PATTERN GOODNESS AND THE PERCEPTION OF VISUALLY MASKED PATTERNS

by

HERBERT H. BELL

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KANSAS STATE UNIVERSITY
Manhattan, Kansas

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Approved by:

Stephen Handel

Major Professor

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INTRODUCTION

Visual perception is not the immediate consequence of retinal stimulation. Visual perception is the product of a complex encoding of stimulus information at a number of different levels (Weisstein, 1966; Haber, 1969). Support for this view of perceptual processing has been provided by a number of studies using backward masking (e.g., Weisstein, 1966; Liss, 1968; Haber, 1970).

Averbach and Coriell (1961) demonstrated that if a target stimulus (TS) is followed by a second visual stimulus, the masking stimulus (MS), under certain conditions TS will not be correctly perceived. This erasing of a previously presented stimulus by a subsequent stimulus is known as backward masking and depends on a number of factors, two of which are discussed below (see Kahnman, 1968).

One factor is the physical similarity of the two stimuli. A number of studies have demonstrated that masking effects are partially dependent upon the contour similarities of TS and MS (Werner, 1935; Sekuler, 1965; Liss, 1968). Fehrer (1965; 1966) has shown that the more similar the stimuli are in size the greater the masking effect. Additional evidence has been advanced by Stewart and Purcell (1970) suggesting that the masking effect is dependent upon the unique combination of TS and MS. Liss (1968) interprets the effects of different maskers on the same TS as reflecting the use of central mechanisms: the more effective the masker, the more likely the two stimuli are to be processed by the same central mechanism.

Another factor is the interval between the termination of TS and the presentation of MS. Generally, increasing the interstimulus interval (ISI) produces better performance. Weisstein (1966) attributes this increase in performance to the greater amount of information which has been encoded prior to the presentation of MS; the assumption being that MS causes a disruption in the processing of TS. Since it is assumed that the presentation of MS disrupts the encoding of TS, backward masking has become a technique to assess the complexity of encoding a visual stimulus (see Haber, 1969). An alternative explanation for the phenomenon of backward masking has been advanced by Eriksen (e.g., Eriksen & Hoffman, 1963; Eriksen & Steffy, 1964). This interpretation maintains that the presentation of a second visual stimulus shortly after the termination of TS produces a degrading of the first stimulus by luminance summation.

The above studies have relied on a very limited class of stimuli, alphamerics, in their attempt to study the encoding of visual information. Most studies have focused on the physical properties of the stimuli and procedure while neglecting the psychological aspects of perception. This approach defeats its own purpose since recent theoretical interpretations have suggested that the perception of a single stimulus is not simply dependent upon the properties of the presented stimulus. Stimuli are perceived as members of stimulus sets and the factors which influence perception are the properties of these stimulus sets, not the characteristics of the individual stimuli. In order to study visual perception, it is necessary to specify the properties of the stimulus set from which the individual stimuli were selected (Garner, 1966).

Garner (1962; 1966) has suggested that visual stimuli are perceived as members of stimulus sets containing psychologically equivalent stimuli, with pattern goodness being inversely related to the number of equivalent stimuli within each set. This relationship has been confirmed by Garner and Clement (1963) and Handel and Garner (1966) using dot patterns as stimuli. These patterns were formed by placing five dots in the cells of a 3x3 matrix. It is possible to group all 126 five-dot patterns into sets containing either one, four, or eight different patterns by the use of an objective criteria of rotation and reflection (R&R). Rotation involves turning the pattern through successive 90° steps while reflections (mirror images) are taken for each of the patterns formed by these rotations. Pattern goodness is highly correlated to the number of patterns which are equivalent to the rated pattern when the size of the equivalence set is defined by an objective measure, R&R.

A number of studies have demonstrated that pattern goodness is also an important factor in the latency of pattern sorting (Royer, 1966; Clement & Varnadoe, 1967; Clement & Weiman, 1970) and in the latency of applying a verbal label to a pattern (Clement, 1964). These studies have shown that good patterns are sorted and named faster than poorer patterns containing the same number of elements. Such findings are consistent with a number of earlier studies which demonstrated that as patterns become more complex, hence capable of being discriminated in more ways, the speed of discrimination decreases (Deese, 1956; Anderson & Leonard, 1958). Good patterns are more readily perceived as wholes and pattern goodness reflects the number of steps involved in the encoding process (Garner, 1970; Clement & Varnadoe, 1967).

