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Chunking by the rat in the radial-arm maze.

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CHUNKING BY THE RAT IN

THE RADIAL-ARM MAZE

by

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ABSTRACT

The present study examined the ability of rats to acquire a chunking reference rule to facilitate performance on a radial-arm maze. Thirteen male hooded rats were exposed to a 16 arm maze composed of alternating striped and white arms. The experimental animals (N=7) were taught to enter first one set of 8 arms, then the remaining set of 8 arms based on the arm pattern. Control animals (N=6) were allowed to search the maze unconstrained. For the first phase all animals recieved a two minute darkened delay in the centre of the maze after correctly sampling the first eight arms. For the second phase the parsing cue was removed and for the third phase both groups were allowed free choice of the 16 arms. Results showed that the experimental group made a greater number of correct choices out of the 16 arms for all three phases than the control animals. The experimental animals maintained the chunking reference rule even after the removal of the parsing cue and during the free choice phase. Therefore, support was lent to the rule-learning hypothesis of animal learning which suggests that animals are capable of generating internalized representations of abstract rules. This is in direct contrast to the associative school which maintains that animals form simple S-S associations which control responding.

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CHAPTER I

Introduction

Miller examined short term memory (STM) in humans and found that STM capacity was 7+2 bits of information. Humans, however, group the bits of information together forming chunks to increase the amount of information stored in STM (ie. 7+2 chunks). Therefore, a chunk may be considered a unit of information organized according to a rule or corresponding to a familiar pattern which assists in encoding and retrieval of information (Simon, 1974). This organization of information has come to be known as a chunking strategy.

The chunking strategy has been shown to aid information processing in human serial learning tasks (Bower & Winzenz, 1969; Restle & Brown, 1970; Restle, 1972). Chunking may occur as a result of a strategy employed by the subject (Restle, 1972; Simon & Kotovsky, 1963), or it may be facilitated when information is segemented in a particular manner such as "parsing" (Bower & Winzenz, 1969) or "phrasing" (Bower & Springston, 1970). For example, to induce a subject to chunk a series of numbers into smaller groups, a temporal pause might be presented after the presentation of each group (Bower & Winenz, 1969). Bower and Springston (1970) found that phrasing facilitated recall better when it prompted more meaningful coding than when it did not (eg., FBI, PHD, TWA, IBM versus FB IPH DTW AIB M).

Implicit in the idea of chunking is the process of an hierarchical central reorganization of information. This notion of a cognitive system of organizing information is an alternative to the earlier associative chaining hypothesis which emphasizes the relationship between successive events (Ebbinghaus, 1885/1964). These two models of information processing and the feasability of their applications to animal behavior and learning are currently being debated (Hulse & Dorsky, 1979; Capaldi & Molina, 1979; Roitblat, 1982; Roitblat, Pologue, & Scopatz, 1983). The question is one of how best to characterize what is learned by the animal in a memory task. Does the animal form some internal representation of the formal structure of the stimulus events analagous to formal representations that people utilize? Or does the animal merely chain together associations between stimulus events? Clearly, one must first understand the paradigm through which the debate emerged, then examine the divergent models of learning.

SERIAL LEARNING PARADIGM

Early Serial Learning Studies

Hulse and Campbell (1975) originally set out to examine the properties of patterns of reinforcements in albino rats using a brightness discrimination task. Hulse (1978) claimed that the 1975 study marked the beginnings of experimentation on the behavioral properties of patterned

strings of elements.

Hulse and Campbell (1975) constructed three different element sets consisting of five quantities of food: 0, 1, 3, 7, and 14 food pellets. One group of animals received an element set with the pattern of a simple next rule, ordered montonically from largest to smallest (14-7-3-1-0). For the second group the element set was reversed as reinforcements became progressively larger (0-1-3-7-14). A third group received one of three possible element sets: (a) a random order of the five quantities for each repeated pattern, (b) a random order of four quantities with the final element remaining 0, and (c) a random order of four quantities with the final element remaining 14.

Given these elements, the animals were taught a brightness discrimination task in a T-maze during which a correct choice of the reinforced alley resulted in a series of runs of a particular element set. Therefore, each correct trial would consist of five subsequent "runs" for reinforcement. Two questions under consideration were: (1) Would animals learn to discriminate? (2) Would the animals respond to the changing food quantities; that is, would they be sensitive to serially changing food quantities? Running speed (in seconds) was chosen as the measure of the animal's ability to track the increasing and decreasing serial patterns with accuracy.

Animals did learn to easily choose one brightness cued arm over the other. More importantly, the animals learned

to track reward magnitudes within each series of runs as was evidenced by increasing running speeds for the monotonically increasing pattern (0-14) and decreasing speeds for the monotonically decreasing pattern (14-0). The animals who received a random pattern ran at a relatively constant speed across the series.

Of interest to the present study was the possible underlying mechanisms of the the rat's ability to track a serial pattern. Hulse and Campbell suggested that one possibility was that the rats may have learned a series of S-S or S-R associations between the successive elements (Hull, 1931; Skinner, 1934; Capaldi, 1967). This line of reasoning implied that the food quantity sets would reflect respective response strengths. More specifically, each quantity of food signalled to the animals the quantity on the next run. Hulse and Campbell also offered a second account which postulated the occurrence of a cognitive internalization of the serially ordered pattern. If cognitive structuring was the operative mechanism then the formal structure of the pattern could be a "next rule" used to arrive at the value of successive elements in the pattern (Hulse, 1978).

To summarize, the issue became whether the animal encodes any internal representation that depends on some structural feature of the large, formally defined pattern, or learns simple pair-wise associations between neighboring elements in the pattern? Hulse and Dorsky (1977) addressed

the two propositions in a series of four experiments.

Using the same task described previously, Hulse and Dorsky (1977) assumed that the rats would operate on something more than pair-wise associations. Monotonic (14-7-3-1-0) versus nonmonotonic (14-1-3-7-0) patterns were first examined with the prediction that tracking would be better for the monotonic pattern. The rats learned to track the monotonic pattern much faster than the nonmonotonic pattern. Therefore, it was assumed that rats were sensitive to the pattern of a consistently decreasing number of food pellets. A pair-wise association strategy would have resulted in no difference in running speeds between patterns because both patterns presented a consistent association between 14 at the beginning of the set and 0 at the end of the set. Furthermore, because the monotonic pattern was a simpler structure (with a progressive decrease to 0) Hulse and Dorsky concluded that patterns with simple formal rule structures were encoded by the rats as simple internal representations. A second experiment, comparing strong (14-7-3-1-0) and weak (14-5-5-1-0) monotonic patterns, confirmed the expectation that a simple pattern should be more easily represented in memory.

A third experiment determined that the animals could transfer from one decreasing monotonic pattern to another. Finally, for the fourth experiment, Hulse and Dorsky predicted that animals would divide a lengthy serial pattern into commonly repeated substructures similar to the grouping

strategy used by humans (Simon & Kotovsky, 1963). The
animals were presented with multiple repetitions of
decreasing pellets (eg., 14-7-3-1-0-14-7-3-1-0-14-7-3-1-0).
After 20 trials the rats just began to differentiate the
0-pellet element from the other elements, thus providing
weak support for the coding hypothesis. Taken together, the
results from all four experiments suggest that rats learn
some abstract representation of simple rule structures in
serial pattern tasks.

Over the next few years Hulse and his colleagues
expanded upon the functional similarity between rat and
human serial learning. Hulse and Dorsky (1979) and Hulse
and O'Leary (1981) presented further support that formally
simple patterns were easier to learn than formally complex
patterns. Also, Hulse and Dorsky used a simple straight
runway to demonstrate again that rats could generalize from
one set of pattern elements to a new set. In addition,
Fountain and Hulse (1981) found that rats could extrapolate
patterns to anticipate a new element implied by a pattern's
formal structure; that is, when an extra decreasing element
was added to the set, the animal anticipated the reduced
quantity without previously experiencing it.

Fountain, Evenson, & Hulse (1983) extended the
cognitive rule-learning hypothesis to determine how pattern
complexity and length interact to affect pattern difficulty.
They found that long, complex patterns were learned more
slowly than short, complex patterns but long simple patterns

were learned faster than short simple patterns. The findings
were attributed to rule-learning. A long simple pattern
would provide the animal with more repeated instances of the
rule to facilitate learning. However, for long complex
patterns relatively more rules would be needed for an
adequate description of the foraml structure so that more
element lists would have to be remembered.

Associative Approaches to Serial Learning

Capaldi and Molina (1979) argued that tracking ability
was a function of element discriminability rather than
simple internal representations. They found that tracking
was better for a weakly monotonic (15-15-0-0 or 14-14-2-0)
and nonmonotonic (1-29-0) pattern than for a strong
monotonic pattern (15-10- 5-0). The more highly
discriminative patterns, that is, the patterns which
produced the best tracking, were weak monontonic and
nonmonotonic patterns. These results contradicted the
earlier findings of superior tracking for strong monotonic
patterns (Hulse & Dorsky, 1977, 1979). Further work by
Capaldi and co-workers substantiated the associative view
that rats learned to anticipate elements of an orderly
series of reward magnitudes by employing memories of earlier
reward events in the series (Capaldi, Verry, & Davidson,
1980a, 1980b; Capaldi & Verry, 1981). The better the
discriminability between the elements, the stronger the
associations, and the better the tracking ability of the

animal.

