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Properties of visual memory for block patterns

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Abstract. Several characteristics of short-term visual memory (STVM) were specified through a series of experments, by using block patterns (BPs) of varying complexity. In experiment I, the characteristics of its acquisition process were examined through a recall task. The recall rate at a single glance (exposure time less than 0.3 sec.) is more than 90% for 3-by-3, and 4-by-4-L BPs. For 4-by-4-H BP, an improvement in recall rate was not found even when exposure time was increased to 2.4 sec. The recall rate for 6-by-6-H, 7-by-7, and 8-by-8 BPs did not change even when the exposure time was increased to 9 sec. In experiment II, the characteristics of the STVM decay process were examined using a recall task. Though a difference between 4-by-4-L and 4-by-4-H was found in the acquisition rate, one for the forgetting rate was not found. No decay was found for 6-by-6 BPs. Furthermore, the information obtained during a short duration was not forgotten for 4-by-4, and 6-by-6 BPs. It was concluded from these results that : 1) The acquisitoin rate into STVM depends upon figural complexity. 2) The forgetting rate does not depend upon figural complexity. 3) The limit of STVM was between 3-by-3, and 4-by-4-L BPs. 4) The recall performance for 6-by-6 BPs reflects the information stored in long-term visual memory. Although the acquisition rate into STVM depended upon figural complexity, it appeared in Experiment IV that the number of subpatterns into which subjects segmented BPs when memorizing them was highly correlated with rated fugural complexity. It also appeared that the number of memory chunks estimated from the data of inter-recall-interval was not correlated with the complexity. Finally, a process model for visual memory for block patterns was proposed.

Short-term Visual Memory (STVM) has been distinguished from verbal short-term memory and Iconic memory (Posner et al., 1969; Dale, 1973). The letters of the alphabet have been used as stimulus materials for the investigation of STVM. However, during the letter matching task (Posner et al., 1969), it is difficult to clearly distinguish name information from purely visual information. To overcome this difficulty, various stimulus patterns have been used to investigate the memory for visual information only. These include block patterns (BPs;Phillips & Baddeley, 1971), line segment length (Blick,1969), dot position (Dale,1973),and font type (Kirsner and Sang,1979). The purpose of these studies was to find evidence for the existense of STVM by distinguishing it from other types of memory. Although such evidence was found, the persistence of STVM was found to vary. Posner et al (1969) for example obtained a value of 1.5 sec, while Phillips and Baddeley (1971) obtained a value of 3-9 sec. This difference results not only from the difference between stimuli but also depends upon the degree of similarity between the target and distractor in the recognition task (Paivio and Bleasdale, 1974). It has also been determined that retention performance is quite affected by a visual intervening task during retention such as the addition of two figures, but not by a verbal one such as counting down from a given number (Mitchell, 1972;Ichikawa, 1982). Furthermore, it is known that when there is no intervening task, visual memory information can be rehearsed as well as verbal memory. Decay of memory has not been found in the non-intervening task condition (Nickerson, 1976;Mitchell, 1972) and in fact an increase of recognition performance was found in some cases (Graefe and Watkins, 1980;Intraub, 1979). From the effect of interference, two separate components of visual memory, namely STVM and long-term visual memory (LTVM), were identified (Phillips and Christie, 1977 a, 1977 b). Phillips and Christie (1977 a) also found the same distinction from the serial position function in recognition task for BPs. Although much evidence was found for the existence of STVM and LTVM, their spatial and temporal characteristics have not been specified well enough. Furthermore, it is also unknown how the characteristics are related to the stimulus structure and its complexity.

In the present paper, we investigate the characteristics of STVM in terms of its learning curve and forgetting curve, by using BP of various complexity. In particular in this study, using recall tasks, we investigate how the acquisition parameter of the learning curve and the decay rate of the forgetting curve vary with pattern complexity. The reasons why BPs of various complexity were used are: 1) recall performance can be checked exactly. 2) BPs of various complexity can be made easily. 3) The ways of measuring figural complexity for BPs have been proposed by several researchers (Chipman, 1977; Yodogawa, 1982). 4) BPs form fundamental pattern of two dimensional natural shapes. In other words, results obtained from BPs can be easily. extended to memory performance for natural patterns.

In Experiment Ⅰ, it was examined how acquisition rate of visual information into memory changed with figural complexity. In Experiment Ⅱ, we examined how recall rate deteriorated during intervening task. In Experiment Ⅲ, we also examined how the information obtained during a short-duration is forgotten. In Experiment Ⅳ, it was examined whether two psychological variables (i.e., number of subpatterns and number of memory chunks) are related to the figural complexity and the acquisition rate of the BP. Finally, a mathematical model which can predict the results was proposed.

Experiment Ⅰ

In this experiment, we measured the relationship between the exposure time and immediate recall rate for BPs of varying complexity and matrix size.

Method

Stimuli: BPs were used as stimuli. Half of the cells in the n-by-n matrix (n=4,and 6) were selected at random, and painted over in black. From the population of such BPs, we selected the set of BPs in which all black cells were connected and largest width for both the rows and columns were n.

Next, we calculated Horizontal-Vertical symmetry (H-V-S) as a structural variable (difined as follows), and the number of turns (NT) as quantitative variable for all of the selected 10,000 6-by-6 BPs and 3000 4-by-4 BPs. According to Chipman (1977), NT is the total number of corners of the BP, and H-V-S is defined as follows:

First, a subpattern of length $m(2<m<n)$ is taken out of each row of the BP(n-by-n). If it is symmetrical, it is given the score m. The total score for all m is defined as horizontal symmetry (H-S). For each column, the score of symmetry is calculated in the same way and defined as vertical symmetry (V-S). The sum of H-S and V-S is designated H-V-S.

Finally, we selected 40 BPs which were high in the quantitative variable and low in the structural variable (H-group), and another 40 patterns in which the distribution of these variables was reversed (i.e. low and high respectively; L-group).

Although, in this series of experiments, 4-by-4, and 6-by-6 BPs were mainly used, 3-by-3, 7-by-7, and 8-by-8 BPs were also used in a subsidiary role without being devided into H and L groups.