The present study was designed to investigate the importance of pattern goodness in visual pattern perception. If pattern goodness does correlate with the number of steps involved in the encoding process, then pattern goodness should be related to performance in a backward masking task.

The first experiment was designed to confirm the relationship between pattern goodness and the size of the equivalence set for five-dot patterns and to extend this finding to patterns comprised of four dots. The second experiment was designed to investigate the importance of pattern goodness in the reproduction of a pattern presented under backward masking conditions. In order to assess the importance of pattern goodness, five different equivalence sets of both four and five-dot patterns were selected to provide a range of rated goodness. Three different MS were employed in order to reduce the likelihood of a specific TS-MS combination influencing the results. These three MS were: a 3x3 matrix with nine dots, a random dot grid with the same figure-ground ratio as the 3x3 matrix, and the complement of TS. The complement of TS was created by placing dots in the four cells of the 3x3 matrix left empty by each five-dot pattern, and vice versa.

EXPERIMENT I

This study attempted to replicate the relationship found between pattern goodness and the number of equivalent patterns formed by R&R of five-dot patterns. Furthermore, it investigated this relationship with a set of four-dot patterns. If the concept of equivalents is an important factor in pattern perception, a similar relationship should exist between the number of equivalent four-dot patterns obtained by R&R and the rated goodness of the pattern.

It should be noted that for each five-dot pattern there are four cells left empty in the 3x3 matrix. It is possible to create another set of patterns, containing four dots, by filling the empty cells of the five-dot patterns. This procedure produces two sets of patterns containing either four or five dots, with each set being the complement of the other. Using this procedure the number of patterns created by R&R of a five-dot pattern is equal to the number of patterns formed by the R&R of its four-dot complement.

Method

Stimuli.--All four and five-dot patterns were formed by placing a 0.25 in. diameter black dot in the center of one cell of a 3x3 matrix. Each cell of the matrix was 0.5 in. square and the patterns were placed on 4x6 white cards without the matrix outline.

The stimuli consisted of 86 out of the 126 possible arrangements of five-dots within a 3x3 matrix and their 86 four-dot complements. Representative patterns are shown in Fig. 1. Each pattern shown in Fig. 1 is from a set of equivalent patterns as defined by R&R. The 86 five-dot patterns consisted of all 46 unique patterns formed by R&R of the patterns of equivalence sets size one and four, and the 40 unique patterns formed by the rotation of the representative patterns of equivalence set size eight. The 86 four-dot patterns were the complements of these five-dot patterns.

Task and subjects.--Sixteen students from introductory psychology classes at Kansas State University served as Ss and received class credit for participation. Each S was run individually and received a different random order of the 172 stimuli. The S's task was to rate each pattern on a seven point scale, with "1" being very good and "7" very poor. The Ss were allowed to examine eight patterns to insure a frame of reference, but then worked continuously without being allowed to look back. The Ss were self-paced and required about 30 minutes to complete the task.

Results

The mean goodness ratings obtained for each of the equivalent pattern sets is shown in Fig. 1. An analysis of variance was performed separately on the four and the five-dot patterns as summarized in Table 1. The total variance observed in the ratings can be divided into two major components, that due to differences between equivalence sets and that due to differences within a particular equivalence set. For the five-dot patterns 94% of the variance is attributable to the 23 different

Figure 1 Caption

Fig. 1. Mean ratings of pattern goodness for the different dot patterns. The number in the pattern code denotes the size of the equivalence set defined by R&R, while the letter identifies the pattern set. The rank ordering of the goodness ratings is indicated by the number in parentheses.