The above studies led Hulse (1980) to concede that multi-element associations could coexist with rule learning strategies. Moreover, Hulse noted that, given a specific procedural difference in Capaldi and his colleague's work, there may have been learning situations more conducive to associative learning and other situations more conducive to rule learning. Capaldi's work consistently utilized short patterns of three and four elements while Hulse and his associates employed patterns of five or more elements. Thus, Hulse suggested that when patterns were short, contained few exemplars of the formal structure, and were high in discriminability among pattern elements, associative principles based on element memories may have been sufficient. However, when patterns were long with many different stimulus events increasing memory load, the rat may have searched for a consistent within-pattern relationship (a rule) to more easily anticipate elements within the pattern.

Capaldi, Nawrocki, and Verry (1982) responded to Hulse's (1980) claim of a situation specific responding by testing for associative responding in five element patterns. Comparing a weak monotonic pattern (14-5-5-1-0) to a nonmonotonic pattern (5-5-14-1-0), Capaldi et al. found that the rats better anticipated the 1 pellet event in the nonmonotonic pattern. They attributed the anticipation to discriminative associative learning with the memory of one

event signalling the next event. Furthermore, Capaldi et
al. stated that better tracking of the nonmonotonic pattern
was contradictory to the poor tracking of a nonmonotonic
pattern, predicted by the rule-encoding hypothesis. However,
later proponents of Hulse (Fountain & Annau, 1984) would
most likely suggest that the 5-5-14-1-0 pattern was not
complex because it easily separates into two chunks, 5-5 and
14-1-0, allowing the animal to follow a rule.

Finally, a study by Capaldi, Nawrocki, & Verry (1983)
brought serial learning investigations into the most recent
vein of questioning: Does the animal formulate rules in the
manner of chunking or does the animal formulate
anticipations of future events in the manner of S-S
associations? Capaldi et al. examined the nature of the
rat's anticipation of events by noting the running speed on
the middle element of a three element pattern (eg., 10-0-10,
10-0-0). A previous study by Self and Gaffan (1983) had
suggested that the rat always anticipated the reinforcement
on the current run, which implied an S-R association.
Instead, Capaldi et al. found that running speed on the
second element was determined by the anticipation of future
reinforcement consistent with an S-S view of association.
Capaldi et al. (1983) concluded that a serial mapping view
could provide an alternative to the serial chaining view
because the animal did form some internal representation of
the events of the series. However, lest it appear that
Capaldi et al. agreed with Hulse and colleagues' rule-

learning hypothesis, it should be noted that nowhere in the discussion did they acknowledge Hulse's work. In fact, Capaldi et al. dismissed the possibilitiy of chunking with little explanation. Thus, the question remains: Will the animal encode an internal representation that depends on some structural feature of the large formally defined pattern, or learn simple pair-wise associations between neighboring elements in the pattern?

HIERARCHICAL ORGANIZATION VERSUS INTERITEM ASSOCIATIONS

Fountain, Henne, and Hulse (1984) pursued the notion that rats were capable of forming internal representations with an emphasis on the facilitative effects of chunking on the encoding of the representations. Fountain et al. believed that, just as in tests of human serial learning (Simon & Kotovsky, 1963; Restle & Brown, 1970), rats activel, search for structure and chunk a complex pattern into simpler, structurally same subpatterns. Furthermore, the authors suggested that chunking could be facilitated by phrasing within the pattern as had been found with human subjects (Restle, 1972). Recall that a pattern is phrased if sets of elements are segregated by some type of cue in the pattern such as a temporal pause. Optimal phrasing occurs when the cues are placed so as to correspond with the higher order rule transitions between the chunks.

Using Hulse and Campbell's (1975) T-maze task, Fountain, Henne, and Hulse (1984) examined how rats use

phrasing cues to chunk a serial pattern consisting of several sucessive repetitions of 14-7-3-1-0 reinforecements. In the first experiment two phrasing cues were tested: (1) a temporal pause of 15 minutes between each subpattern, and (2) a place cue such that the rat would receive its food quantities from a different location for each subpattern. The animals were divided into four groups so that one group received the place cue, a second group received a combined temporal and place cue, a third group received only the temporal cue, and the fourth group received no cue. In a second phase all animals experienced the no cue condition.

Animals in the three phrasing condition groups were able to accurately track the subpatterns, but running speed remained constant for the nonphrasing group. However, when the phrasing cues were removed, only those animals in the prior place cue group were able to maintain their tracking ability. Of particular interest was the diminished performance of the temporal cue group whose performance was below that of the control group. Indeed, the control group began to show evidence of tracking the subpattern by the last few trials. Fountain et al. (1984) concluded that phrasing subpatterns could facilitate pattern tracking. However, the temporal cue facilitated learning only a lower order structure, the "decreasing subpattern" rule (intrapattern), but not higher order structure, the "repeat subpattern" rule (interpattern). It was determined that the 15 minute break segregated the closely contiguous elements

into disassociated patterns which accounted for the intrapattern learning as opposed to the interpattern learning.

Fountain et al. (1984) further demonstrated that a place phrasing cue not only facilitates pattern tracking but also the learning of the repeat rule of the subpattern. For the second experiment two groups received a place cue and one group received no cue. Of the two place cue groups, one group was given "good" phrasing (14-7-3-1-0/14-7-3-1-0) and one group was given "bad" phrasing (14-7-3/ 1-0-14-7-3). For the "good" phrasing group the cue was removed at either an early, middle, or late stage of training. The authors felt that consistent running times to the 0 pellet for all good phrasing animals would reflect between set pattern learning.

All of the good phrasing animals did track better than the control group, during the no cue test phase. Time of cue removal had no effect on these differences. The bad phrasing group showed the poorest performance of all the groups, which suggested that the misplaced cue actually hindered performance. Overall, Fountain et al. (1984) were able to demonstrate that rats learned phrased patterns sooner when the cue was congruent with the pattern's formal structure. As well, the gradual increase in tracking by the control group supported the contention that rats do search the pattern for simple features of formal structure such as recurring subpatterns. More specifically, if the hierarchical pattern is periodic (14-7-3-1-0 repeat), then

the rat can abstract and learn a formal representation.

Fountain and Annau (1984) provided more evidence of hierarchical organization in rat memory. They found that rats were capable of accurately tracking a double rule pattern consisting of a formally simple pattern (25-18-10-3-1-0) whose successive elements were separated by an embedded three element subpattern (6-6-0). The accurate tracking performance showed that rats have the capacity to discriminate pattern structures within pattern structures. In effect, the rat could hold in memory some representation of one structural chunk while responding to the elements of a second structural chunk. The authors also explained that chunking and sorting processes were most useful to the rat in situations in which patterns were long and well organized. However, when the rat had to respond to a number of repetitions in the pattern, a phrasing cue would facilitate the process. Lastly, Fountain and Annau changed the food reinforcement to brain stimulation reward (the element numbers representated pulses), to show that rats can generalize a relational rule. Thus, more support was lent to a cognitive abstract rule-based model of serial learning.

Despite the recent work of Fountain and his associates, Capaldi continues to propose an associative view of serial learning. Capaldi, Verry, Nawrocki, and Miller (1984) investigated the effects of phrasing in terms of interitem

associations. Capaldi et al. contend that a phrasing cue overshadows a previous 0 item as a signal for a reward item on the next run together with the 0 item to constitute a chunk. The phrasing cue alone would signal the next and largest reward to prevent or reduce interference from previous items. Phrasing cues are considered important as discriminative stimuli rather than as stimuli promoting chunking.

Capaldi et al. (1984) did find that good phrasing cues generate more accurate tracking than bad phrasing cues which they attributed to the overshadowing described above. An extinction phase during which no reinforcement was given was also examined. The good phrasing group was found to be less resistant to extinction with less vigorous responding on each run. The bad phrasing group responded more vigorously during the extinction phase. Capaldi et al. (1984) suggested that the interitem association between the last item of one series and the first item of the next series was not overshadowed by a bad phrasing cue. Therefore, each item retained its orginal anticipatory discriminative value. Given that the pattern decreased monotonically (14-7-3-1-0), the 0 item maintained the strongest signal that another 14-7-3-1-0 pattern would begin, hence, the more vigorous responding on nonreinforced trials. Still it could be argued that the anticipation of future rewards by the bad phrasing group was actually an encoded "repeat after 0 rule". However, in a later study, Capaldi, Nawrocki,

Miller, and Verry (1986) insisted that the anticipation of future events based on past events was an example of remote associations, that is, associations between two events separated by intervening events.

Recently, Terrace (1987) claimed to demonstrate chunking in pigeons using a more complex serial learning task. The previous studies of both Hulse, Capaldi, and their associates involved successively chained events with feedback after each run (different amounts of reinforcement). Terrace employed a serial learning task in which the discriminative stimuli were presented simultaneously with no feedback until a sequence had been completed.

The simultaneous lists presented to the pigeons consisted of colours and achromatic geometric forms. Pigeons had to correctly peck a specific order of the elements before receiving reinforcement. One group of pigeons received a task in which elements of the same dimensions were clustered; that is, pigeons had to first peck colours then form stimuli. Other groups received either a homogeneous set of elements or unorganized heterogeneous sets of elements. Terrace hypothesized that the organized element sets would facilitate chunking and produce faster learning of the serial order of the set. All animals did learn their respective orders, but groups not recieving the clustered sets required more sessions to reach criterion. Terrace suggested that, just as with humans (Miller, 1956),

the pigeons who received the clustered sets were able to chunk the set into two units to reduce memory load. The other pigeons had to recall the sequential order of all five elements. Terrace also noted that it had yet to be shown that an animal could chunk items not organized in a specific manner. This last note is of particular relevance to the present study.

