square tests showed all of these comparisons differed significantly from chance expectancy ($p < .001$). In general, reports of features to the left of the fixation point were more frequent than reports of features to the right of the fixation point. The square was also analyzed for horizontal straight line elements that were reported to be above and below the fixation point. All reports of horizontal line elements for the square were of the bottom horizontal side.

Conditional probabilities were computed in order to further examine the sequential properties of the fragmentation of the patterns with repeated presentations. These proportions represent the probability of reporting a given element on Trial N + 1 given the report of a specific element on Trial N. Tables 1-4 present the conditional probabilities for each of the four stimulus patterns. The fragments upon which these probabilities were computed were the same as those presented in Fig. 1. Generally, the probability was highest to repeat the same fragment on Trial N + 1 that was reported on Trial N. However, there were four

Table 1
Conditional Probabilities for Fragments of the Square

Fragment:	Fragment: Trial N + 1						
Trial N	Blank		—		□	U	□
Blank	.68	.17	.05	.06	.01	.00	.03
	.37	.24	.03	.30	.00	.03	.02
—	.50	.03	.23	.00	.07	.10	.07
	.02	.13	.00	.68	.05	.07	.05
□	.00	.00	.00	.50	.21	.08	.21
U	.02	.05	.02	.07	.00	.67	.17
□	.05	.01	.01	.05	.07	.03	.78

Table 2
Conditional Probabilities for Fragments of the Triangle

Fragment	Fragment: Trial N + 1							
Trial N	Blank	/	\	^	—	∠	△	△
Blank	.62	.12	.08	.02	.11	.01	.01	.03
/	.33	.48	.02	.02	.07	.08	.00	.00
\	.70	.00	.15	.00	.15	.00	.00	.00
^	.10	.00	.10	.60	.00	.00	.10	.10
—	.14	.03	.00	.00	.69	.08	.01	.05
∠	.13	.06	.00	.00	.06	.25	.06	.44
△	.05	.10	.00	.15	.00	.00	.50	.20
△	.05	.01	.00	.03	.03	.07	.03	.78

exceptions to this generalization shown in Tables 1 and 2.

If one examines the most likely pattern of construction beginning with a blank and progressing to the entire figure, single line elements were the first to be reported, and gradually more elements of the patterns were reported until the complete figure was reported. Examination of the pattern of occurrences of conditional probabilities less than .05 in Tables 1-4 indicates that it was unlikely to report simple (single) elements after the report of more complex elements. Similarly, it was unlikely to report complex elements or the entire configuration given the report of a single element or no elements. Using the triangle as an example, the most probable sequence of events given a blank on Trial N was the report of a left oblique line

Table 3
Conditional Probabilities for Fragments of the Triangle-Circle

Fragment: Trial N	Fragment: Trial N + 1						
	Blank	/	∠	/∩	∟	△	△○
Blank	.58	.26	.05	.03	.03	.05	.00
/	.37	.41	.02	.11	.07	.01	.01
∠	.18	.10	.50	.04	.08	.06	.04
/∩	.06	.15	.04	.46	.23	.02	.04
∟	.08	.02	.08	.08	.58	.01	.15
△	.17	.00	.03	.11	.03	.52	.14
△○	.02	.00	.01	.02	.12	.01	.82

Table 4
Conditional Probabilities for Fragments of the HB

Fragment: Trial N	Fragment: Trial N + 1						
	Blank	I	II	HB	B	BB	HB
Blank	.60	.26	.11	.00	.02	.00	.01
I	.21	.54	.23	.00	.02	.00	.00
II	.07	.30	.59	.02	.01	.00	.02
HB	.11	.07	.00	.57	.07	.00	.18
B	.00	.03	.05	.00	.65	.19	.08
BB	.03	.01	.00	.07	.05	.84	.02
HB	.00	.01	.03	.10	.00	.01	.85

element on Trial N + 1, followed by a left acute angle, and then the entire figure. A different pattern of results obtained with the square and HB figures. Following the report of a blank, the most probable fragment was a single vertical line followed by parallel lines. Following the report of parallel lines, the most probable event was to again report a single vertical line. Other features were reported with relatively lower probabilities, eventually leading to a report of the complete pattern.