CODE	5-DOT PATTERNS		4-DOT PATTERNS	
	PATTERN	MEAN GOODNESS RATING	PATTERN	MEAN GOODNESS RATING
1-a		1.3 (1)		2.6 (9)
1-b		1.8 (2.5)		1.2 (1)
4-a		1.8 (2.5)		2.8 (10)
4-b		2.1 (4)		2.1 (4)
4-c		2.4 (5)		2.2 (5)
4-d		2.7 (6)		2.9 (13)
4-e		2.9 (7)		3.6 (16)
4-f		3.3 (8)		2.1 (2)
4-g		3.3 (9)		2.4 (7)
4-h		3.4 (10.5)		3.4 (15)
4-i		3.4 (10.5)		2.1 (3)
4-j		4.2 (15)		2.2 (6)
4-k		4.6 (16)		3.3 (14)
8-a		3.9 (12)		4.2 (17)
8-b		4.0 (13)		2.8 (11)
8-c		4.2 (14)		4.5 (18)
8-d		4.8 (17)		2.8 (12)
8-e		4.9 (18)		5.5 (21)
8-f		5.0 (19)		5.8 (23)
8-g		5.2 (20)		2.5 (8)
8-h		5.3 (21)		4.8 (19.5)
8-i		5.3 (22)		4.8 (19.5)
8-j		5.6 (23)		5.5 (22)

equivalence sets, while only 6% is due to differences between patterns within the same equivalence set. The variance accounted for by these same factors for the four-dot patterns was 85% and 15%, respectively.

The 23 equivalence sets can be divided into three groups according to the size of the equivalence set, since all patterns have either one, four, or eight equivalent stimuli. The size of the equivalence set accounts for 68% of the total variance for the five-dot patterns and 58% of the variance in the four-dot patterns. This analysis clearly indicates that the size of the set of psychologically equivalent patterns, as determined by the criteria of R&R, is the important factor in the perceived goodness of a pattern.

The mean goodness ratings for each of the five-dot equivalence sets were compared with the goodness ratings obtained by Handel and Garner (1966), while the four-dot ratings were compared with their five-dot complements. A comparison of five-dot patterns produced both a Pearson correlation coefficient and a Spearman rank order correlation coefficient of .97. The correlation coefficient between the mean goodness ratings of the five-dot patterns and their four-dot complements was .68, with a rank order correlation coefficient of .64.

In summary, this experiment is consistent with previous research. Patterns which have few equivalents, as defined by R&R, are judged as better patterns than those with more equivalents. This relationship between pattern goodness and the size of the equivalence set is valid for patterns of both four and five dots. It is possible that

Table 1

Analysis of Variance of Goodness Ratings of Dot Patterns

Source	5-Dot Variance %		df		4-Dot Variance %		df	
Equivalence sets	94		22		85		22	
Size of eq. set		68		2		58		2
Eq. sets of same size		26		20		27		20
Patterns within eq. sets	6		63		15		63	
Total	100		85		100		85	

the ratings of the four-dot patterns were confounded by some type of aesthetic preference since patterns forming squares, e.g., 1-a and 4-a, were rated much lower than their five-dot complements. This experiment does, however, clearly indicate that the number of equivalent patterns is an important factor in the perceived goodness of a pattern.

EXPERIMENT II

Experiment I indicated that pattern goodness is highly correlated with the number patterns produced by R&R. The purpose of this experiment was to investigate the importance of pattern goodness in the processing of a visual pattern. Since backward masking is a procedure which disrupts the encoding of visual information and pattern goodness is a reflection of the number of steps involved in the processing of a visual pattern, it was hypothesized that the difficulty of correctly describing TS would be directly related to TS goodness in a backward masking paradigm, the poorer TS the more difficult its description.

To investigate this hypothesis ten equivalence sets were selected from Experiment I. These patterns were selected to represent a range of pattern goodness from 2.1 to 5.8 and to avoid obvious axes of symmetry. In addition, six different ISIs and three different maskers were selected in order to investigate the range of the masking effect.

Method

Subjects.--The six Ss were paid volunteers with normal uncorrected vision from introductory psychology classes at Kansas State University.

Each S had previously served in a backward masking experiment using different four and five-dot patterns.