Clearly, there is impetus for further research, specifically in other animal learning paradigms. Capaldi and Miller (1988) claimed that anticipation of remote associations might aid in linking together a variety of learning situations. However, studies by Hulse, Fountain, and Terrace indicate that hierarchical organization is also applicable to learning situations. It is also conceivable that both associative and rule-learning processes may operate concurrently or one as a function of the other. For example, consider a working memory task which requires the retention of information necessary for accurate performance within a specific trial (Honig, 1978). Such a task would involve retrospection, memory of previous information within the trial, and prospection, memory of some future aspect of the trial outcomes (Honig, 1978). Capaldi and Miller (1988) suggested that prospection was similar to the anticipation of future rewards. Conversely, prospection could also be understood as the animal's anticipation based on an internally represented rule. Thus, it seems logical to further investigate associative and rule-learning hypotheses

through the specific constructs of retrospective and
prospection in working memory. The radial arm maze is one
such paradigm which lends itself easily to the study of
working memory and the learning of lists.

RADIAL ARM MAZE PARADIGM

Memory Processes and the Radial Arm Maze

Olton and Samuelson (1976) first introduced the radial-
arm maze to investigate the characteristics of working
memory. The orginal apparatus consisted of eight arms
radiating out from a circular central platform like spokes
on a wheel. At the beginning of each test a food reward was
placed at the end of each arm. Albino rats were placed on
the central platform and allowed to choose freely among the
eight arms until all the food was collected. The animals
performed well, choosing an average of 7.5 different arms in
the first eight choices. Olton and Samuelson suggested that
the animal formed in working memory a list of places which
had been chosen and which should not be repeated during the
trial.

Olton and Samuelson's model of spatial working memory
provides the basis for the proposed study. The model
considered a place as.an item to be stored in a working
memory list. Olton (1978) explained that, as one result of
a choice, information about a place is processed and stored
in working memory as an item which can be treated

independently of its spatial location. Thus, continuous spatial information could be transformed into a list of discrete nonspatial items.

Further research supported the role of short term or working memory in radial maze performance. Olton, Collison, and Werz (1977) increased the maze size to 17 arms and discovered that rats still performed above chance, choosing an average of 14 different arms in the first 17 choices. Other studies determined that cues necessary for accurate performance were extra-maze cues associated with the arms rather than odor cues or response algorithms (Suzuki, Augerinos, & Black, 1980; Kraemer, Gilbert, & Innis, 1983).

Cook, Brown, and Riley (1985) examined the nature of memory representations used in the radial maze. Cook et al. believed that rats could avoid previously chosen arms by either maintaining representations of previously visited arms (retrospection), or by maintaining representations of to-be-visited arms (prospection). On a 12-arm maze, rats were allowed to make 2, 4, 6, 8, or 10 choices before they were removed from the maze for a retention interval. They were then returned to finish the maze. If the rats remembered retrospectively, then an interpolated delay near the end of a trial would disrupt performance because the amount of information to remember over the delay would be greater. If the rats retained prospective information about the remaining baited arms, then later interpolated delays would result in less disruption because memory load was

less.

Cook et al. (1985) found that a delay in the middle of a choice sequence produced the greatest disruption in performance. Therefore, the authors proposed that the rats possessed a dual-encoding mechanism which allowed for a switch from retrospection to prospection depending on the requirements of the situation (ie., the early or late interpolated delay). Moreover, the authors also described prospective coding as a function of reference memory or long term knowledge because the representations of anticipations are a result of generalizing information after many trials. In effect, a rule was learned. This view of prospection moves away from the associative view of Capaldi and Miller (1988).

Olton and Papas (1979) modified the search task on a 17-arm maze to provide another measure of working and reference memory. The authors wanted to determine the relationship between hippocampal damage and working and reference memory deficits. Only eight arms in fixed locations were baited and rats had to avoid entering unbaited arms (reference memory rule) and remember which arms of the baited set had been entered previously (working memory). Reentries into correct arms after the bait was retrieved were considered measures of working memory errors. Entries into arms that remained unbaited were considered reference memory errors. Olton and Papas found that septo-hippocampal lesions permanently impaired performance

only on the working memory aspect of the task. Performance
on the reference memory aspect of the task recovered to
preoperative levels. In a similar study, Gage (1985) found
the measures to be accurate when applied to the eight-arm
maze as well.

To demonstrate "chunking", it is not sufficient to show
that some serial-order tasks are easier to acquire and
maintai.: than others. A better proof of chunking is that a
specific serial-order rule in reference memory facilitates
performance in working memory whether or not such a
reference rule is easily learned. Previous animal research
never attempted to determine this facilitative effect.
However, human research on chunking consistently tries to
show enhanced working memory performance (Halpern, 1986).
The present study was designed to determine the effect of a
reference serial-order rule on working memory performance in
the radial arm maze.

Chunking in the Radial Arm Maze

Recently, Cohen, Burkhart, Jones, and Innis (1988)
investigated the effects of a reference memory rule on rats'
spatial working memory. The design involved a more
complicated reference rule than that used by Olton and Papas
(1979). Experimental hooded rats were required to enter
first one set of four baited arms (Set A), then enter the
remaining set of four arms (Set B) in an eight-arm maze.
The sets of arms were distinguished by different floor

textures, gridded or smooth. The rats did not receive reinforcement in Set B until all arms in Set A were searched. Thus, a subtle phrasing cue was provided. A control group was allowed free choice of all arms regardless of texture.

Cohen et al. (1988) believed that working memory would be utilized for performance within Set A and Set B, respectively. It was believed that failure of working retrospective memory would be indicated by reentries within Set A or Set B. Failure of prospective or reference memory was thought to be indicated by premature entries into Set B. Any returns to Set A arms after correctly sampling Set B arms were also considered as failures in reference memory. Cohen et al. postulated that evidence for chunking in the rats would be shown by enhanced performance in working memory. The assumption was that the rat would need only to remember up to four locations of arms with the operative set as opposed to up to eight separate locations.

Performance on the eight-arm maze did not differ between the experimental and control groups. However, Cohen et al. noted that the arms of the maze were widely separated from each other and spatially differentiated by different extra-maze cues so that retention of spatial locations was relatively easy for all animals. In their second experiment, retention of less well differentiated arms was tested for each group. The reduction in spatial differentiation disrupted performance more in control

animals.

For a final test all animals were given free choice trials of 8, 12, and 16 arms. Experimental rats were expected to extend their search sequence rule to the larger sizes. The experimental animals did maintain some aspects of the rule as was shown by their consistent initial entries into Set A arms, but they did not show superior performance than control rats. Furthermore, the experimental rats did not cluster responses to the two sets.

Cohen et al. (1988) offered two reasons to account for the apparent failure of animals to chunk. First, Cohen et al. suggested that the search strategy may not have offered an advantage to other possible strategies for securing rewards because the animals were run until they had completed searching all arms. This line of reasoning was in accordance with Hulse's (1980) argument that chained discrimination may be an optimal strategy under some situations. Second, intra-maze cues (arm texture) are generally less salient than extra-maze cues (Kraemer, Gilbert, & Innis, 1983). The less salient intra-maze cues may have actually hindered the formation of the reference rule. The present study was designed to eliminate these deficiencies.

STATEMENT OF THE PRESENT PROBLEM

The present study extended the research of Cohen et al. (1988) and Fountain, Henne, and Hulse (1984) by examining

the effects of a parsing cue on chunking. The purpose of the present experiment was two-fold. First, following the suggestions of Cohen et al. (1988), it was hoped that the study would establish the radial arm maze as a superior paradigm for examining animal learning and cognition. Second, given the specific measures of retrospection, prospection, and chunking, the application of both associative and rule-learning models were investigated.

A pilot study was performed on the eight-arm maze to test the effects of a temporal parsing cue. Rats were taught to enter first one set of four arms, then a second set of four arms based upon the intra-maze arm brightness cue (white or black/white stripes). Various extra-maze cues such as plants or foil paper could be viewed from the periphery of the arms. The parsing consisted of a two minute darkened delay in the central chamber, utilizing both temporal and visual cues. The cue occurred immediately after the rat had sampled the first set of arms. The experimental animals exhibited the signs of parsing within 40 days of training. However, the animals showed some difficulty in maintaining the rule when they were transferred over to the 16 arms with free choice. The control animals did not develop a chunking rule.

Based on Hulse's (1980) claim that following a chunking rule may be more efficient for a long list with an obvious pattern, the present study increased the number of arms in the rule learning phase to 16 and created a maze

configuration which required the rat to pay attention to the intra-maze cues (arm pattern). The arm pattern alternated white and stripes so that every two arms shared one extra-maze cue (ex. plants, blanket, foil paper). Therefore, when remembering previously visited arms the animal had to note the arm pattern to ensure correct choices. The two minute darkened delay followed the rat's successful completion of the first set of eight arms. A control group received the same parsing cue except that all the arms were baited at the onset of a session. A second phase was run in which the temporal/visual parsing cue was elminated. In a final phase, 16 arms were baited for both groups and the animals were allowed free choice.

The present design allowed for examination of two issues of chunking, specifically, the occurrence of spontaneous chunking and the facilitative effects of chunking. First, as was noted earlier, Terrace suggested that future studies consider whether animals have the ability to spontaneously chunk a pattern to simplify a task. The performance of the control group in the present study provided an indication of spontaneous chunking because the search-sequence rule was not enforced for that group. For the control group the parsing cue only marked the completion of half the maze regardless of pattern of arm choices. Evidence of spontaneous chunking would also support the rule-learning hypothesis because the control animals will .have come to represent the pattern in a more hierarchical

form rather than a simple chaining of subsequent events.

