REPRODUCTIVE MEMORY FOR DIAGONAL AND NONDIAGONAL PATTERNS IN CHIMPANZEES

JACQUES VAUCLAIR[1], HOWARD A. ROLLINS, JR[2] and RONALD D. NADLER[3]

[1]Yerkes Regional Primate Research Center, Emory University, Atlanta, Georgia (U.S.A.)

[2]Dept of Psychology, Emory University, Atlanta, Georgia (U.S.A.)

[3]Yerkes Regional Primate Research Center & Dept of Psychology, Emory University, Atlanta, Georgia (U.S.A.)

ABSTRACT

Vauclair, J., Rollins, H.A., Jr., and Nadler, R.D., 1983. Reproductive memory for diagonal and nondiagonal patterns in chimpanzees. Behav. Processes, 8: 289-300.

   Two male juvenile chimpanzees were trained to reproduce from memory geometric patterns composed of lighted cells in a 3 x 3 matrix. In Experiment I, subjects reproduced 3-cell horizontal, vertical and diagonal patterns with either 0- or 5-second delay between stimulus offset and response. Diagonals were more difficult and were more affected by delay than were nondiagonal patterns. The sequence of response to diagonals was less structured than to nondiagonals. In Experiment II, more complex 4-cell patterns were used and, following training, subjects were tested for transfer to new patterns. Again, diagonals were more difficult to reproduce than nondiagonals. Transfer of training to new patterns requiring different motoric responses was successful. Similar to Experiment I, organization of responding was greater for nondiagonals than for diagonals. These results are discussed with regard to the presence of internal representation of visual information in nonhuman primates.

INTRODUCTION

   Memory for pattern reproduction (referred to as the MPR paradigm) can be used as an experimental tool for the study of representational processes in nonhuman primates. In this paradigm, subjects are briefly shown a visual pattern consisting of backlighted squares in a rectangular matrix. The task for the subject is to remember which cells were on and respond to them some time after stimulus offset (Medin, 1969). MPR tests have been used extensively in research with monkeys, and several reviews are available (e.g., Davis, 1974 ; Medin and Davis, 1974 ; Medin et al., 1976). For example, Motiff (1975) investigated the reproduction by rhesus monkeys of patterns composed of straight-line sequences forming horizontal, vertical and diagonal patterns, as well as random arrangements of four cells. Random patterns were the most difficult to learn, diagonal patterns were more difficult to reproduce than horizontal patterns,

and straight-line, horizontal and vertical patterns showed no significant differences in difficulty of reproduction.

Although there are substantial data on many species regarding difficulty with discrimination of diagonal forms (Lashley, 1938 ; Sutherland, 1957 ; Rudel and Teuber, 1963 ; Olson, 1970 ; Appelle, 1972 ; Wilkie and Summers, 1982), a review of the literature revealed only one study related to pattern reproduction in chimpanzees. Levere (1966) used a technique of pattern completion ; only one cell of four-cell patterns was completed by the subject in this study. It was found that chimpanzees performed better on horizontal and vertical patterns than they performed on diagonal patterns.

The first aim of the present study, therefore, was to gather further evidence on the ability of chimpanzees to reproduce patterns. The second goal was to examine the sequence in which the cells of individual patterns were reproduced : in an organized manner (i.e., by responding to contiguous elements of the pattern with minimal changes of direction), or in a more-or-less random sequence. If the characteristics defining a pattern are perceived and stored as independent elements, then a random order might be expected. If, on the other hand, those characteristics are stored as a whole, we might then expect the subject to reproduce the pattern in an organized way (e.g., top to bottom for a vertical pattern). Such an analysis of response sequences might also help explain why some patterns (such as diagonals) are more difficult to reproduce than other patterns.

EXPERIMENT I

Methods

Subjects. Two experimentally naive male chimpanzees (*Pan troglodytes*), Mort and Brent, 4.5 and 5 years of age, respectively, served as subjects. Both subjects were housed in individual cages in one room.