Stimuli.--The TS were five equivalence sets (4-b, 4-d, 4-k, 8-f, 8-h) of both four and five-dot patterns. The patterns were formed by punching 0.25 in. diameter holes in the appropriate cells of a 3x3 matrix. Each cell of the matrix was 0.5 in. square and the matrix outline was not shown on the 4-ply black posterboard. The matrix subtended 1.5° of visual angle when viewed from 57 in.

Three different maskers were also employed in this study. The three MS used were: the 3x3 matrix with all nine holes punched out; a random grid comprised of 0.0625 in. diameter holes producing the same figure-ground ratio as the 3x3 matrix; and the complement of the pattern used as TS.

The stimuli were rear illuminated in an Iconix three field tachistoscope (Model 6131). The luminance of TS field without the stimulus card was 84 mL. and for MS field 78 mL. The holes of the five-dot patterns occupied 1.1% of the total usable area in the stimulus field while the holes of the four-dot patterns occupied 0.9%. The holes of the random masker and the 3x3 matrix with all nine holes punched out accounted for 2.1% of the total area within the field.

The pre and post-exposure fields were completely dark. A faint red light, which served as a fixation point appeared at a point corresponding to the center of the 3x3 matrix for 1.5 sec. This fixation light terminated 10 msec. prior to TS presentation. Both

TS and MS were presented for 50 msec. The complement and 3x3 masker were separated from TS by ISI of 30; 70; 110; 150; 190; or 230 msec; while the random masker was delayed by 10; 30; 50; 70; 90; or 110 msec. These values were chosen on the basis of preliminary experiments which clearly showed that the random masker produced less masking. Ambient light was supplied by a 60-watt bulb located behind S.

Procedure.--The Ss were run individually for five sessions, and were given detailed instructions prior to the first session. These instructions stressed accuracy rather than speed. The Ss were told that this was an experiment in pattern perception and that their task was to describe the first of the two patterns after the second pattern had terminated. The Ss described TS by checking the appropriate cells in a 3x3 matrix drawn on the answer sheet. The Ss were told that the first pattern would always contain either four or five dots. The Ss were instructed to fixate on the red light that began each trial. The Ss were self-paced and required about one hour to complete each session. The Ss were adapted to ambient conditions for the first 10 minutes.

Each ISI-MS combination was presented for four successive trials with a different TS on each trial. The order of presentation was different for each S on each day with the presentation orders being counterbalanced across Ss and days.

Design.--There were six different ISIs, 3 maskers, and 40 patterns (ten equivalence sets with four patterns per set) for a total of 720 possible conditions. Each S received 360 presentations, one under each of the 360 conditions produced by presenting only two of the four patterns within each equivalence set with a particular MS-ISI combination. In addition, 30 catch trials were used to prevent the recall of a pattern from its complement. On each catch trial a pattern from the equivalence sets not selected as TS was followed by another pattern containing the same number of dots. An analysis of the errors indicated that Ss were not attempting to recreate TS from its complement.

In order to establish the importance of pattern goodness in a backward masking situation, prior to the actual collection of data, one pattern from each equivalence set was presented for one msec. without being followed by a masker. The Ss were required to reproduce this pattern.