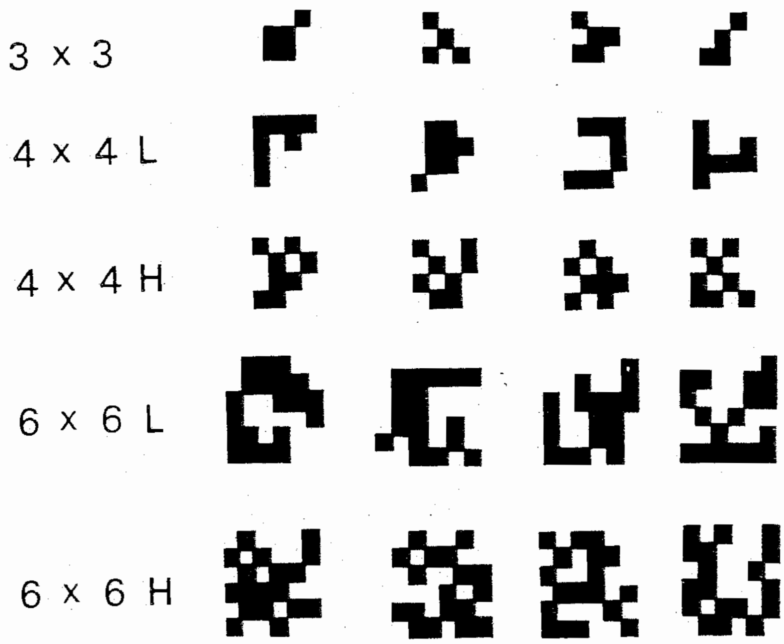

Figure 1. Examples of BPs used in this experiment.

Next, it was confirmed that there is a significant difference, not only in the physical parameter, but also in the psychological complexity for the H group and the L group patterns selected in this way. We let subjects select one BP among the 4-by-4 BPs at random, and assumed its complexity to be 100. Then the subject was instructed to evaluate the pattern complexity for all BPs (80 4-by-4 BPs and 80 6-by-6 BPs). We converted the rating score into a deviation value and calculated the average deviation value for five subjects. We derived this value for each pattern. The average values and the standard deviations for the pattern complexity belonging to each group are shown in table 1. It shows

Table 1. Average complexity and standard deviation for each BP group.

4-by-4-L	4-by-4-H	6-by-6-L	6-by-6-H
33.65 (2.67)	46.43 (2.13)	48.42 (3.01)	61.08 (3.26)

that the estimated complexity for the H group and the L group in each 4-by-4 and 6-by-6 BP is perfectly separated. Then we examined the relationship between the above-mentioned variables and complexity. Chipman (1977) also investigated this relationship using 6-by-6 BPs. In this experiment, however, the matrix size was changed. To avoid an accompanying change of H-V-S with matrix size, the above defined H-V-S value is devided by the following normalization cofficient;

$$\alpha = n^2 (n^2 + 3n + 1) /3$$

We will refer to the normalized H-V-S value as simply H-V-S. Assuming the average rated complexity value for each BP to be a dependent variable, and H-V-S and NT to be an independent variables, we carried out a multiple regression analysis in which it appears that;

$$(\text{ average complexity}) = 26.47 - 0.49 \times (\text{H-V-S}) + 0.87 \times (\text{NT})$$

Here, the multiple correlation coefficient was 0.953. The regression line shows that the maximum complexity value is determined by NT and perceived complexity is reduced by the degree of symmetry (H-V-S).

In experiment I, 20 BPs were used as stimulus patterns and were selected from 4-by-4-L, 4-by-4-H, 6-by-6-L, 6-by-6-H. Furthermore, we used 20 BPs for each 3-by-3, 7-by-7, and 8-by-8 which were not divided into H and L groups. The average values and the standard deviations of NT and H-V-S for these BPs are shown in table 2. The mask pattern was an 8-by-8 black BP with only the white grid line on the black background.

Table 2. The average value and standard deviation of N.T. and H-V-S for BPs used in this experiment.

	NT	H-V-S
3-by-3	10.0 (1.05)	0.27 (0.05)
4-by-4-L	11.1 (1.2)	0.24 (0.02)
4-by-4-H	22.8 (1.2)	0.1 (0.02)
6-by-6-L	21.3 (3.4)	0.19 (0.02)
6-by-6-H	40.7 (3.38)	0.12 (0.02)
7-by-7	41.3 (2.4)	0.27 (0.03)
8-by-8	53.4 (3.5)	0.27 (0.03)

Procedure: A three field tachistoscope (Tachistoscope No. 232 DP-type made by Takei machinery Industrial) was used. A BP was presented 500 msec after the start signal (buzzer) and the mask pattern (A black square) was presented for 500 msec (I.S.I.=0). Because each cell of the BP is 0.36° by 0.36° , the 3-by-3, 4-by-4, 6-by-6, 7-by-7, and 8-by-8 BPs were presented at 1.1° by 1.1° , 1.4° by 1.4° , 2.2° by 2.2° , 2.5° by 2.5° , and 2.9° by 2.9° sizes respectively. As soon as the mask pattern disappeared, the subject attempted to reproduce the BP with a pen by marking the positions of the black cells in a blank matrix of the same size on a response sheet. The subjects were told beforehand that exactly half of the cells were black for BPs with sides divided into an even number of cells (4-by-4, 6-by-6, 8-by-8), and that one more, or less, than half of the cells were black for other BPs. When the subject finished the reproduction, the next trial began. BP exposure times for the first group of subjects was 0.056 sec, 0.1 sec and 0.28 sec for the 3-by-3 BP, 0.1 sec, 0.28 sec and 0.4 sec for the 4-by-4-L BPs, 0.1 sec, 0.28 sec, 0.56 sec, and 1.12 sec, 2.4 sec for 4-by-4-H BPs, 1.12 sec, 2.4 sec, 4.8 sec and 15 sec for the 6-by-6-L BPs, and 8.96 sec, 15 sec, and 30 sec for the 6-by-6-H BPs.