Apparatus. The apparatus consisted of one 3 x 3 matrix board composed of nine 3 x 3 cm square cells, each 3 cm apart. The 3 x 3 configuration of cells was mounted on a square Lexan board and vertically presented to the subject. Each cell could be backlighted by an incandescent lamp. A slight touch by the subject on a stationary sensor located in the center of the cell signified a response to that cell. When subjects touched a cell that had been illuminated during the display period of the trial, the light again was illuminated automatically. Stimulus display and sensors were controlled by a computer which was programmed to display subsets of lighted cells and record each response by the subject. One M&M candy was dispensed immediately following the third response for trials in which all three cells of the pattern were correctly reproduced. All other combinations of correct and incorrect responding

terminated the trial without reinforcement.

Stimulus Patterns. Each stimulus consisted of simultaneously backlighting three of the nine cells in the display. Three types of patterns were presented : three horizontal rows ; three vertical columns ; and both diagonals. Each pattern was presented for 3 seconds and there was a 30-second interval prior to presentation of the next stimulus. Each pattern type was presented in random order six times per session for a total of 16 sessions. Selection for presentation in a session of the six patterns of each type from the pool of patterns of that type was random.

Procedure. Each subject received 10 sessions consisting of approximately 100 pretraining trials with one lighted cell and approximately 400 trials with two lighted cells. Vertical, horizontal and diagonal type patterns were presented an equal number of times during two-cell trials. Subjects were trained to an 80 % correct criterion. Reinforcement occurred regardless of the order of response.

Following pretraining, subjects were exposed to 16 sessions, one per day, with each session approximately 20 minutes in duration. Six vertical, horizontal and diagonal patterns were presented in each session. For eight sessions, the subjects could respond immediately following offset of the display (0-sec delay) ; for the remaining eight sessions, subjects were required to delay 5 seconds following offset of the pattern (5-sec delay). Sessions of 0- and 5-sec delays were alternated. Trials were initiated with the sound of an 0.5-sec tone. At the offset of the display, a second tone occurred which signalled the subject to respond (a beeping tone was sounded during the 5-sec delay interval). Ten seconds were allowed for completion of the response. Responses made during presentation of the display were not reinforced or recorded. If less than three responses occurred within the time limit, the trial was repeated. Additionally, multiple responses to a single key were recorded as a single response.

RESULTS

Two dependent variables were examined in Experiment I : proportion of cells reproduced correctly, and sequence of responses made to patterns reproduced perfectly.

Proportion Correct

The proportion of cells reproduced correctly for each pattern type, delay interval, and subject are shown in Table I. Both subjects had much more difficulty with diagonal patterns than with horizontal or vertical patterns. Performance declined when the delay was introduced between stimulus offset and response, and the effect of the delay was greater for diagonal than for

TABLE 1

Proportion of cells reproduced correctly in Experiment I as a Function of
Pattern Type and Response Delay.

Response Delay	Animal	Pattern Type		
		Horizontal	Vertical	Diagonal
No Delay	Mort	.99	.83	.64
	Brent	.96	.96	.78
5-Second Delay	Mort	.96	.75	.53
	Brent	.92	.92	.63

nondiagonal patterns. These differences were confirmed by analyses of variance
on the data for each subject, with pattern type (3), delay (2) and session (8)
as independent variables. Variance associated with the six replications of each
pattern within sessions was used as an estimate of error variance, with the
interaction of replication with each independent variable, or combination of
independent variables, as the error term. Only results that were significant
at the 5% level or less are reported, except where noted. For both subjects,
there were main effects of pattern type [$F(2,10)$ = 121.46 for Brent ; $F(2,10)$ =
307.83 for Mort] and session [($F(7,35)$ = 4.44 for Brent ; $F(7,35)$ = 8.95 for
Mort]. In addition, the pattern type by session interaction was significant for
Mort [$F(14,70)$ = 3.32], indicating that performance on diagonals improved over
sessions while performance on the other patterns did not improve over sessions.
The also was a main effect of delay [$F(1,5)$ = 10.74 for Mort ; $F(1,5)$ = 14.01
for Brent]. The delay reduced reproductive memory for both subjects.