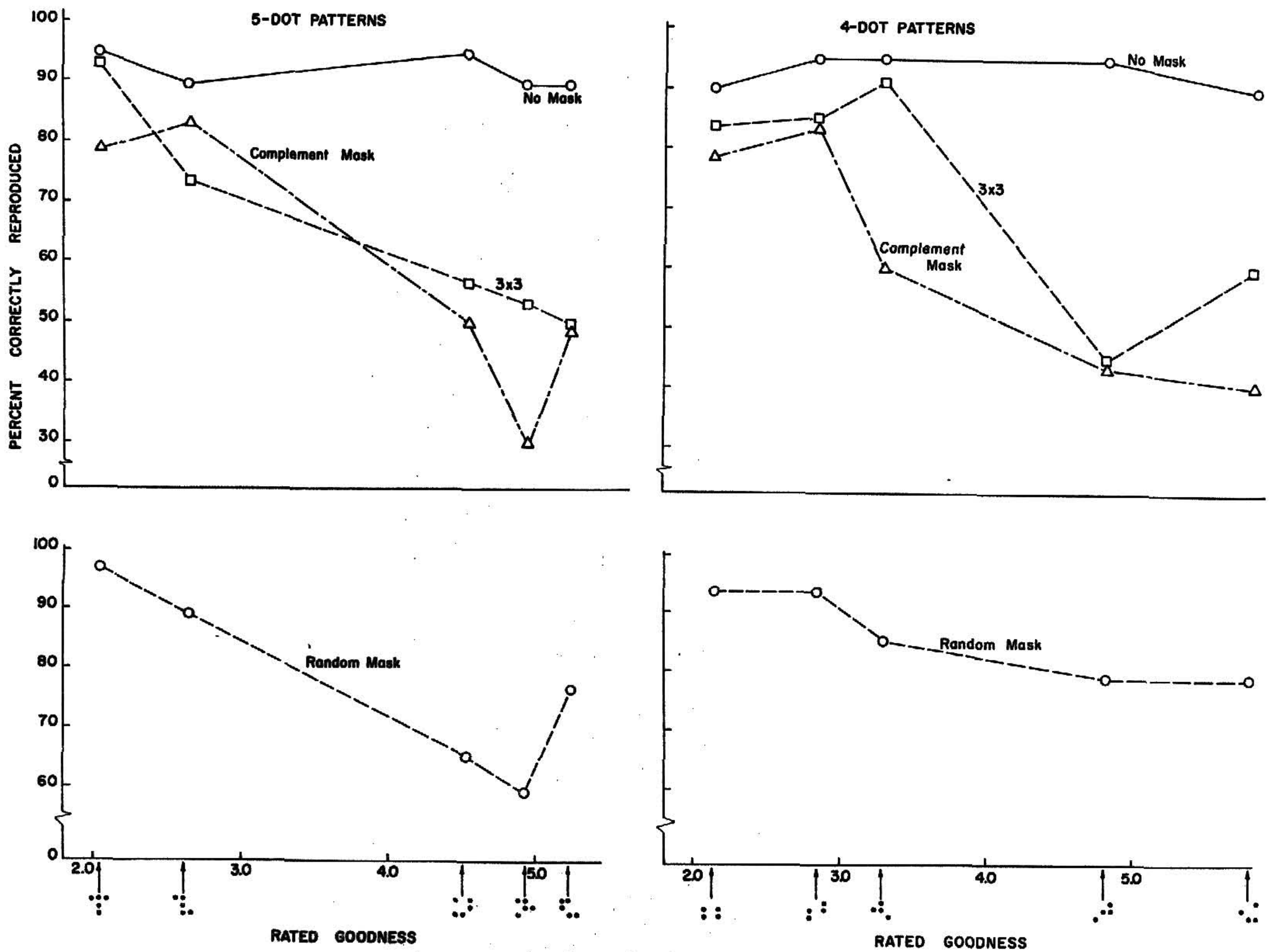
Results

The dependent variable was the percentage of patterns correctly reproduced under each masking condition. The percentage of patterns correctly reproduced as a function of pattern goodness is shown in Fig. 2.

No masking.--The data obtained under the no mask condition indicated that pattern goodness had no effect upon the correct reproduction of a pattern. All patterns were equally easy to reproduce. The mean percentage of patterns correctly reproduced was 93%.

Figure 2 Caption

Fig. 2. The percentage of patterns correctly reproduced as a function of pattern goodness for each of the masking stimuli, combined across Ss, sessions, and ISI.


5-DOT PATTERNS
4-DOT PATTERNS
PERCENT CORRECTLY REPRODUCED
No Mask
Complement Mask
3x3
Random Mask
RATED GOODNESS
2.0
3.0
4.0
5.0
0
30
40
50
60
70
80
90
100

Subjects.--Since the six *Ss* gave quite similar results, pooled data have been presented. All *Ss* improved across sessions at approximately the same rate, with a deviation from the mean percentage correct of not more than 6% of any *S*.