The triangle reached the criterion of five successive correct reproductions of the stimulus pattern in the lowest mean number of trials ($\bar{X} = 61.0$), followed by the square ($\bar{X} = 67.7$). The mean number of trials to criterion for the triangle-circle and HB patterns were 106.1 and 110.6, respectively. A one-way analysis of variance performed on the number of trials to criterion showed a main effect for pattern [$F(3,56) = 5.30$,

$p < .005$]. Multiple comparisons of the means for each pattern were made using Duncan's range test, $R_2(56) = 25.35$, $R_3(56) = 33.02$, $R_4(56) = 34.17$, $p < .05$ (cf. Edwards, 1972). These results indicate that the square and triangle patterns required significantly fewer trials to criterion than either the triangle-circle or the HB figure but that the differences between trials to criterion for the triangle vs square and triangle-circle vs HB were not significant. The trend suggested by these results is for the patterns containing only straight line elements (i.e., triangle and square) to require fewer repetitions to reach criterion than the more complex figures that contained both curved features and more elements (i.e., triangle-circle and HB).

The data plotted in Fig. 2 represents the probability of correctly reporting the entire pattern as a function of trials. These curves were collapsed over the four patterns, since the individual functions were nearly identical for each pattern. The curve labeled "D" indicates that exposure duration at which the first fragment was reported, and D + 1 and D + 2 represent

Fig. 2. Probability of correct identification of a stimulus pattern as a function of repeated exposures. (The dashed lines represent the function $P_n = A - B/n$, whereas the solid lines represent the function $P_n = k \log n + P_1$.)

increments in D of 1 and 2 msec, respectively. The probability of correctly reporting the entire pattern increases over trials for all three curves in Fig. 2. It is also apparent that the probability of correctly reporting the presented pattern rises most sharply over the first 15 trials.

Haber and Hershenson (1965) proposed a descriptive function to describe the repetition effect that was expressed by the equation $P_n = A - B/n$, where P_n is the probability of a correct response on Trial n , A is the asymptote, and B is the probability of being correct on the first trial. The results predicted from this model for the present study are presented as the dashed lines in Fig. 2. Comparison of these dashed curves with the data plotted in Fig. 2 suggests that Haber and Hershenson's model does not describe the data from the present study very well.

A better fit was provided by the equation $P_n = k \log n + P_1$, where P_n is the probability of correctly reporting the pattern on Trial n , k is a constant, n is the number of trials, and P_1 is the probability of correctly reporting the pattern on the first trial. These functions are shown as the solid lines in Fig. 2.

DISCUSSION

The sequential construction of the stimulus patterns in the present study were quite similar in many respects to fragmentations found in studies employing stabilized image techniques. For example, Pritchard (1961), using a contact lens method of stabilization, and Michalewski (1970), using a prolonged afterimage technique, obtained qualitatively similar patterns of fragmentation for the stimuli used in the present study. MacKinnon, Forde, and Piggins (1969) have presented relative frequency data for fragments of a square viewed under conditions of steady fixation, prolonged afterimage, and contact lens stabilization. Their fragmentation data was both qualitatively and quantitatively similar to the fragmentation patterns obtained in the present study. For example, MacKinnon et al (1969) reported that parallel sides of a square were the most frequently reported element and single vertical lines were the next most frequently reported element for that pattern.

Orientation specific effects for single line elements have been reported in the stabilized image literature. For example, vertical and horizontal lines have been found to be more salient features than oblique line elements when measured in terms of total duration of visibility, when viewed as stabilized images (Atkinson, 1972; Wade, 1972) and in terms of fade frequency (Schmidt, Fulgham, & Brown, 1971). In the present study, vertical line elements tended to be more salient features than horizontal line elements for the square and HB. Similarly, for the triangle, horizontal line elements were reported more often than oblique line elements. However, for the triangle-circle configuration, oblique line elements were reported more frequently than

horizontal line elements. This finding may reflect the influence of the circle, which was in close proximity to the right oblique line element. Pritchard (1961) reported that, when the triangle-circle configuration was presented as a stabilized retinal image, sides of the triangle tended to fragment in conjunction with part of the circle.

MacKinnon et al (1969) presented conditional probabilities for the fading and regeneration of fragments of a square viewed under conditions of steady fixation, prolonged afterimage, and contact lens stabilization. In their study, a complete square was initially presented and that pattern degenerated to fragments and eventually disappeared. In the present study, the fragments should occur in the opposite order, because the original presentations were perceived as blanks and conditional probabilities were determined for the sequence of fragmentation leading up to the report of a complete square. With this difference in mind, the results obtained by MacKinnon et al are quite comparable to the conditional probabilities obtained in the present study. Similar conditional probabilities for the overall sequence of fragmentation were found in both studies. For example, given the report of the entire square in the MacKinnon et al study, the most likely fragment to be reported was three sides. Given the report of three sides in the present study, the most likely event on the next exposure was the report of the complete square.