In the preliminary experiment, we found that recall rate of complex patterns did not change for short exposure duration. So relatively longer exposure duration for 6-by-6-H was selected in the first group of subjects. We examined recall rate for short exposure duration to verify this phenomenon. For the second group of subjects, 6-by-6-H, 7-by-7, and 8-by-8 BPs were exposed for 1.12 sec, 2.24 sec, 4.48 sec, and 8.96 sec. Following ten practice trials, there were 17 experimental blocks for group 1 and 12 experimental blocks for group 2. Each experimental blocks consisted of five trials. Each block contained one of possible combinations of BP complexity and exposure duraiton. The subject was informed of the conditions at the outset of the session. The order of presenting the blocks varied across subjects. We checked the response patterns cell by cell and percentage of cells correct was called the recall rate for each BP.

Subject: Tweleve students (six in the first group and six in the second group) participated in this experiment.

Results and Discussion

The results are shown in Figure 2 and 3. For 3-by-3, and 4-by-4 BPs,

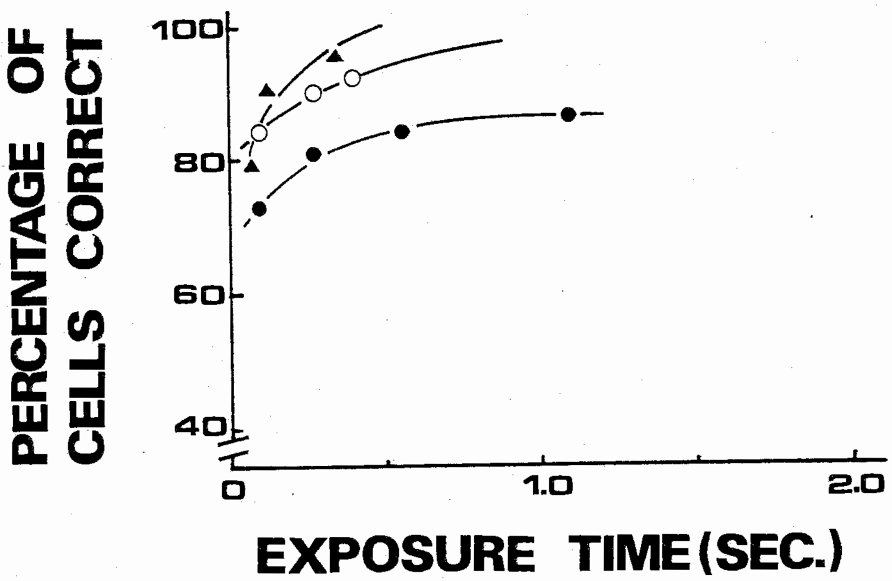

Figure 2. Recall rate (percentage of cells correct) as a function of exposure time for 3-by-3 (closed triangle) 4-by-4-L (open circle) and 4-by-4-H (closed cirlce).

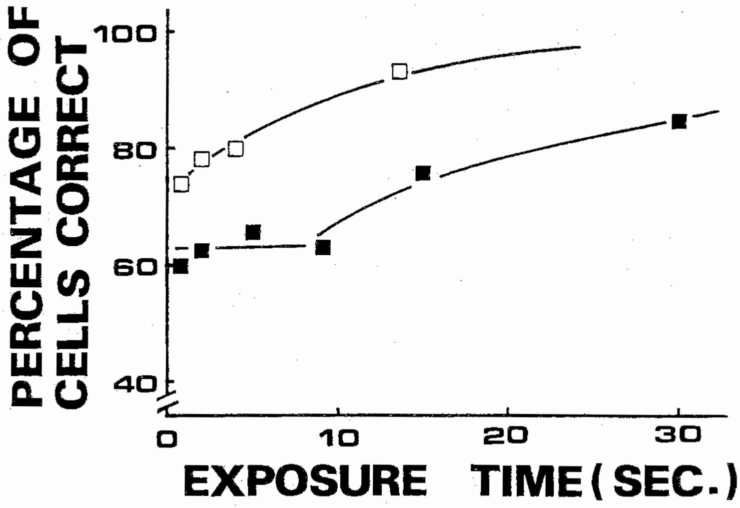

Figure 3. Recall rate (percentage of cells correct) as a function of exposure time for 6-by-6-L (open square) and 6-by-6-H (closed squre).

a significant effect of the exposure time on recall performance was found (3-by-3, $F(2,15)=9.3$, $p<0.05$; 4-by-4-L, $F(2, 12)=8.63$, $p<0.05$; 4-by-4-H, $F(4, 25)=4.18$, $p<0.01$). For both 3-by-3, and 4-by-4-L BPs, a recall rate of more than 90% was obtained at a single glance (exposure time=0.28 sec). For the 4-by-4-H BPs, however, significant differences in recall accuracy were not found with exposure times longer than 0.28 sec ($F(3,16)=2.29$, $p<0.05$). The accuracy was around 0.85 even with an exposure time of 2.4 sec. On the other hand, for BPs of 6-by-6-H, 7-by-7, and 8-by-8, recall performance did not change even when exposure time was increased up to 8.96 sec (Table 3, 6-by-6-H, $F(3, 20)=1.21$, $p>0.05$; 7-by-7, $F(3, 20)=3.1$, $p>0.05$; 8-by-8, $F(3, 20)=1.47$, $p>0.05$). For the 6-by-6-L BP, the average recall performance slightly improved with an increase of exposure time up to 2.4 sec, but this was not significant ($F(3, 20)=0.56$, $p>0.05$).

From these results, it appears that the limit to memory performance for a single glance exists between 4-by-4-L and 4-by-4-H. With more complex

Table 3. Recall rate (standard deviation) as a function of exposure time.

exposure time (sec.)	1.12	2.24	4.48	8.96
7-by-7	0.64 (0.02)	0.75 (0.05)	0.69 (0.02)	0.67 (0.05)
8-by-8	0.64 (0.05)	0.62 (0.02)	0.67 (0.02)	0.65 (0.01)

patterns, a phase in which recall performance does not increase was found. Especially in the case of complex BPs (e.g. 6-by-6 H), an increase in recall performance was not seen by an exposure time less than 9 sec.