Diagonal patterns may have been more difficult in the present study because
these patterns always involved center cells and corner cells, whereas on many
trials, horizontal and vertical patterns involved cells along the periphery of
the matrix, or non-center cells. Medin (1969) has shown that pattern difficulty
varies as a function of such parameters in nonhuman primates. In order to
determine whether diagonals are more difficult without these confounding factors
the horizontal, vertical and diagonal patterns which included the center cell
were examined to determine if the probability of correct response to the common
center cell varied across pattern types. Since there were differing numbers of
trials for each pattern type that involved the center cell, proportions of
trials on which the center cell was correctly reproduced were examined. These

proportions were, for horizontal, vertical and diagonal patterns, respectively, .94, .87 and .77 for Mort, and .94, .79 and .59 for Brent. For both subjects, these proportions differ significantly across pattern type by the Chi Square Test for Independence : for Mort, 5.77, p < .06 ; for Brent, 15.89, p < .05. Therefore, the responses of both subjects to the common central cell varied systematically as a function of the orientation of the three cells, with the diagonal orientation producing the highest proportion of errors.

Response Order

For perfect reproduction of three-cell patterns, there are six possible sequences in which responses can be made. To the extent that subjects perceive patterns as wholes and organize their responses on the basis of this standard, one might anticipate that some response orders, reflecting such an organization, would occur more frequently than other response orders. The most organized output would be to respond in a spatially consecutive order to the three cells of a pattern (e.g., for vertical patterns, from top to bottom or from bottom to top). Table II illustrates the proportion of correctly produced patterns that were reproduced in any one of three classes of response orders, varying in degree of organization.

TABLE II.
Proportion of correctly reproduced patterns that were produced in each of three possible orders.

| | Pattern Type | | | | | |
| | Horizontal | | Vertical | | Diagonal | |
Response Order	Mort	Brent	Mort	Brent	Mort	Brent
Three spatially consecutive	.32	.47	.62	.57	.55	.33
Middle cell first	.17	.36	.16	.23	.36	.50
End cells first	.51	.16	.22	.20	.09	.17
Number of correct trials	87	83	45	85	11	30
Chi square	14.54*	12.30*	17.21*	20.33*	3.44	5.00

 * Significant at p < .05.

The results indicate that Brent was more likely to reproduce horizontal and vertical patterns in the more organized orders than would be expected by chance, whereas Mort reproduced only vertical patterns in an organized manner. Neither subject reproduced diagonals in the most organized way. If the subjects responded to cells only in a random order, then each of the three orders should

have occurred with approximately equal frequency. For four of the six columns
in Table II, Chi-Square Goodness of Fit tests indicated that responding
deviated from chance and, for three of these columns, the more organized
orders of responding occurred most frequently. In only one case, i.e., Mort's
responses to horizontal patterns, did the sequence "end cells first" occur
significantly more frequently than would be expected by chance.

The results of Experiment I suggest that the chimpanzee is very proficient
at reconstructing from memory simple geometric patterns and that when
reproduction is successful, response sequences to some patterns are more likely
to be organized than random. However, subjects clearly had difficulty
reproducing the diagonal patterns and, when successful, the diagonal was
reproduced in random sequences. In addition, when subjects were required to
retain the pattern in memory for 5 seconds, reproduction of the diagonal
patterns was observed to be more difficult than reproduction of the other
patterns. Furthermore, since reproduction of the common central cell varied
as a function of pattern type, difficulty of reproducing diagonal patterns must
involve more than simple responding to single cells. These findings suggest
that diagonal patterns are more difficult to reproduce, in part because of
processes related to storage in, and/or retrieval from, memory. One hypothesis
that may explain this suggestion is that diagonal patterns are stored in terms
of the individual cells with which that pattern is comprised, whereas vertical
and horizontal patterns are stored in memory as three-cell units.

EXPERIMENT II

The pattern of results for Experiment I suggests that the chimpanzee is able
to encode the structure of visual patterns, particularly vertical and horizontal
patterns, retain that structure in memory, and use the structure to organize
recall of the patterns. However, it is possible, given the design of Experiment
I, to argue that the subjects learned a fixed sequence of motor responses to
each of the patterns that reflects motor behavior and not representational
structure. If, however, the subjects learned some fixed motor sequence to each
pattern, there should be little or no transfer of learning from training
patterns to new test patterns when the sequence of motor responses is different.
Experiment II used more complex, four-cell patterns which contained either
diagonal or nondiagonal components and a transfer of training design to assess
these hypotheses.