Second, the elimination of the parsing cue would serve to determine more specifically if parsing cues act merely as a discriminative stimuli (Capaldi, Verry, Nawrocki, & Miller, 1984) or also as facilitators for encoding of a higher order rule (Fountain, Henne, & Hulse, 1984; Fountain & Annau, 1984). If the experimental animals continued to use their search-sequence pattern after the elimination of the parsing cue, then their performance could not be attributed to associations of highly discriminative events. However, if accuracy of search sequence behavior decreased after the removal of the temporal/visual parsing cue, an associative process might be considered. Based on the findings of Fountain, Henne, and Hulse (1984), it was predicted that the rule would remain intact.

Finally, the effectiveness of chunking to increase the rats' capacity to store information in short term memory was exam:ed (Miller, 1956; Simon, 1974). Given the long list of items (16 arms), it was predicted that experimental animals would make fewer reentry errors than control animals, thus indicating that chunking facilitated the encoding and retrieval of spatial locations of previously entered arms. Experimental rats should be able to reduce their load on working memory by "dumping" locations of Set A arms while entering baited Set B arms. However, control rats should not be able to reduce their load of retaining earlier entered arms. Therefore, experimental rats should make

fewer reentries to earlier arms (their first eight choices) than control rats.

To summarize, the independent variable was the enforced chunking strategy so that there were two groups of animals, chunking and nonchunking. As well, both groups were exposed to two different phases. A parsing cue was provided for the first phase and removed for the second phase. The total number of correct choices out of 16 served as the measure for best overall performance. Returns to previously visited arms indicated failure of working memory. For the experimental animals (chunking condition) premature entries into Set B and returns to Set A after correctly sampling Set B were considered failure of reference memory (ie. learning the chunking strategy).

Both groups were also given a free choice test in which all arms were baited. Overall performance was again measured by the total number of correct choices. The number of arms of the same pattern sampled successively indicated maintainance of the chunking rule. The size of each "same arm pattern" run was also determined. Further detail of the dependent variables is provided in the method section.

CHAPTER II

Methods

Subjects

The subjects were 13 male Long Evans hooded rats from
the University of Windsor Psychology Department's breeding
colony. Seven animals were in the experimental group and six
animals were in the control group (one animal became ill and
was dropped from the experiment). The animals had
previously completed the pilot study chunking task described
earlier and were approximately 200 days old at the onset of
the present experiment. The animals were originally matched
on weight (300g). For the duration of the present
experiment the animals were individually housed in a room
with an 8/12h dark/light cycle. The experimental sessions
occurred in a lit running room during the animals' dark
cycle. The animals were maintained on a free access to dry
food and a water deprivation cycle of 0.5h of water after
each daily session. The animals received two days of ad
libitum water every two weeks.

Apparatus

An elevated wooden 16-arm radial maze, painted flat
grey, was used. The maze consisted of 16 arms, each 6.4cm
wide and 49.2cm long, radiating from a circular platform,
56.2cm in diameter. Each arm terminated at a 20.3cm square
goal platform which contained a recessed .5ml brass cup.
Plexiglass walls, 28cm high and 69.5cm long, separated the

arms and prevented the rat from jumping across arms.
Entrance to the arms was controlled by a grey circular
guillotine door, 32.7cm high. The door could be raised 30cm
to expose the rat on the central platform to all arms.
Removeable metal strips were placed on the arms and goal
platforms so that two types of visual cues, black/white
stripes and white, could be presented. Wooden blocks, 28cm
high, could be placed at the opening of any unused arms. The
entire maze was mounted on a central column raising the
platform and arms 72cm above floor level.

The maze was centrally located in a 3.96m x 3.66m room
containing metal storage cabinets, a sink, a one-way mirror,
and a door into the observation room. A number of other
distinct extra-maze cues were placed around the periphery of
the maze so that the cues could be easily viewed from the
arms. The stimuli included: suspended red and white beach
balls, red and white paper streamers, a suspended beige
checkered beach blanket, silver foil paper, green plants,
black and white papers with geometric shapes in the opposite
colour, and a stool. A video camera was suspended 80cm
above the central platform. The camera was connected to a
t.v. monitor in the observation room to allow the
experimenter to view that portion of the maze which could
not be seen through the one-way mirror. The guillotine door
also could be raised and lowered from the observation room.
An electric timer in the observation room was started when
the guillotine door was lowered and stopped when it was

raised to ensure constant intertrial intervals.

Procedure

Preliminary Training. After an initial period of ad libitum water the rats were placed back on a water deprivation schedule and reintroduced to the 8-arm maze for 10 sessions. The configuration of the maze consisted of alternating white (W) and black/white striped (BW) arms, spaced so that there were four sets of arms each with a W and BW arm (see Figure 1). The location of the arms remained fixed so that the white arms were always to the rat's left. Because each set of two arms faced only one extra-maze cue it was believed that the rat would be forced to use the intra-maze cues (arm pattern) when remembering previously visited arms (Kraemer, Gilbert, & Innis, 1983).

The rats were acquainted with the basic task of running to the end of each arm for liquid reward. For the 8 arm maze the rats were given eight choices before removal to home cages. Between each choice there was a 15s containment in the central chamber to control for response chaining. Rewards consisted of 0.5ml sweetened water (.10% sodium cyclamate). The rats remained in the previous randomly assigned control and experimental groups.

For the experimental group four animals completed the maze by entering first the W arms (Set A), then the BW arms (Set B). The other experimental animals ran from BW to W. Only the arms in Set A initially were baited so that an animal learned to enter Set A first. The
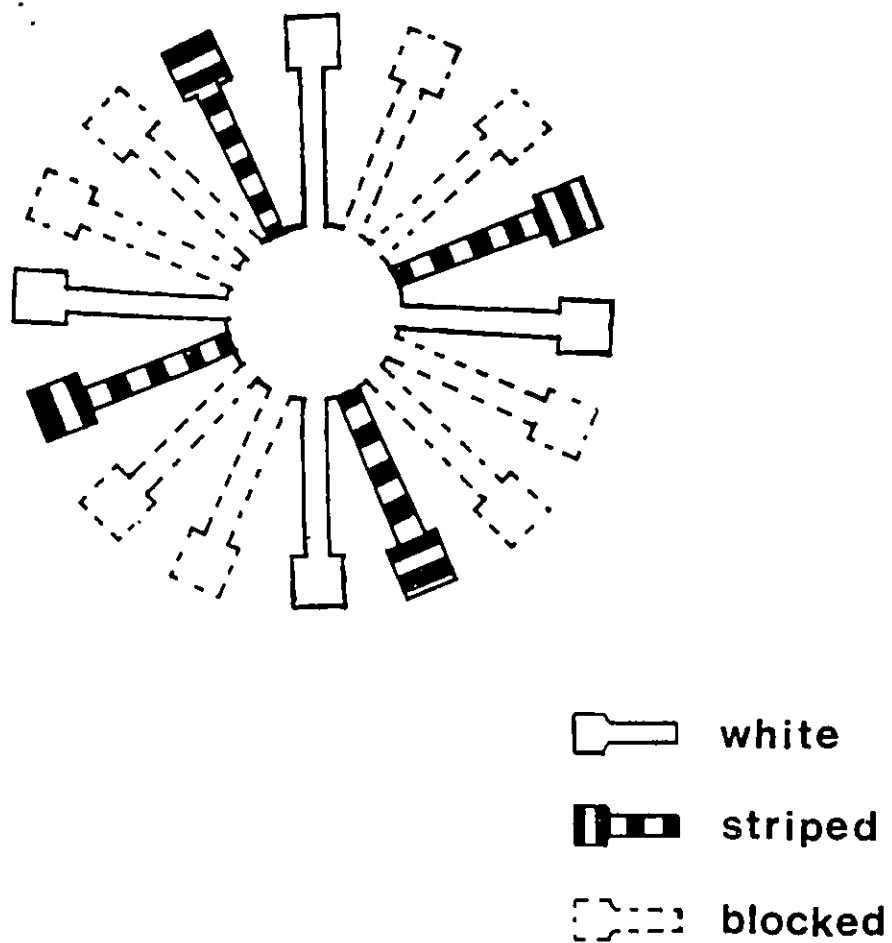
Figure 1. Eight arm radial maze configuration.

animal was then reinforced for entries into Set B. Thus, Set
A and Set B were dependent upon the intra-maze cues.

Once Set A arms were visited the animal was contained
on the first arm visited in Set B. The experimenter then
entered the test room and baited all the arms in Set B.
Baiting all Set B arms never took more than 60s. It was
believed that this specific baiting procedure would
eliminate possible redundant shift cues. Upon completion of
baiting the arms, the experimenter returned to the viewing
room, opened the guillotine door, and continued with the
remaining delayed exposures.

The control animals were also exposed to W arms and BW
arms. However, all arms were baited at the onset of each
session so that the controls had free choice of the eight
arms. To ensure consistent treatment, control animals
expereienced a similar pseudo baiting procedure. When a
control rat entered its fifth baited arm it was contained on
the arm and the experimenter entered the room. The
experimenter approached the fifth sampled arm and the
remaining arms with the water dispenser but did not bait
them.

In addition, both experimental and control animals were
given a parsing cue after the fourth arm was sampled. Once
the rat was contained in the centre after its fourth correct
choice the experimenter opened the door of the test room,
turned off the lights, then closed the door. At this
portion of the test a timer was set for 2 minutes. After the

2 minute period, the experimenter again opened the test room door, turned on the light, then returned to the observation room and opened the guillotine door for the animal's fifth choice. The remaining choices were presented with the usual 15s delay. For the experimental animals the parsing cue signalled that half of the arms had been sampled and that only Set B arms remained. For the control animals the parsing cue also signalled that half of the arms had been sampled.