The finding of relatively frequent reports of features to the left of the fixation point as opposed to features to the right is not an uncommon finding in tachistoscopic recognition tasks (White, 1969). White cited evidence that this laterality difference may be due to such factors as postexposure trace scanning, handedness, ocular dominance, and cerebral dominance.

Schuck (1973) has provided recent evidence that may account for the relatively low frequencies of reports of meaningful fragments obtained for the HB pattern in the present study. Schuck found that continuous verbal reporting of fragments of an HB pattern viewed under stabilized conditions produced a high frequency of meaningful fragments such as H, Hb, and 3. However, when Ss were required to draw their responses, as was done in the present study, the frequency of meaningful fragments dropped sharply. Thus, it appears that in studies of the fragmentation of patterned stimuli the use of verbal reports may introduce a response bias by increasing reports of meaningful fragments.

With respect to the growth of identifiability of the stimulus patterns, it was found that Haber and Hershenson's (1965) model provided a poor fit of the data from the present study. The data, however, were fit quite well by the log function $P_n = k \log n + P_1$, where P_n was the probability of a correct recognition on Trial n , n was the number of trials or repetitions, and P_1 was the probability of a correct identification on the first trial. This function has only one free parameter and does not require the estimation of an asymptote. The log

function states that identifiability increases as some constant proportion of the number of trials. The log function also provided a good fit for Haber and Hershenson's (1965) data. It might be pointed out, however, that both Haber's function and the log function presented here are empirical descriptive functions and hold little theoretical significance. As Doherty and Keeley (1972) have suggested, until more about the processes that might account for the repetition effect is known, any theoretically based quantitative prediction of the repetition effect is precluded.

In both the present study and studies of stabilized retinal images, visual pattern information available to the observer has been drastically reduced. In the latter, the information reduction is effected by the cancellation of eye movements, and in the former, by the reduction of time in which a stimulus is available for information processing. It might be pointed out that in both cases no information can be obtained from systematic eye movements, since patterns presented for durations that range from 2 to 5 msec are well below the duration of saccadic eye movements. This suggests that the absence of systematic eye movements may be a critical factor in accounting for the manner in which pattern information is processed under conditions of stabilized retinal images and repeatedly presented brief visual stimuli.

Both eye movements and repeated observations are important aspects of Hebb's (1949) cell assembly theory. Haber (1969) has suggested the Hebbian model as a possible basis of the repetition effect. Pomerantz, Kaplan, and Kaplan (1969) also interpret the repetition effects in similar terms. Within a Hebbian framework, repeated exposures of the same stimulus would lead to the sampling of different features on different repetitions. Cell assemblies for some features may be excited several times and in conjunction with other cell assemblies relevant to the stimulus pattern presented. A sufficient number of repetitions would eventually be expected to give rise to the entire set of feature cell assemblies that constitute the entire pattern. The effect of increased duration or luminance would be to provide a stronger arousal of the relevant cell assemblies, thereby accounting for the more rapid identification of patterns presented at longer durations.

Another possible interpretation of the repetition effect could be referred to as an aggregation hypothesis (e.g., Doherty & Keeley, 1972; Neisser, 1967; Weintraub & McNulty, 1973). This hypothesis states that some partial information is perceived and stored. This partial information is then combined with the incoming information on the next trial until the complete stimulus is identified. The data of the present study are in part consistent with an aggregation hypothesis. The aggregation hypothesis would predict construction of the patterns to proceed from simple to complex, as was found in the present study. However, the aggregation hypothesis would also imply that, once a given feature is reported, one would not regress to reporting fewer or

less complex features on subsequent trials. The same prediction would be expected if phenomenal clarity of the percept improved over trials, as suggested by Haber (1969). The conditional probability data from the present study indicated that this was not necessarily the case. Rather, there were instances when the entire stimulus was reported, yet Ss would report fragments of the stimulus pattern on subsequent exposures. Similarly, there were cases when Ss reported simple fragments after reporting more complex fragments.

The nature and sequential properties of the patterns of fragmentation reported in the present study may have implications for the physiological processes underlying form perception. However, the present state of knowledge of physiological mechanisms involved in feature extraction does not allow for straightforward interpretation of the sequence of reporting fragments or orientation effects found in the present study.

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NOTES

1. During debriefing, nearly all Ss indicated that they were not aware that the same stimulus was being presented on every trial.
2. It should be noted that this criterion was chosen on the basis of the tradeoff between the number of Ss reporting the fragments and the overall percentage of fragments included in the analysis. For example, relaxing the criterion to 5 Ss out of 15 would include only an additional 5% of the fragments in the analysis. On the other hand, increasing the criterion to 7 Ss out of 15 would account for only 66% of the fragments, a loss of 16%.

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