Regression by integral curve and acquisition rate

We applied an integral curve for the recall rate data obtained in this experiment and examined the relationship between exposure time and recall rate. For the recall rate (P),

$$P = P_o + (1 - P_o) (1 - \exp(- A (t - t_o)))$$

is applied. Here, P_o, A, and t_o are constats. The acquisition rate in this curve is determined irredpective of P_o. If t_f is defined as the time in which the tangent line at an arbitrary exposure time (t') reaches a perfect recall performance (P=1, perfect recall), the following formula may be found;

$$1/ (t_f - t') = A$$

This acquisition rate A was calculated by applying the above integral curve with a value of t_o ; 0.1 sec for 3-by-3, and 4-by-4-L, 1.12sec 6-by-6-L BPs, and 8.9 sec for the 6-by-6-H BPs. It was not fitted to the 4-by-4-H BP as the recall accuracy did not reach 100% as was mentioned above. The results are shown in table 4.

Table 4. Learning curve for each of BP group

3-by-3	P = 0.9 + 0.1 (1- exp (-3.83 (t - 0.1)))
4-by-4-L	P = 0.84 + 0.16 (1- exp (-2.32 (t - 0.1)))
6-by-6-L	P = 0.74 + 0.26 (1- exp (-0.1 (t - 1.12)))
6-by-6-H	P = 0.63 + 0.37 (1- exp (-0.04 (t - 8.96)))

The acquisition rates for 3-by-3, and 4-by-4 BPs are 20-90 times larger than that for the 6-by-6 BPs.

Experiment II

In this experiment we investigate how the recall rate changes when an intervening task is given to the subjects after presentation of the BP. In other words, we estimate the forgetting rate for BPs of various complexity from the forgetting curve. These experiments were conducted at the exposure duration at which an immediate recall rate of about 90% was obtained.

Method

Stimuli: The stimuli were 4-by-4 and 6-by-6 BPs used in Experiment I.
Procedure: The BP was presented 500 msec after the start signal. A table of random numbers was exposed after presentation of the BP. Subjects were instructed to focus their attention upon reading the random numbers aloud as fast as possible. When the table disappeared, the subjects marked the black cells of the BP on the response sheet as in Experiment I. For the first group of subjects, 4-by-4-L, and 4-by-4-H BPs were presented for 0.3 sec, and 1.0 sec respectively. For the second group of subjects, 6-by-6-L, and 6-by-6-H BPs were presented for 20 sec, and 50 sec respectively. Theses exposure durations were based on the results of Experiment I and were selected so that the recall rate would equal approximately to 0.9. The retention interval was 0.5 sec, 2 sec, 4 sec, and 6 sec for the first group, 0.5 sec, 15 sec, 30 sec, and 45 sec for the second group, and 0.5 sec, 1 sec, 2 sec, and 4 sec for the third group. Each subject was tested 6 times at each retention interval and BP type.

Following ten practice trials, there were 8 blocks for the first, and second group, Each block was conducted under one combination of the possible BP complexity and exposure duration. The subject was informed of conditions at the outset of the session. The order of presenting the blocks varied across subjects.
Subjects: A total of 22 subjects (six for the first group, and sixteen for the second group) participated in this experiment.

Results and Discussion

The results for the first group of subjects are shown in Figure 4. The immediate recall rate (retention interval = 0.5 sec) was comparable with that in Experment I. A performance decay was found for both types of BP (4-by-4-L, $F(3, 20)=7.08$, $p<0.01$; 4-by-4-H, $F(3, 20)=8.71$, $p<0.01$). The decay rate shows little difference for 4-by-4-L and 4-by-4-H BPs. On the other hand, no decay was found for 6-by-6-L, and 6-by-6-H BPs as can be seen from the data for the second group (Table 5; 6-by-6-L, $F(3, 76)=0.45$, $p>0.05$; 6-by-6-H, $F(3, 76)=0.48$, $p>0.05$).

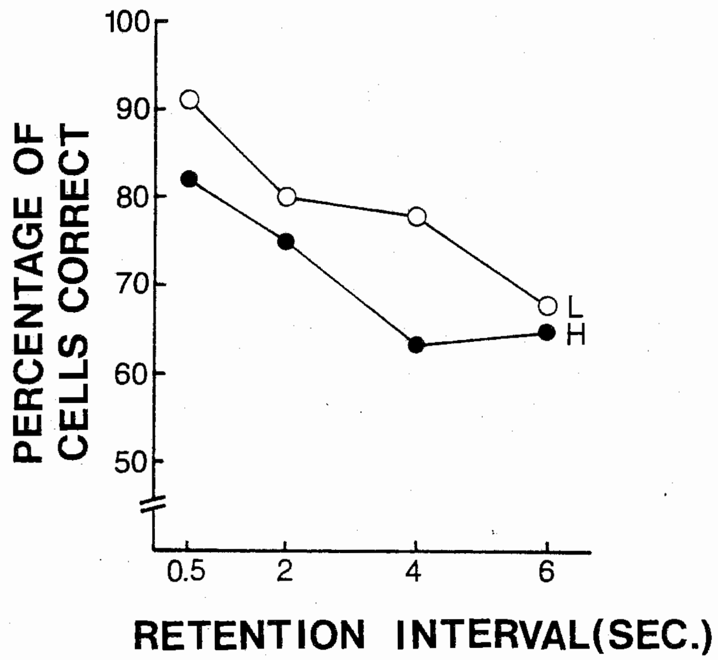

Figure 4. Recall rate as a function of retention interval for 4-by-4-L (open circle) and 4-by-4-H (closed circle).