16 Arm Training: Parsing Cue. The maze was expanded into 16 arms, eight W arms alternating with eight BW arms. The running procedure was similar to that which is outlined in the preliminary training. However, for the experimental animals the sizes of Set A and B were increased to eight arms each and the parsing cue now occurred after the eighth correct choice for both experimental and control groups. All animals received 24 sessions of training. Each rat was allowed only 16 runs on each session for this phase and the remaining two phases.

16 Arm Training: No Parsing Cue. A second phase of the experiment occurred over the next 24 days in which the parsing cue was eliminated. The rest of the running procedure was identical to that of the 16 arm training. The reference rule remained intact.

16 Arm Free Choice Test. For the final phase of the experiment, all animals were exposed to the 16 arm maze without th parsing cue for another 12 sessions. All arms

were initially baited for both the experimental and control groups.

Data Analyses

16 Arm Training. Three dependent variables were analysed: type of entry error, number of choices within a set before a choice to the other set was made, and number of correct choices out of 16. Three types of entry errors could be made by animals in both groups: (1) a repeated entry into an arm in Set A (AA); (2) a repeated entry into an arm in Set B (BB); and (3) a return to Set A after a correct choice in Set B (BA). A premature entry into Set B, an AB error, only could be made by experimental animals. It should also be noted that for the control animals, Set A and Set B were arbitrarily determined by the animal's first eight correct choices and its choices in the remaining baited arms. Within the 24 sessions, number of errors of each type were measured for each animal and averaged over four session blocks in the parsing and no parsing cue phases.

16 Arm Free Choice Test. Three dependent variables were analysed for the free choice test. The first measure was the number of same arm runs made by the animal. The second measure was the number of choices in the first and second runs. The last measure was the total number of correct choices out of 16. An additional analysis was included to examine the type of reentries that the animals made. The reentries were labelled in the same manner as the

previous entry type analyses for the training phases (ie. AA, BB, BA). It was also noted whether the entries were part of the animals true Set A or Set B and not simply the first and second group of eight chosen arms. Each measure was averaged over 2 session blocks.

CHAPTER III

Results

For the analyses of the first two phases the trials
were divided into 6 blocks of 4 sessions. For the number of
different entry types (errors) two separate MANOVAs were
performed: (1) comparing AA, BB, and BA entry data between
groups [Groups x Blocks (6)], and (2) examining blocks
within the experimental group with AB entries included
[Blocks]. A third MANOVA was run for the number of choices
made in one set before switching to the opposite set for
each set [Group x Block]. The number of correct choices was
analysed by an ANOVA [Group x Block]. Similar MANOVAs and
the ANOVA were utilized to compare the parsing phase to the
no parsing phase [Group x Phase x Block]. As suggested by
Hair, Anderson, and Tatham (1987), post hoc analyses were
carried out by Scheffe comparisons and ANOVAs performed on
composite dependent variables.

For the final test phase the number of runs to arms
with the same intra-maze cue, the number of choices in the
first and second runs, and the number of correct choices
were divided into 6 blocks of 2 days. An ANOVA was
performed on the number of runs and the number of correct
choices [Group x Block]. A MANOVA was employed to analyze
the number of choices in the first and second runs [Group x
Block]. For the number of AA, BB, and BA entries the days
were divided into 2 blocks of 6 for analysis by way of a
MANOVA [Group x Block]. Again, where appropriate, post hoc

analyses were carried out by Scheffe comparisons and ANOVAs performed on dependent variable contrasts.

16 Arm Training: Parsing Cue.

Figure 2 shows the number of errors of each type per session for both groups over blocks. As seen in Figure 2, both groups reduced reentries (AA errors) in Set A to nearly 0 by the last block of sessions. In Set B, the experimental group again made almost no BB errors by block 2 while the control animals continued to make both BB and BA errors across blocks. Most notable of the entry type trends was the experimental group's great decline in AB entries and the control group's consistent maintenance of BA entries. Results of the MANOVAs confirmed these observations. Overall, there were main Group and Block effects (Wilk's .069, $F(3,9)=40.33$ p<.0001; Wilks .621, $F(15,146)=1.84$ p<.03, respectively). Both groups reduced errors but for experimental animals there was a more drastic reduction ro lower levels. This tendency was further supported by a significant Group x Block interaction (Wilk's .539, $F(15,146.71)=2.45$ p<.003). Examining the experimental group alone, Block was also significant (Wilk's .154, $F(15,77.70)=5$ p<.0001). Individual comparisons revealed that the control group made more BA and BB entries than the experimental group (p<.05). ANOVAs on composite dependent variables revealed that experimental rats made more AB entries than AA and BB entries $(F(5,30)=9.32$ p<.01, $F(5,30)=16.45$ p<.01, respectively). Overall, the control
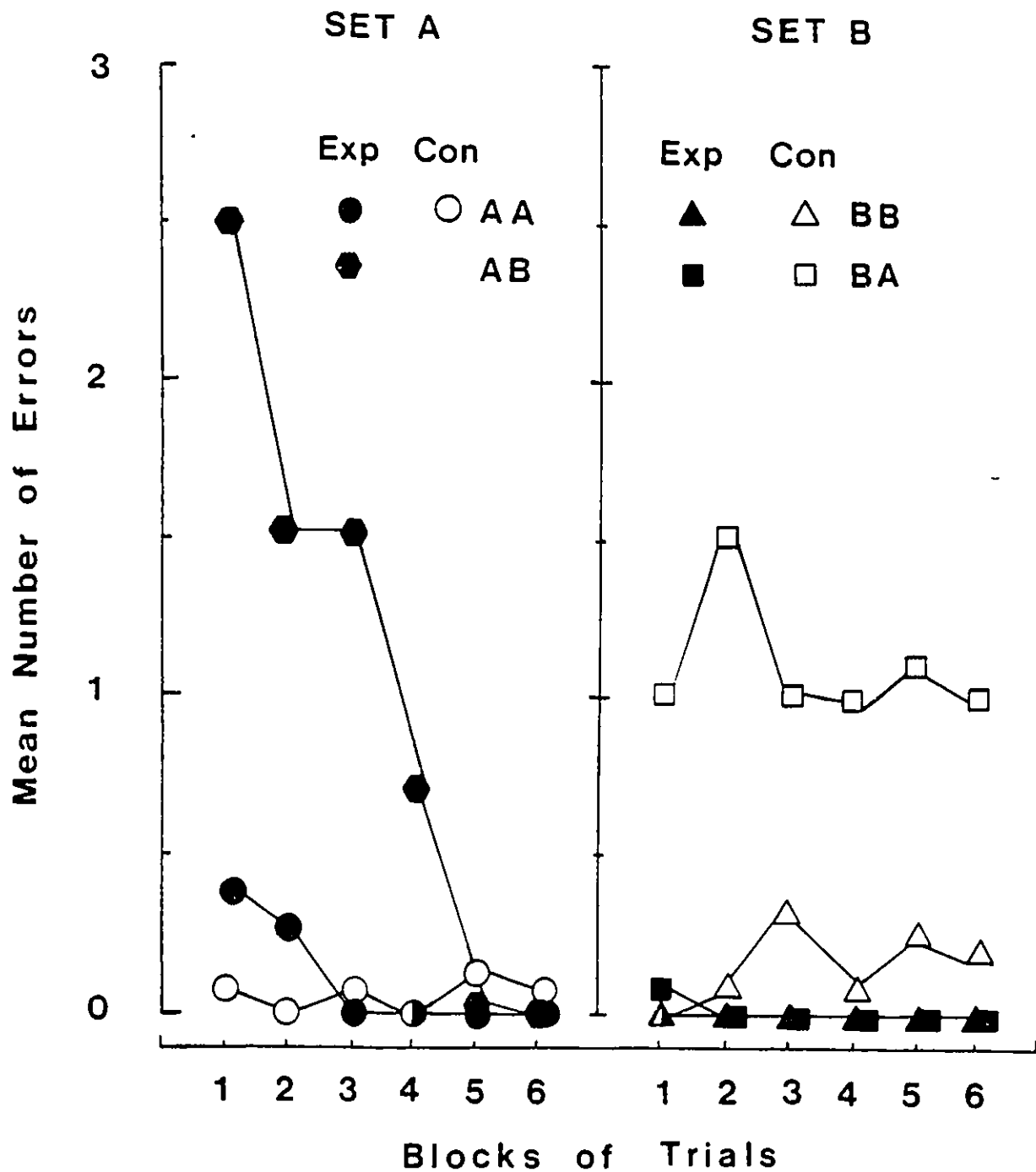
Figure 2. Mean number of error types across blocks for sets A and B under the parsing condition.

animals made more returns to Set A and more repeated entries in Set B while the experimental animals made more premature switches to Set B.

Figure 3 depicts the number of choices made before the first choice to the opposite set for both Sets A and B. For Set A the experimental group increased their amount of searching in Set A over blocks. The control group remained fairly stable at 8 or slightly more choices. Choices above 8 indicate a repeated choice in the first set. Of particular interest is the steady increase in Set B across blocks by the experimental animals. After making fewer choices in the first block than the control animals, the experimental animals made consistently more choices in Set B than the control group. These observations were confirmed by the MANOVA procedure. Again, the analyses revealed both Group and Block significant main effects (Wilk's .072 $F(2,10)= 63.71$ p<.0001, Wilk's .393 $F(10,108)=6.41$ p<.0001, respectively). The Group x Block interaction noted in Set B was also significant (Wilk's .481 $F(10,108)=4.76$ p<.001). For the experimental group, Scheffe tests revealed a significant increase in number of choices in Set A from block 4 through to block 6 and a significant increase across blocks for Set B (p<.05). Scheffe tests also showed that experimental rats made significantly fewer choices in Set A than the control rats until block 4 and significantly more choices in Set B than the control rats from block 4 (p<.05).