Methods

Stimulus Patterns. Each stimulus consisted of backlighting four of the nine
cells of the same display used in Experiment I. The twelve patterns used in this
experiment are shown in Table III. Each pattern was presented for 3 seconds, and

there was a 30-second interval prior to the presentation of the next stimulus. Subjects could respond immediately following the offset of the display (0-sec delay).

TABLE III

Proportion of cells correctly reproduced for each pattern during training and test phases of Experiment II.

Pattern Type	Pattern Shape	Training		Test	
		Mort	Brent	Mort	Brent
Training Patterns					
1. Nondiagonal	o o o o	.91	.98	.95	1.00
2. Nondiagonal	o o o o	.93	.88	.95	.98
3. Nondiagonal	o o o o	.96	1.00	1.00	1.00
Mean		.93	.95	.97	.99
4. Diagonal	o o o o	.82	.83	.95	.97
5. Diagonal	o o o o	.77	.81	.95	1.00
6. Diagonal	o o o o	.90	.82	.95	.93
Mean		.83	.82	.95	.97
Test Patterns					
7. Nondiagonal/Similar	o o o o			.88	.91
8. Nondiagonal/Similar	o o o o			.89	.95
9. Diagonal/Similar	o o o o			.86	.91
Mean				.88	.92
10. Nondiagonal/New	o o o o			.98	.96
11. Nondiagonal/New	o o o o			.88	.89
12. Diagonal/New	o o o o			.59	.64
Mean				.82	.83

Procedure. Patterns 1-6, as shown in Table III, were presented in daily
sessions of 12 trials each. Each of the training patterns shown in Table III
was presented from one to three times per session, such that a total of six
diagonal and six nondiagonal patterns was presented each session.Approximately
equal numbers of each training pattern was presented over all sessions. A
criterion of 80 % correct responding on both diagonal and nondiagonal patterns
was used ; Mort required 17 sessions and Brent required 18 sessions to reach
this criterion.

Immediately following training, subjects were exposed to 14 test sessions,
one session per day. Twelve patterns per session were presented in random
order : the six training patterns, and six new patterns, as shown in Table III.
Three of the new patterns (patterns 7-9) were variations in orientation of the
training patterns. The remaining three patterns (patterns 10-12) were entirely
different. With these exceptions, Experiment II followed the procedure and
format of Experiment I.

Results

Proportion Correct. The proportion of cells reproduced correctly for each
pattern is shown in Table III. An analysis of variance was performed on the
performance of each subject, with pattern type (diagonal versus nondiagonal)
and sessions as factors. The six replications of each pattern type (three
patterns presented from one to three times) were used to assess error variance,
with the interaction of replication and independent variables used as the error
term. The analysis of variance indicated significant main effects of session
$[F(16,80) = 2.91$ for Mort ; $F(16,80) = 2.01$ for Brent], showing a modest
improvement across sessions, and of pattern type $[F(1,5) = 38.47$ for Mort ;
$F(1,5) = 60.42$ for Brent]. The three nondiagonal patterns clearly were less
difficult to reproduce than the three diagonal patterns. This effect of patterns
accounts for 80 % of the total variance for Mort and 75 % of the total variance
for Brent.

The proportion of cells reproduced correctly across the 14 test sessions for
both old and new patterns is also shown in Table III. The only significant
effect was for pattern $[F(11,143) = 12.39$ for Mort ; $F(11,143) = 12.36$ for
Brent]. For training patterns presented during test sessions, the performance
of Mort and Brent was high, with no significant differences between diagonal
and nondiagonal patterns. However, performance dropped for both subjects on
similar test patterns relative to the comparable training patterns [for
nondiagonal patterns, $t(68) = 3.06$ for Mort, and 2.39 for Brent]. The new
diagonal test pattern (n° 12) was extremely difficult for both subjects
relative to the training diagonals $[t(54) = 10.29$ for Mort and 10.38 for Brent].