Table 5. Recall rate (standard deviation) as a function of retention interval.

interval(sec)	0	15	30	45
6-by-6-L	0.86(0.09)	0.87(0.07)	0.85(0.08)	0.84(0.08)
6-by-6-H	0.90(0.09)	0.91(0.08)	0.90(0.12)	0.91(0.12)

From an investigation of the decay rate in verbal learning, Wickelgren (1974) found evidence for the existence of two memory types namely short-term memory and long-term memory. He reported that each decay shows an exponential function ($\alpha e^{-\beta t}$), and exponential power function (α exp $(-\beta t^{-(\alpha+1)})$ respectively. For 3-by-3, and 4-by-4-L BPs, a recall rate of more than 90% was obtained at a single glance in Experiment I. Furthermore, the recall rate for 3-by-3, and 4-by-4 BPs, showed a decay when subjects performed a visual intervening task. These results are consistent with the notion that 3-by-3, and 4-by-4 BPs were stored in short-term memory. These results agree with those of Ichikawa (1982). On the other hand, the learning rate value for the 6-by-6 BP was considerably smaller than that for the 3-by-3, and 4-by-4 BPs in Experiment I. Once learned, however, 6-by-6 BPs were not soon forgotten. These results showed that 6-by-6 BPs were stored in long-term memory.

Experiment III

In this experiment, we examined how the information obtained during a short exposure duration is forgotten.

Method

Stimuli: The stimuli were 4-by-4 and 6-by-6 BPs used in Experiment I.
Procedure: The procedure was the same as in Experiment II except below. 4-by-4-L, 4-by-4-H, 6-by-6-L, and 6-by-6-H BPs were presented for 0.1sec, 0.1sec, 2.5sec, 2.5sec respectively. The retention interval was 0.5sec, 1sec, 2sec, and 4 sec. Following ten practice trials, there were 16 blocks,

each of which was conducted under one combination of the possible BP complexity and exposure duration.
Subjects: 6 subjects participated in this experiment.

Results and Discussion

The results are shown in Table 6. In this experiment, no decay was found(4-by-4-L, $F(3, 20)=1.1$, $p>0.05$; 4-by-4-H, $F(3, 20)=1.26$, $p>0.05$; 6-by-6-L, $F(3, 20)=1.0$, $p>0.05$; 6-by-6-H, $F(3, 20)=2.81$, $p>0.05$). These results suggest that the information obtained during a short exposure

Table 6. Recall rate (standard deviation) as a function of interval.

interval(sec)	0.5	1	2	4
4-by-4-L	0.70(0.11)	0.78(0.07)	0.69(0.17)	0.68(0.12)
4-by-4-H	0.52(0.13)	0.54(0.05)	0.56(0.07)	0.48(0.05)
6-by-6-L	0.71(0.03)	0.71(0.03)	0.66(0.09)	0.68(0.03)
6-by-6-H	0.56(0.06)	0.64(0.06)	0.62(0.04)	0.60(0.05)

duration does not decay soon. This result is in contrast to that of ExperimentII.

Experiment IV

It was shown in Experiment I that acquisition rate depended upon figural complexity. Figural complexity was estimated by subjects on the basis of both a quantitative variable and a structural variable for BPs. As we consider the memory model, it is necessary to look for a variable from which we can estimate the information structure in the acquisition process or storage system. Furthermore, this variable should have a high correlation with the rated figural complexity. For this reason, two variables were examined for every BP in this experiment. One variable was the number of parts into which subjects segmented a BP in order to memorize it. The other variable was the number of memory chunks estimated from the number of pauses in recall (Chase and Simon, 1973).

Method

Stimuli and Procedure:

Experiment on the number of subpatterns Subjects were given response sheets on which BPs were printed and asked; "How many parts do you segment the BPs into when memorizing them? If you can remenber them without segmenting them, you do not have to segment them. " Subjects segmented each BP by drawing in lines with a pen. The number of BPs segmented was 13, 18, 19, 19, 14 for the 3-by-3, 4-by-4-L, 4-by-4-H, 6-by-6-L, and 6-by-6-H BPs respectively. All of these had been used in the experiment mentioned above.

Experiment on the number of memory chunks In this experiment, we measured the number of memory chunks for BPs of 6-by-6-L, and 6-by-6-H, using the method of Chase and Simon (1973). Ten subjects in the second subject group of Experiment II had their responses video-taped completely. We estimated the number of chunks from the number of pauses longer than 2 sec during the marking of the black part of the BP on the response sheet ,i.e., when the inter-recall interval (I.R.I.) was longer than 2 sec. This criterion for the chunk boundary was used by Chase and Simon (1973) and Bartram (1978).

Subjects: Seven students participated in the first experiment and 10 students in the second experiment.

Results and Discussion

The number of subpatterns (N.S.) is shown in table 7. For both 4-by-4, and 6-by-6 BPs, N.S. for H was about 1.5 times more than for L. This ratio

Table 7. Average value and standard deviation of N.S.

3-by-3	4-by-4-L	4-by-4-H	6-by-6-L	6-by-6-H
1.8(0.19)	1.84(0.29)	2.68(0.3)	2.86(0.5)	4.34(0.96)

is approximately equal to that of the rated complexity mentioned in method section for Experiment I (see Table 1). Furthermore, N.S was found to be highly correlated with the rated complexity; the correlation coefficent was 0.984 (Figure 5). The number of memory chunks (N.M.C.) is shown in Table 8. N.M.C. for 6-by-6-L, and 6-by-6-H BPs were about 2.5 and 2.8 respectively. Hence, N.M.C. was less sensitive to figural complexity. Furthermore, in a preliminary observation, a pause longer than 2 sec was seldom found for 3-by-3, and 4-by-4-L BPs.