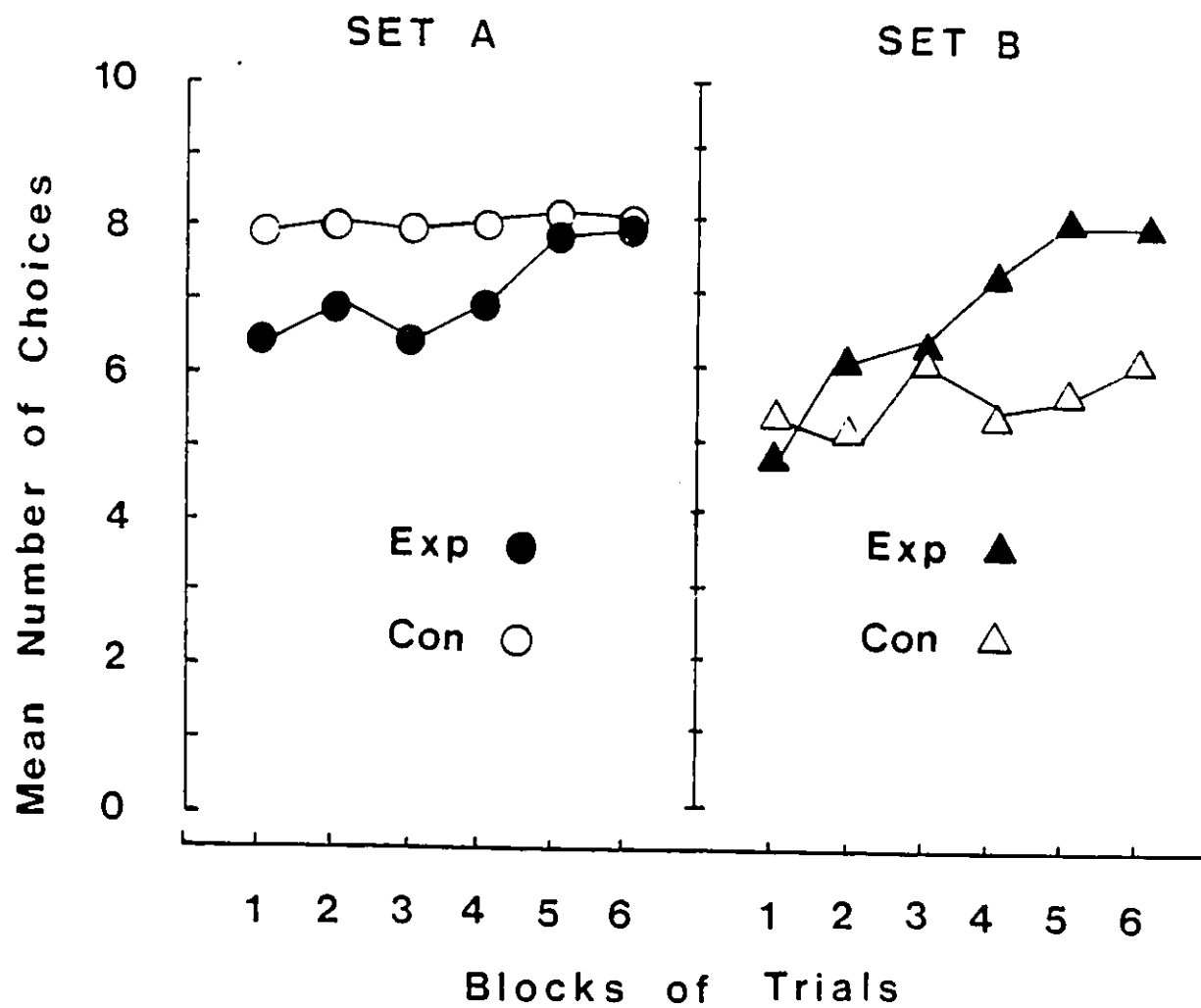Figure 4 shows the number of correct choices per

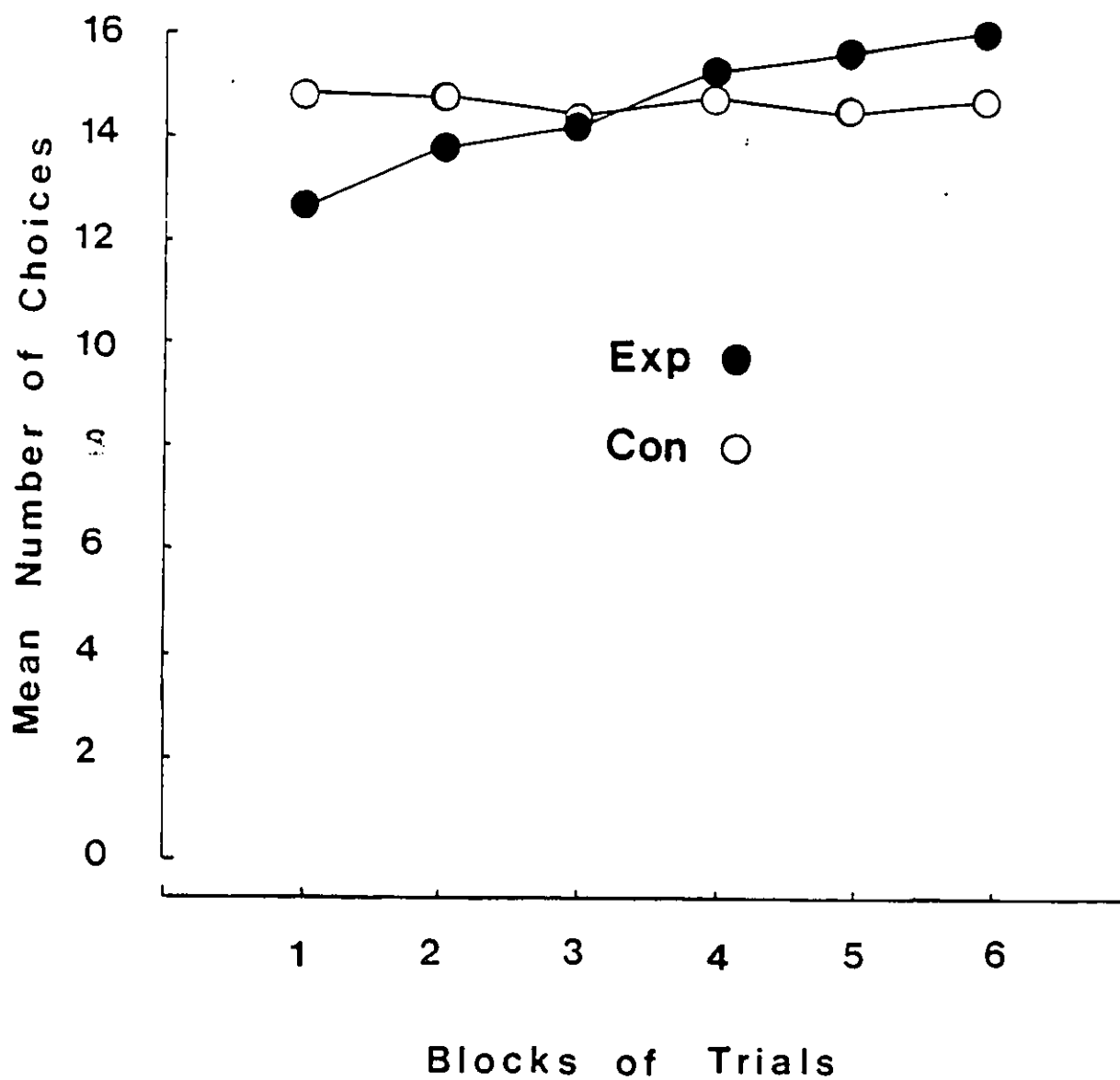Figure 3. Mean number of choices before the first switch to the opposite set under the parsing condition.

Figure 4. Mean number of correct choices under the parsing condition.

session over blocks. The experimental animals increased choices to the same level of responding as the control group by block 3 and continued to increase to perfect responding. The Block effect and Group x Block interaction were significant (F(5,11)=20.79 p<.0001, F(5,55)=25.06 p<.0001, respectively). Scheffe comparisons revealed that experimental rats increased choices significantly across blocks (p<.05). The control group did not significantly change over blocks. Group differences were found in blocks 1 and 2 with the experimental group making fewer correct choices, and in blocks 5 and 6 with the experimental group making significantly more correct choices (p<.05).

16 Arm Training: No Parsing Cue.

Figure 5 shows the number of errors of each type per session over blocks. Inspection of the data from this figure revealed only slight increases from the previous phase. The experimental group increased AA and BB errors in the first block compared to the remaining blocks. The experimental group also made slightly more AB errors. In comparison, the control group reduced their fluctuation for BA errors only. However, the control group's BA errors are higher than all other error types for both groups.