However, only Brent showed more difficulty with the new nondiagonal pattern than with comparable training patterns [t(68) = 2.60]. There was no difference in the similar and new nondiagonal patterns presented to either subject. However, the similar diagonal pattern (n° 9) was less difficult than the new diagonal pattern for both subjects [t(26) = 6.60 for Mort and 6.93 for Brent]. While the diagonal and nondiagonal patterns presented in training and similar tests were not reliably different, for both subjects, the new diagonal pattern (n° 12) was significantly more difficult than the new nondiagonal (n° 11) pattern [t(40) = 9.19 for Mort and 8.46 for Brent].

Order of Response. Of the 24 possible orders for reproducing four-cell patterns, only four orders represent a systematic reproduction of patterns which implies structure. Essentially, each of these four orders involves completion of the three-cell line segment in a spatially consecutive order which is either preceded or followed by a response to the fourth cell. For the "square" and "diamond" shaped patterns, systematic responding was defined as consecutive responses to the nearest adjacent cell in either a clockwise or a counterclockwise direction. Table IV presents the results for order in Experiment II for each animal during training and testing on all patterns. The proportions of trials perfectly reproduced and the proportion of such perfectly reproduced trials that were reproduced in one of the four organized sequences are shown in Table IV. It is evident from the data presented in this table that both Brent and Mort organized their responses to nondiagonal patterns significantly more frequently than would be expected by chance. Brent also organized response order for one of the diagonal patterns (n° 5) more frequently than would be expected by chance, with significant binomial tests in each of these cases.

The proportion of correctly produced patterns during testing that were produced in an organized sequence also is shown in Table IV. On training patterns, organized sequences continued to occur with greater than chance frequency for both animals. However, on the new patterns, there was evidence of organized responding only by Mort on two new nondiagonal patterns (n° 10 and 11). If the degree of organization in response sequence determines, in part, how well the patterns will be reproduced, there should be a significant positive correlation between the proportion of trials reproduced and the degree of response organization. These correlations are presented at the bottom of Table IV. All four correlations are positive and two correlations are significantly greater than 0 regardless of the low sample size.

TABLE IV

Proportion of trials in Experiment II with all cells correct and proportion of trials reproduced in organized sequences.

Pattern type	Pattern	Training Mort Prop. Cor.	Training Mort Prop. Org.	Training Brent Prop. Cor.	Training Brent Prop. Org.	Test Mort Prop. Cor.	Test Mort Prop. Org.	Test Brent Prop. Cor.	Test Brent Prop. Org.
Training Patterns									
1. Nondiagonal	o o o / o	.64	.32*	.87	.48*	.71	.40*	1.00	.29*
2. Nondiagonal	o o o / o	.63	.32*	.62	.28	.79	.00	.93	.31
3. Nondiagonal	o / o / o o	.85	.50*	1.00	.38*	1.00	.29*	1.00	.43*
Mean		.71	.38	.83	.38	.83	.23	.98	.34
4. Diagonal	o o / o / o	.30	.25	.48	.00	.93	.31	.93	.23
5. Diagonal	o / o / o o	.24	.00	.45	.79*	.71	.50*	1.00	.71*
6. Diagonal	o o / o / o	.64	.11	.45	.24	.86	.08	.71	.30
Mean		.39	.12	.46	.34	.83	.30	.88	.41
Test Patterns									
7. Nondiagonal/ Similar	o / o o o					.50	.00	.71	.30
8. Nondiagonal/ Similar	o o / o / o					.57	.25	.79	.27
9. Diagonal/ Similar	o / o / o o					.57	.38	.71	.10
Mean						.55	.21	.74	.22
10. Nondiagonal/ New	o o / o o					.93	.62*	.86	.42
11. Nondiagonal/ New	o o / o o					.50	.43*	.71	.20
12. Diagonal/ New	o / o o / o					.00	.00	.00	.00
Mean						.48	.22	.52	.12
Pearson r		.74**		.11		.39		.70**	

*significant by binomial test, p < .05.   ** significant correlation, p < .05.