It is concluded from these results that N.S. was a better predictor than N.M.C. for memory performance. What then, does N.M.C. mean? Attneave

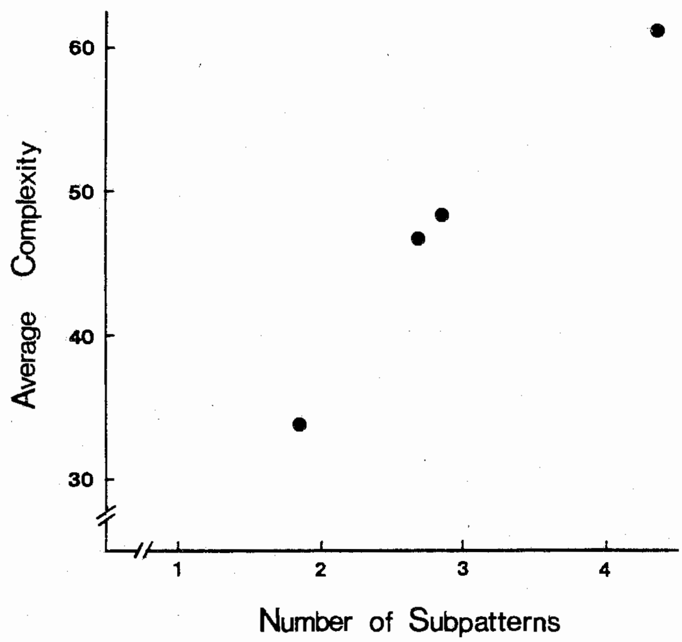

Figure 5. Relationship between average complexity and number of subpatterns.

Table 8. Average value and standard deviation of N.M.C. as a function of retention interval.

interval(sec)	0	15	30	45
6-by-6-L	2.3(0.7)	2.5(0.5)	2.8(0.4)	2.5(0.5)
6-by-6-H	2.6(0.5)	2.9(0.6)	2.9(0.6)	2.9(0.7)

and Curlee(1983) state that the limit of the pattern which can be imaged simultaneously exists between the 3-by-3 and 4-by-4 range. This is closely related to the capacity of STVM found in this paper. We can consider that a recalled pattern of this size is at the capacity of STVM, in processing cycle. If a 6-by-6 BP is divided by the N.M.C., that is, 2.5 - 2.8 as mentioned above, the number of cells in the subpattern is 13-14. This is just between the 3-by-3 and 4-by-4 range. Hence, N.M.C. obtained in this experiment reflects the limit of visualization (Avon and Phillips, 1980).

General Discussion

The primary findings of the present experiments were as follows:

(1) The recall rate at a single glance (exposure time less than 0.3 sec.) is more than 90% for 3-by-3, 4-by-4-L BPs. For 4-by-4-H BP, an improvement in recall rate was not found even when exposure time was increased to 2.4 sec, and recall rate was 85% even at the exposure time of 1.0 sec.

(2) The recall rate for 6-by-6-H, 7-by-7, and 8-by-8 BPs did not change even when the exposure time was increased to 9 sec.

(3) A difference between 4-by-4-L and 4-by-4-H was found in the acquisition rate as mentioned above. However, no difference was found for the forgetting rate.

(4) It was concluded from these results that the limit of STVM was between the 4-by-4-L, and 4-by-4-H BPs.

(5) A high correlation was found between the rated figural complexity and N.S..

Model for visual memory

In this section, we propose a process model for visual memory based only on the recall data mentioned above.

Global and local information From the results of Experiment II, III, it was found that the information about the BP acquired during an exposure of short duration did not decay within 4 sec. This suggests that global information can be acquired and stored with a short exposure time, and that it does not decay within several seconds. Recently, there are many reports that global information about the pattern is extracted faster than local information (Navon, 1977; Hoffman, 1980), at least for the small sizes (Kinchila and Wolfe, 1979). Furthermore, low spatial frequency components of a pattern are transmitted faster than the high spatial frequency to the visual cortex (Vassilev and Strashimirov, 1979; Williamson et al, 1978). These phenomena reflect perhaps the properties of the visual cell in that the speed of signal transmition in the axon of the neurons for the low spatial frequency is faster than that for high spatial frequency (Ikeda and Wright, 1975; Hoffman and Stone, 1971). However, a more detailed algorithm as to how local and global information is processed in the visual system is not known.

In this model, it is assumed that global information about the BP is acquired and stored during exposures of short duration, and that local information develops in visual memory through the processing cycle mentioned below. Therefore, the global information G is inversely proportional to the number of subpatterns (N.S.) mentioned in Expertiment IV and stored in STVM irrespective of the exposure time;

$$G = K_G / N.S.$$

Here, K_G is constant.

<u>Acquisition and forgetting process in STVM</u> According to Loftus (1972) and Inui and Miyamoto (1981), the rate for visual information acquisition deteriorates rapidly after the first 100 msec. After that time, information is not obtained until after 300 msec when a new information acquisition program seems to start. Therefore, world information does not always enter into STVM but with a processing cycle of about 300 msec. In the present model, the rate of visual information stored in STVM at one processing cycle is given by

$$P(t) = A_s \cdot (1 - \exp (-t/T_{as}))$$

This assumption is supported by the data of Avon and Phillips (1980; Figure 1).

If the acquired information in STVM is not rehearsed, it is presumed to be forgotten at;

$$P(t) = A_s \exp(-t/T_{ds})$$

The stimulus pattern was assumed to be temporally summated, that is strengthened, by multiple-looking or visual rehearsal in the processing cycle T. Taking the above decay function into consideration, the memory strength of the pattern after strengthening n times (i.e., after nT sec) can be formulated as;

$$P_{ss}(nT) = A_s + A_s e^{-T/Tds} + A_s e^{-2T/Tds} + \cdots\cdots + A_s e^{-(n-1)T/Tds} = B(1 - e^{-nT/Tds})$$

Here, $B = A_s / (1 - e^{-T/Tds})$

Hence, the acquisition curve can also be writtern as an integral curve. Furthermore, A_s is inversely proportional to N.S.;

$$A_s = K_s / N.S.$$

Here, K_s is constant.

Acquisition and forgetting process in LTVM We suppose that visual information enters into STVM, and at the same time enters into LTVM. The acquisition and forgetting processes can be written by the same equation as for STVM, but the parameter values are different.