These effects were supported by a significant main Group effect (Wilk's .118, F(3,9)=22.25 p<.0002) and a significant Group x Block effect (Wilk's .619, F(15,146.71)=1.86 p<.03). For the experimental group alone, there was a significant main Block effect (Wilk's .250,
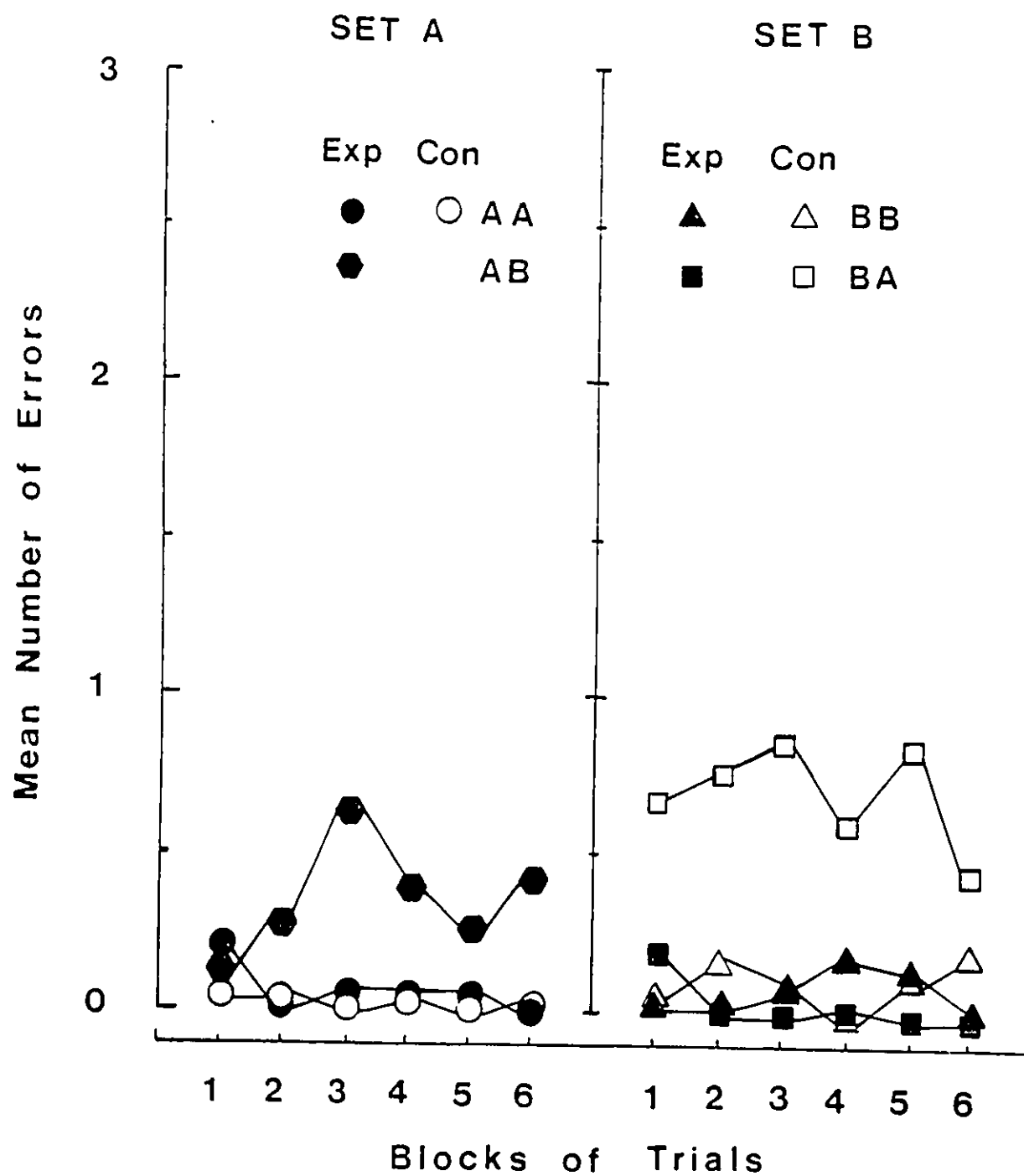
Figure 5. Mean number of error types across blocks for sets A and B under the no parsing condition.

F(20,90.50)=2.35 p<.003). Scheffe post hoc analyses
revealed that the control group made significantly more BA
errors from blocks 2 though 6 than the experimental group
(p<.05). Therefore, the control animals returned to
previously sampled arms in Set A more often than the
experimental animals. The interaction effect was accounted
for by the significant decrease in AA and BA entries from
block 1 to 2 for the experimental group (p<.05). Also for
the experimental group ANOVAs performed on the composite
dependent variables which represented the differences
between the 4 possible error types revealed significantly
more AB entries than BB, AA, or BA entries (F(5,30)=3.77
p<.009, F(5,30)=3.77 p<.009, F(5,30)=4.71 p<.002,
resepectively). Thus, the predominant error for
experimental animals was again a premature switch to Set B.

Figure 6 shows the number of choices made before the
first choice to the opposite set per session over blocks.
The experimental group made consistently fewer choices than
the control group in Set A and consistently more choices in
Set B. It should also be noted that after the first block
in Set A the experimental group first decreased their number
of choices then increased slightly. These observations were
supported by the significant main effects for both Group
(Wilk's .127, F(2,10)=34.15 p<.0001) and Block (Wilk's .622,
F(10,108)=2.89 p<.003). Scheffe contrasts revealed group
differences from blocks 2 through 6 (p<.05). For the
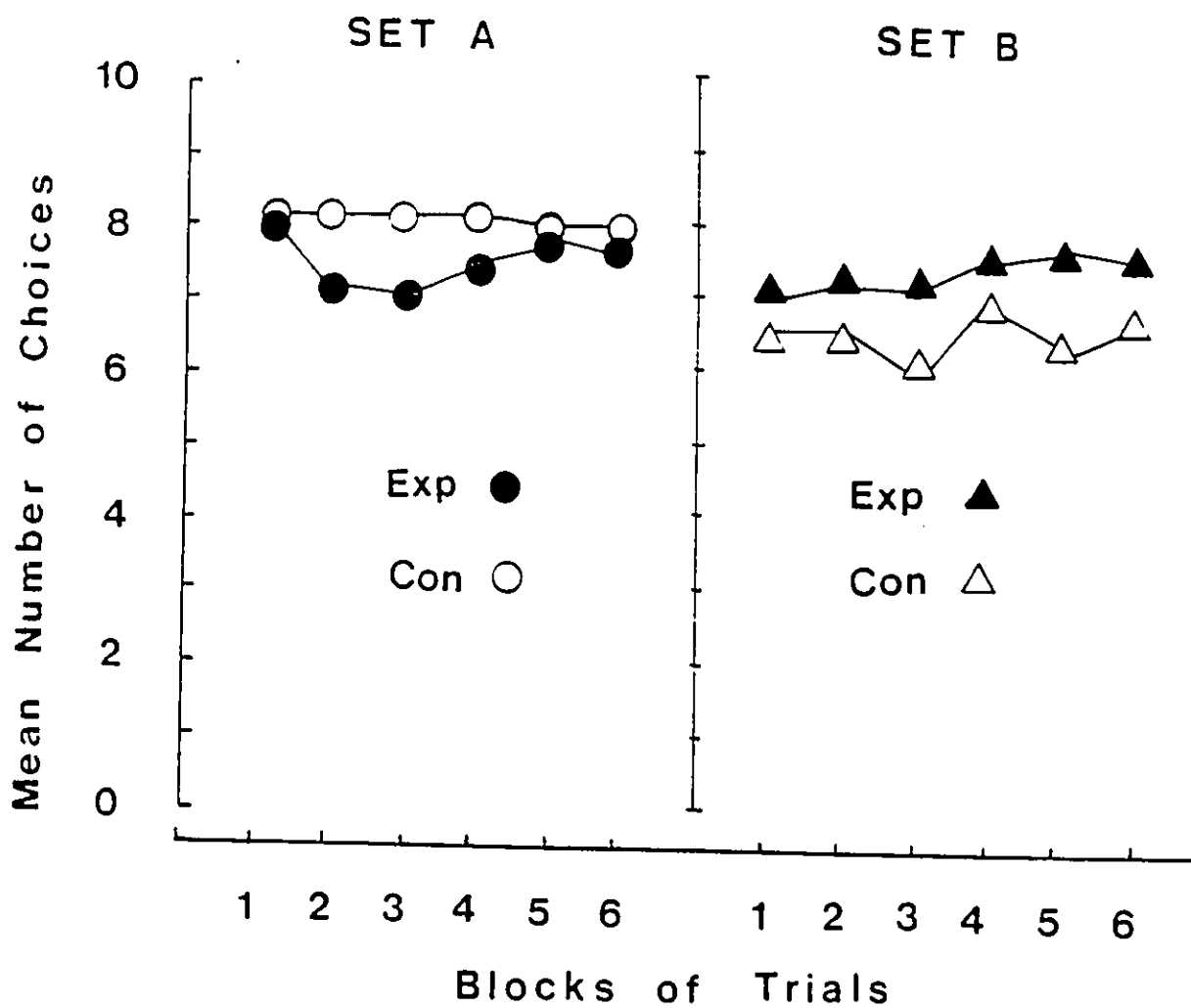experimental group the decrease from blocks 1 to 3 was also

Figure 6. Mean number of choices before the
first switch to the opposite set under the no
parsing condition.

significant (p<.05).

Figure 7 shows the number of correct choices per session over blocks. The experimental animals made slightly more choices than control animals across blocks. This observation was supported by a main Group effect ($F(1,11)=6.88$ p<.02).