DISCUSSION

The present experiments demonstrate that, for chimpanzees, reproduction of diagonal patterns is more difficult than reproduction of nondiagonal patterns (horizontal lines, vertical lines, or combinations of both). Our data are consistent with Motiff's (1975) study on monkeys, with Levere's (1966) work on chimpanzees, and with reports of difficulties by human children in reproducing diagonal patterns on a checkerboard grid (Halford and McDonald, 1977 ; Sallach-Madison et al., 1981). Results of Experiment I also demonstrated that diagonal patterns are produced from memory in a less systematic manner than horizontal and vertical patterns.

These findings suggest that the diagonal pattern is, at first, not conceived as a unit but, rather, as a succession of elements that are more or less independent of one another. Experiment II showed further that reproduction skills acquired in training transferred to patterns that were similar in structure to, but requiring different responses than, patterns to which the subjects were exposed during training. Such a generalization demonstrates that response production is not linked with a specific motor sequence and that the chimpanzees learned something about the perception and organization of the patterns themselves. The capacity shown by chimpanzees to remember and to use patterns of visual information in a non-motoric way clearly parallels the behavior of two- to three-year-old human children and requires the presence of some form of internal representation of the figure to be reproduced (Piaget and Inhelder, 1956 ; Sallach-Madison et al., 1981). The present study examined the chimpanzees's response to very simple visual patterns. Future research must investigate the chimpanzee's reproduction of more complex patterns in order that we may better understand the organizational aspects of reproductive memory.

REFERENCES

Appelle, S., 1972. Perception and discrimination as a function of stimulus
    orientation : the "oblique effect" in man and animals. Psychol. Bull.,
    78: 266-278.
Davis, R.T., 1974. Monkeys as perceivers. In : L.A. Rosenblum (Editor),
    Primate Behavior: vol.3, Developments in Field and Laboratory Research.
    Academic Press, New York, pp. 1-263.
Halford, G.S. and McDonald, C., 1977. Children's pattern construction as a
    function of age and complexity. Child Devel., 48: 1096-1100.
Lashley, K.S. 1938. The mechanism of vision. XV. Preliminary studies of the
    rat's capacity for detail vision. J. Gen. Psychol., 18: 123-193.
Levere, T. E., 1966. Linear pattern completion by chimpanzees. Psychonom. Sci.,
    5: 15-16.
Medin, D. L., 1969. Form perception and pattern reproduction by monkeys. J.
    Comp. Physiol. Psychol., 68: 412-419.
Medin, D. L. and Davis, R. T. 1974. Memory. In: A. M. Schrier and F. Stollnitz
    (Editors), Behavior of Nonhuman Primates. Academic Press, New York, pp2-47.
Medin, D. L., Roberts, W. A. and Davis, R. T., 1976. Processes of Animal Memory
    Lawrence Erlbaum, Hillsdale, N.J., 267 pp.
Motiff, J. P., 1975. Learning and retention of redundant patterns by monkeys.
    In: S. Kondo, M. Kawai, A. Ehara and S. Kawamura (Editors), Contemporary
    Primatology, Vol. 5. S. Karger, Basel, pp. 217-223.
Olson, D. R., 1970. Cognitive Development: The Child's Acquisition of
    Diagonality. Academic Press, New York, 220 pp.
Piaget, J. and Inhelder, B., 1956. The Child's Conception of Space. The
    Humanities Press, New York, 490 pp.
Rudel, R. G. and Teuber, H. L., 1963. Discrimination of line in children.
    J. Comp. Physiol. Psychol., 56: 892-898.
Sallach-Madison, L. M., McGarrah, N. and Rollins, H. A., 1981. Reconstructive
    memory in the second and third years. Paper presented at the annual meeting
    of the Society for Research in Child Development, Boston, MA.
Sutherland, N. S., 1957. Visual discrimination of orientation by octopus. Br.
    J. Psychol., 48: 55-71.
Wilkie, D. M. and Summers, R. J., 1982. Pigeons' spatial memory: factors
    affecting delayed matching of key location. J. Exp. Anal. Behav., 37:
    45-56.