The rate of visual information stored in LTVM at one processing cycle is;

$$P(t) = A_L \cdot (1 - \exp(-t/T_{al}))$$

If the acquired information is not rehearsed, it is forgotten by;

$$P(t) = A_L \exp(-t/T_{dl})$$

The memory strength of the pattern in LTVM after strengthening n times can be formulated as;

$$P_{SL}(nT) = A_L + A_L e^{-T/Tdl} + \cdots\cdots + A_L e^{-(n-1)T/Tdl}$$
$$= C (1 - e^{-nT/Tdl})$$

Here, $C=A_L / (1 - e^{-T/Tdl})$. Furthermore, A_L is inversely proportional to N.S.,

$$A_L = K_L / N.S.$$

Here, K_L is constant.

<u>Model prediction</u> It is assumed that the recall rate is determined by the higher rate of information stored in STVM or LTVM, except for the rate of global information. Furthermore, even for immediate recall, the factor of memory information forgotten during reproduction exists.
This is confirmed by Ichikawa (Note 1) who used the partial report technique(Sperling, 1960). This deterioration would be caused by both time dependent decay (It takes time to reproduce the pattern.) and output interference (Roediger, 1974). To simplify, we described these effects on the recallable informatiton C as;

$$C = \max \{ P_{SS} \cdot e^{-W/Tds}, P_{SL} \cdot e^{-W/TdL} \}$$
$$W = W' / 2$$

Here, W' is the time to reproduce the pattern.
Final recall rate P_R was written by

$$P_R = (G + C) / 2 + 0.5$$

This equation corrected the value (C+G) for guessing because subjects knew that half of the cells of the BP were black.
The model involved 6 parameters; K_G, T_{ds}, T, K_s, T_{dl}, K_L. We chose the parameter values as in Table 9. W' was determined from the data in

Table 9. Parameter values used in the simulation.

parameter		value
decay rate of STVM	T_{ds}	0.5 (study phase for one pattern)
		2.0 (after stimulus presentation)
decay rate of LTVM	T_{dl}	32
(increment of STVM)	K_S	1.66
(increment of LTVM)	K_L	0.03
processing cycle	T	0.28
(global information)	K_G	0.88

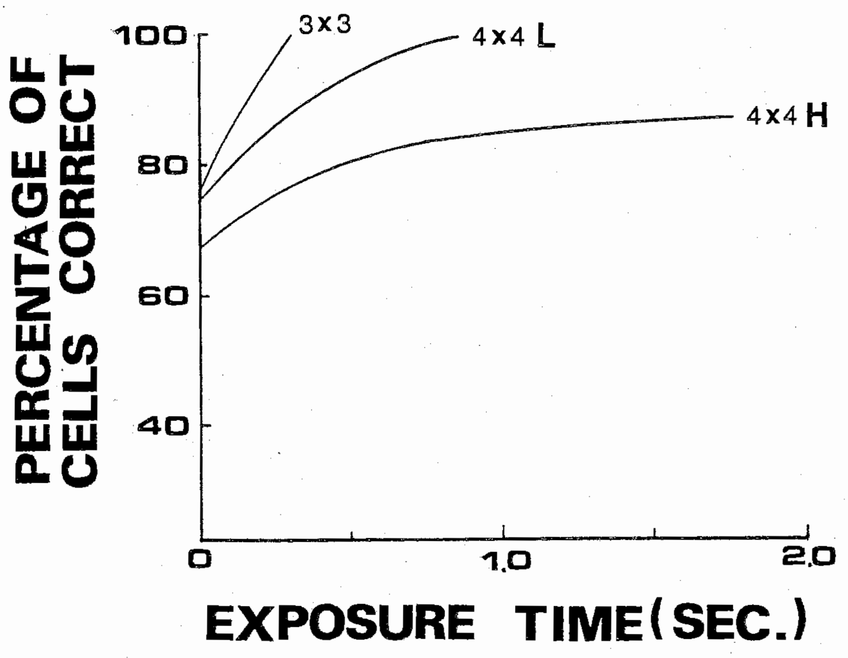

Figure 6. Predicted recall rate as a function of exposure time in the same condition of Experiment I.

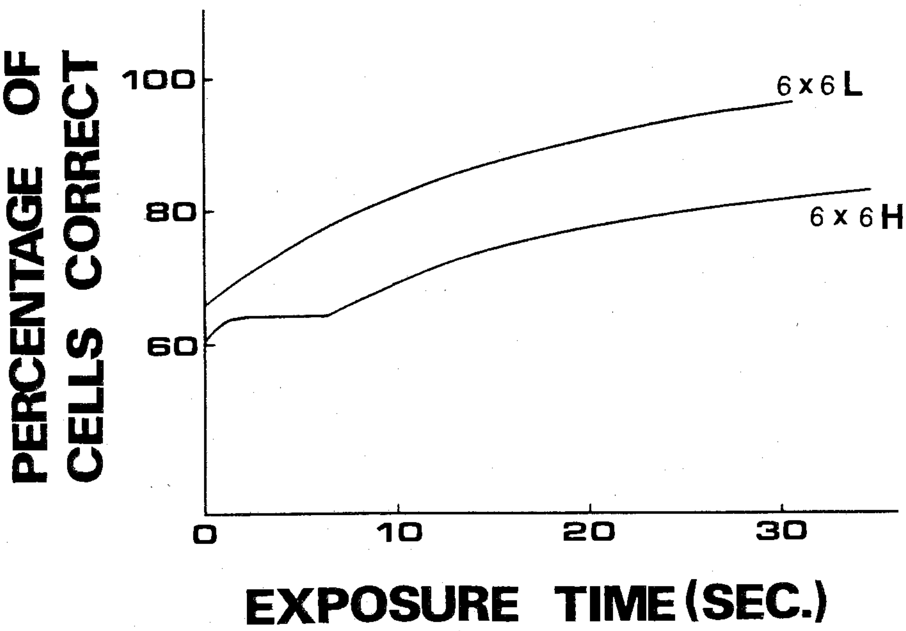

Figure 7. Predicted recall rate as a function of exposure time in the same condition of Experiment I.

the preliminary experiment. As a result, W' was found to be a function of the matrix size. In the model, W' was set to be 1.8, 5.0, 10.0 (sec) for 3-by-3, 4-by-4, and 6-by-6 BPs respectively.