Sessions.--The data have been combined across experimental sessions. Although sessions was a significant variable, it showed no interactions with the other variables. The mean percentage correct for each experimental session was: 42%; 52%; 64%; 73%; 80%.

Interstimulus interval.--An analysis of variance, summarized in Table 2, was performed separately on the four and five-dot patterns for each of the three maskers. This analysis indicates that ISI was an important factor in the correct reproduction of patterns masked by both the 3x3 and complement maskers, but was unimportant when patterns were masked by the random grid. The ISI accounted for approximately 30% of the variance observed with the 3x3 and the complement maskers and about 20% of the variance associated with the random masker. An analysis of variance was also performed to determine if ISI interacted significantly with either the different TS or MS. No significant interactions were found.

MS.--The effectiveness of the various maskers is shown in Fig. 2. The random masker was analyzed separately because of the different ISIs associated with it. An analysis of variance, pooling across all interactions to obtain the error term since no two-way interaction was significant, indicated that for the five-dot patterns the 3x3 and

Table 2

*F*s Obtained From Separate Analyses of Variance

Source	Masker		
	Complement	3x3	Random
	5-Dot Patterns		
Pattern	16.7**	9.4**	5.9*
ISI	9.1**	5.1*	2.2
	4-Dot Patterns		
Pattern	13.3**	11.2**	2.4
ISI	5.5*	4.8*	1.0

Note: *df* pattern = 4:20. *df* ISI = 5:20.

* $p < .01$ ** $p < .001$

complement maskers were not significantly different accounting for less than 2% of the total variance. A similar analysis for the four-dot patterns revealed a significant masker effect accounting for 6% of the variance.

TS.--Figure 2 shows that pattern goodness is an important factor in the reproduction of a masked stimulus. When no MS was presented performance was essentially equivalent for all patterns, but the introduction of MS caused a disparity in the percentage of patterns correctly reproduced as a function of pattern goodness. The analysis of variance summarized in Table 2 indicates that the different patterns were an important factor in the correct reproduction of TS. An average of 45% of the total variance was accounted for by the patterns used as TS.

The patterns used as TS were grouped on the basis of their goodness ratings. For the five-dot patterns, equivalence sets 4-b and 4-d ($\bar{X}$ goodness rating 2.3) were rated significantly better than patterns 4-k, 8-f, and 8-h ($\bar{X}$ goodness rating 4.9). Similarly, for the four-dot patterns equivalence sets 4-b, 4-d, and 4-k ($\bar{X}$ goodness 2.8) were significantly better patterns than 8-f and 8-h ($\bar{X}$ goodness 5.3). Based upon these groupings a series of *a priori* *t* tests (Kirk, 1968) were used to assess the importance of pattern goodness in the correct reproduction of patterns. These *t* tests are summarized in Table 3. The results clearly indicate that patterns which are considered good patterns are correctly reproduced more often than poor patterns when followed by a masker.

Table 3

t Values Obtained From Comparison of Correct

Reproductions as a Result of High or Low Goodness

Masker	5-Dot Patterns	4-Dot Patterns
Complement	7.7**	6.5**
3x3	5.4**	6.4**
Random	4.0**	2.7*

Note: *df* = 20 * $p < .01$ ** $p < .001$

Further support for the importance of pattern goodness in a backward masking situation was provided by the product moment correlation coefficients between the percentage of patterns correctly reproduced and their rated goodness at each ISI. The mean correlation, averaged across ISI, between the rated goodness of a pattern and the percentage of times it was correctly described was -.66 for the four-dot patterns and -.74 for the five-dot patterns.

Error data.--The above results demonstrate that good patterns are identified more easily than bad patterns. Analysis of the errors suggests furthermore that patterns were perceived as wholes, and not as four or five dots.

First, there was no tendency for the errors to occur within a particular row or column of the matrix. If Ss employed any type of sequential encoding, errors might be expected in the lower row or right-most column of the matrix.