Based on these parameter values, we calculated the recall data. At first, the predicted recall rate were shown as a function of the exposure time in Figure 6 and Figure 7. These data fit well the results of Experiment I (see Figure 2 and 3). Especially, it should be noted, the model predicted the two phases of the acqusition curve for 6-by-6-H BPs.

Next, the predicted forgetting curve for 4-by-4 BPs are shown in Figure II. This curve was calculated with a condition of exposure time, 0.3 sec, and 1.0 sec for 4-by-4-L, and 4-by-4-H BPs respectively.

Finally, the predicted data and actual data for several conditions are shown in Table 10. All data in the table were predicted by the model satisfactorily.

<u>Relationship to other findings</u> The time constant for LTVM (T_{ds}) was 16 times as large as that for STVM (T_{ds}). This ratio is comparable to that

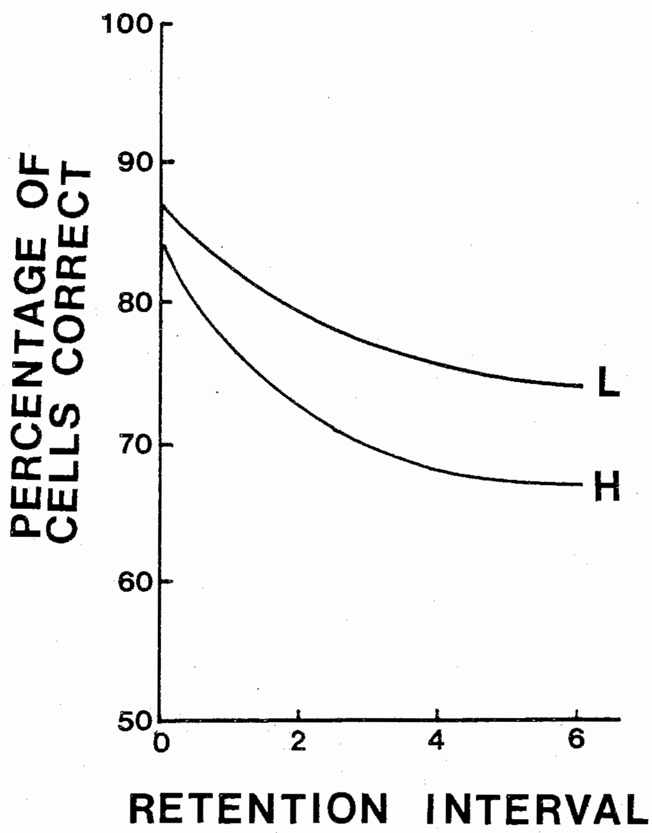

Figure 8. Predicted recall rate as a function of rentention interval for 4-by-4-L and 4-by-4-H.

Table 10. Percent correct observed and predicted by the model

pattern complexity	exposure duration	predicted	observed
4-by-4-H	(STVM capacity)	87	87
6-by-6-L	20 sec	91	85
6-by-6-H	less than 6 sec	64	63
6-by-6-H	50 sec	88	90
4-by-4-L	0.1 sec	74	71
6-by-6-L	0.1 sec	66	69

found in verbal memory. The decay rate of LTM was assumed to be about 30 times longer than that of STM in Kintsch and Polson (1979) and 10-20 times in Wickelgren (1972). In general the time constant for LTM (and possibly for LTVM) would become larger with study time (Bower, 1967).

Furthermore, a persistence of STVM which is an inverse of the decay rate was 2 sec in the model. This value coincided well with several studies(Oyama et al, 1981; Inui and Oiri, Note 2).

Cristie and Phillips (1979) presented 4, 4-by-4 BPs, one at a time every 3 sec. Their subjects performed free recall 1.5 sec after presentation of the last BP. They found that only for the last pattern was the recall more accurate than for the rest (recency effect). The model also predicts their data if the BPs used in their experiment were considered to be of the 4-by-4-H type (possibly so) and if the last BP was recalled first. The results are shown in Figure 9, and this accords well with their data (Christie and Phillips, 1979; Figure 1).

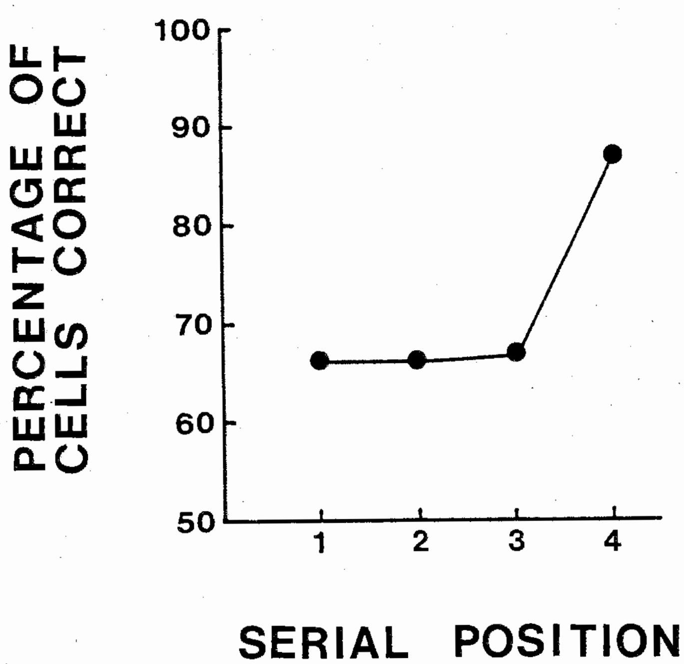

Figure 9. Predicted recall rate as a function of serial position in the same condition of Christie and Phillips(1979).

Reference Note

1. Inui,T.,and Oiri,M (Examination of persistence time of short-term visual memory.) In: Proceedings of the 2nd meeting of the Japanese Psychonomic Society, Tokyo, November, 1983.
2. Ichikawa,S. (The factor on the forgetting of the short-term visual image and refreshing model.) In: Proceedings of the 46th meeting of the Japanese Psychological Association, Kyoto, July, 1982.

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