Second, Ss often reproduced four-dot patterns when a five-dot pattern was the TS. For five-dot patterns, 50% of the errors involved an incorrect five-dot pattern and 50% involved reproducing an incorrect four-dot pattern. However, the four-dot pattern was not usually four of the five dots of the original pattern. Any five-dot pattern contains five four-dot patterns so that by chance, $\frac{5}{126}$ (4%) errors would be four-dot subsets of the original pattern. Here, 7% of the errors were four-dot subsets. This further demonstrates that Ss are not sequentially processing, dot by dot, the pattern.

When four-dot patterns were the TS, about 90% of the errors were incorrect four-dot patterns.

Third, the number of errors involving the mislocation of one dot was three times as great for the poor patterns. Since there was no tendency for these errors to produce more symmetrical or better patterns, nor any tendency for them to occur within particular parts of the matrix, these errors suggest Ss were forming the gist of the pattern rather than sequentially processing the pattern.

DISCUSSION

The results of Experiment I were consistent with previous research. The fewer the number of alternatives a given pattern has, as determined by the R&R criteria, the more likely it was to be considered a good pattern. This relationship was true for both four and five-dot patterns, although the results were less consistent for the four-dot patterns.

Experiment II indicated that pattern goodness was an important factor in the processing of visual information. The differential performance observed under the masking conditions was highly correlated with the goodness of TS.

The difference in performance between the no mask and the masking conditions may be conceptualized as the product of state limitations (Garner, 1970). State limitations are conditions associated with the experimental situation, e.g., stimulus duration or intensity, which produce performance lower than the maximum obtainable under ideal circumstances. The maximum obtainable performance for a given stimulus depends on the ability of an organism to process the important aspects of the stimulus. The maximum performance is therefore process limited.

Since Ss were performing almost perfectly under the no mask condition, it may be assumed that pattern goodness is not an important factor in process limited performance. The performance observed under the various masking conditions was the result of state limitations imposed by the masking conditions. The differences in performance observed as a function of pattern goodness indicate that pattern goodness is an important factor in determining state limited performance.

The analysis of the error data failed to provide any evidence for the processing of TS as a series of independent elements. This suggests that TS were encoded as visual patterns. A similar proposal has been advanced by Clement (Clement & Varnadoe, 1967; Clement & Weiman, 1970) to explain performance in sorting tasks. It appears reasonable to assume that Ss attempt to process these stimuli as whole patterns, with poor patterns requiring more processing than good patterns.

Although the present experiment was not designed to distinguish between the various interpretations offered for the phenomena of backward masking, the results of this experiment are the consequence of central rather than peripheral mechanisms. A peripheral explanation cannot account for the importance of pattern goodness in the correct description of the pattern, since pattern goodness should not influence the sensory aspects of the perceptual process. A unique TS-MS combination is not an adequate explanation, since similar effects were obtained under all masking conditions. Furthermore, no differences were observed as a consequence of which pattern within an equivalence set was presented.

A central explanation for these results is consistent with Garner's (1966) analysis of perception. Perception is an active processing of stimulus information dependent upon properties of stimulus sets. Pattern goodness is a reflection of the number of stimuli which are psychologically equivalent to a presented stimulus. The larger the equivalence set, the more information there is to process in the encoding of a particular stimulus (Clement & Varnadoe, 1967).

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HERBERT H. BELL

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Department of Psychology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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Previous research has indicated that pattern goodness is related to the number of patterns which are psychologically equivalent to the rated pattern. These studies have also suggested that pattern goodness is an important factor in the encoding of visual information. Experiment I confirmed the relationship between pattern goodness and the number of equivalent stimuli for 4 and 5-dot patterns. The fewer the number of equivalent stimuli, the better the goodness rating of a pattern. Experiment II investigated the relationship between pattern goodness and perceptual encoding through the use of a backward masking procedure. The dependent variable was the percentage of patterns, selected from Experiment I, which were correctly reproduced when followed by 1 of 3 maskers, after 1 of 6 ISI. In addition, all patterns were presented without being masked. The results indicated that pattern goodness was unimportant under the no mask condition, but directly correlated with performance under the masking conditions. The better the pattern the more likely it was to be correctly reproduced. The ISI was also an important variable in the reproduction of the patterns. These findings were interpreted as supporting the importance of pattern goodness in the encoding of visual stimuli.