A separate set of comparisons between the parsing and no parsing phases for each measure also was performed. Examining the number of errors of each type for both the experimental and control groups revealed a significant Phase effect (Wilk's .224, $F(3.9)=10.37$ p<.002). For the number of errors of each type for the experimental group alone, Phase and Phase x Block were significant (Wilk's .055, $F(4,3)=12.85$ p<.03; Wilk's .124, $F(20,90.5)=3.96$ p<.0001, respectively). Scheffe comparsions found that the control group made more BA errors or returns to Set A in the parsing phase for blocks 2 and 6 (p<.05). Animals in the experimental group made more AB errors in the parsing phase for blocks 1 and 2, and more AB errors in the no parsing phase in blocks 5 and 6 (p<.05). Experimental animals also made more repeated AA errors in the parsing phase for block 2 (p<.05). Thus, premature switches to Set A occurred in both the early learning stage of the first phase and in the later stages of the last phase.

A significant Group x Phase x Block interaction (Wilk's .520, $F(10,108)=4.18$ p<.0001) was found for the number of
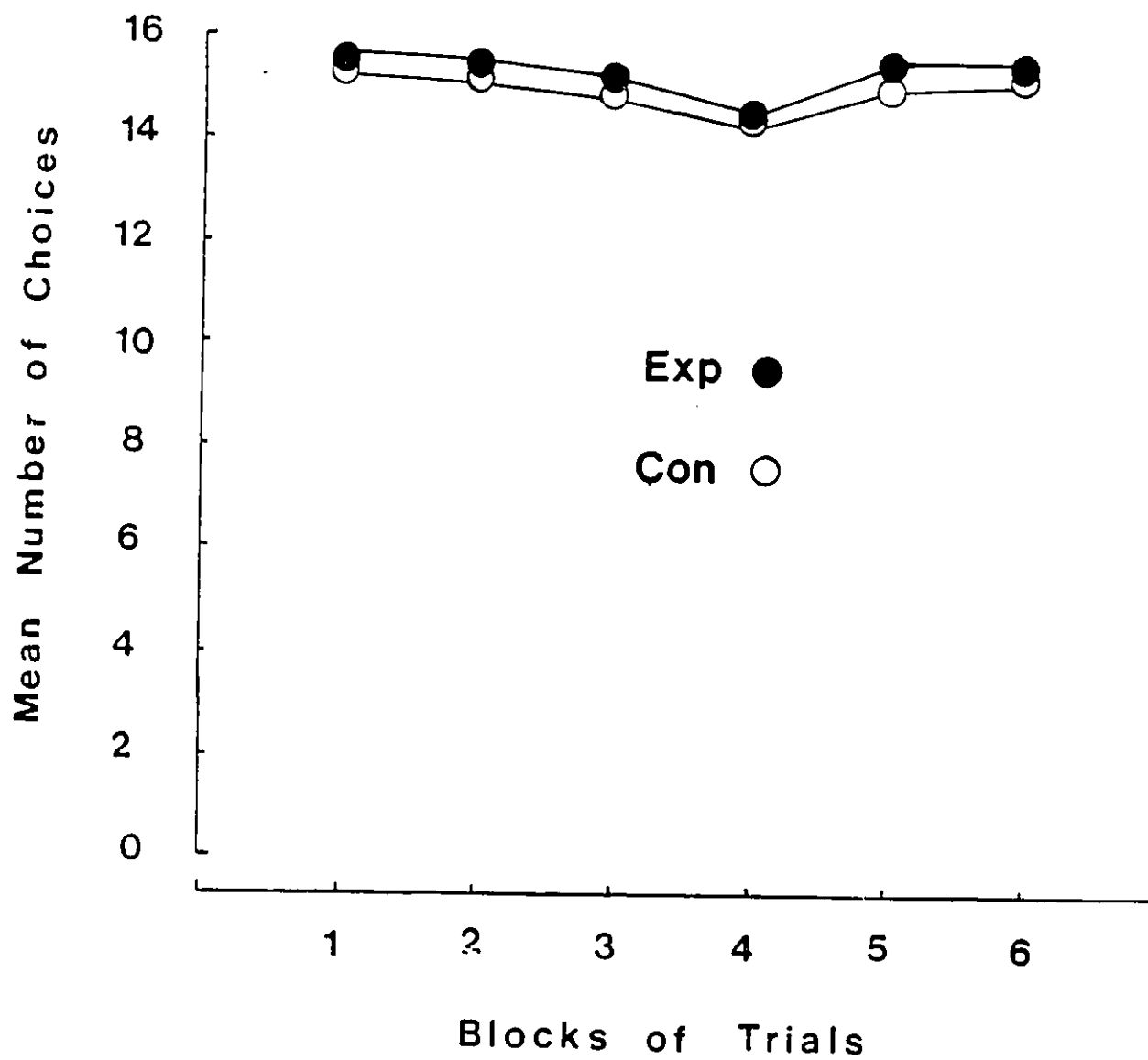
Figure 7. Mean number of correct choices
under the no parsing condition.

choices in each set. Post hoc analyses revealed that the experimental group made more choices in the both Sets A and B under the no parsing condition for blocks 1 and 2 but made fewer choices in Sets A and B under the no parsing condition in blocks 5 and 6 (p<.05). The control group made more choices in Set B under the no parsing condition for blocks 3 through 5 (p<.05). However, as the earlier analyses revealed, the experimental animals continued to make more choices in Set B under the no parsing condition than the control animals.

An analysis of the number of correct choices uncovered another significant Group x Phase x Block interaction (Wilk's .123, F(5,55)=13.48 p<.0001). Scheffe comparsions showed that the experimental group made more correct choices in the no parsing phase for blocks 1 through 3 and more correct choices in the parsing phase for blocks 5 and 6 (p<.05). Control animals performed better in the no parsing phase for blocks 3 through 5 (p<.05). Again, as mentioned earlier, the experimental animals performed more accurately in both the parsing and no parsing phases.

16 Arm Free Choice Test.

Figure 8 shows the number of same arm runs per session over blocks made by both groups when given free choice of all 16 arms. A significant main Group effect (F(1,12)= 439.92 p<.0001) was found in which control rats made more runs. Figure 9 shows the number of choices per session in the first and second runs. Again, a main Group effect
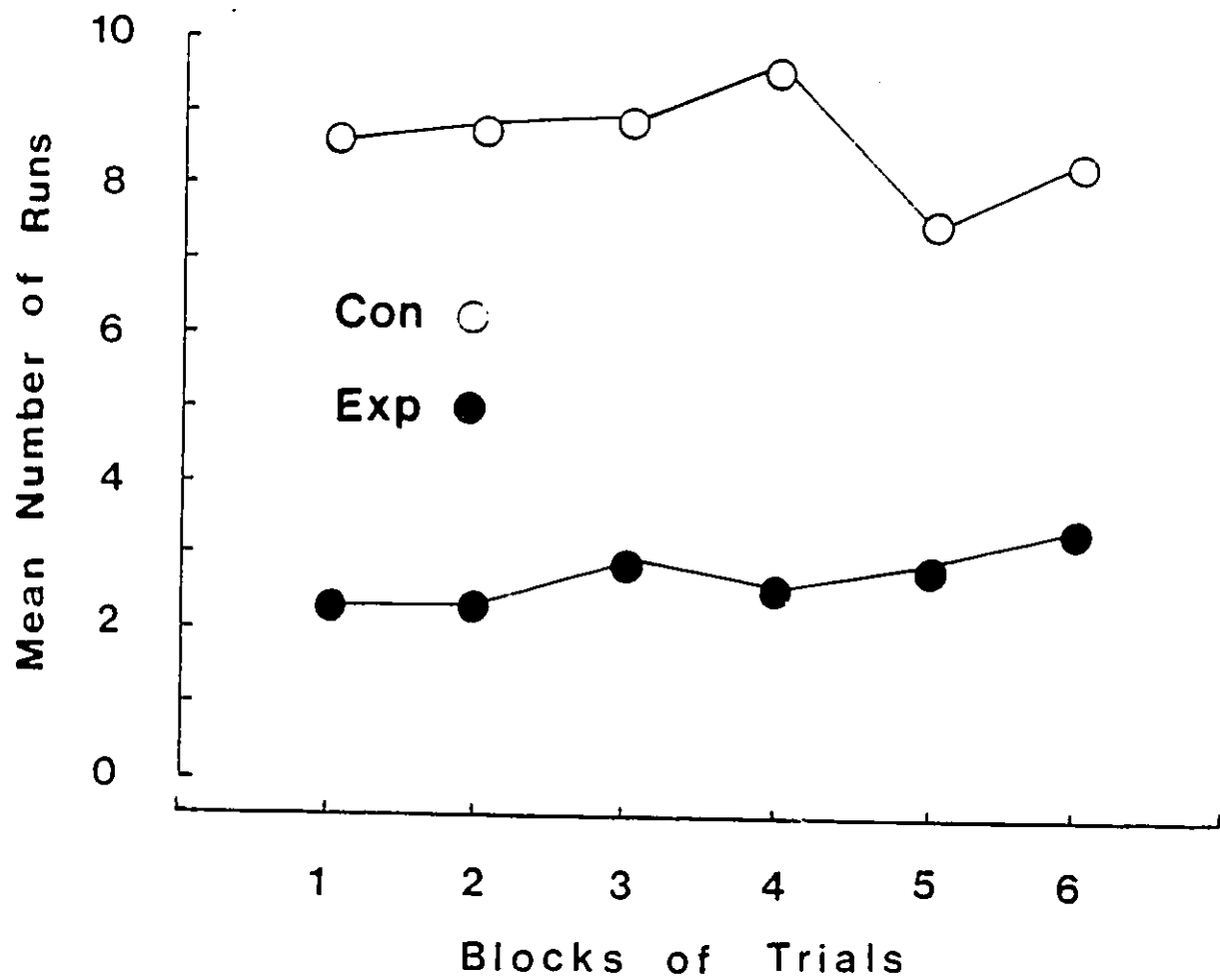
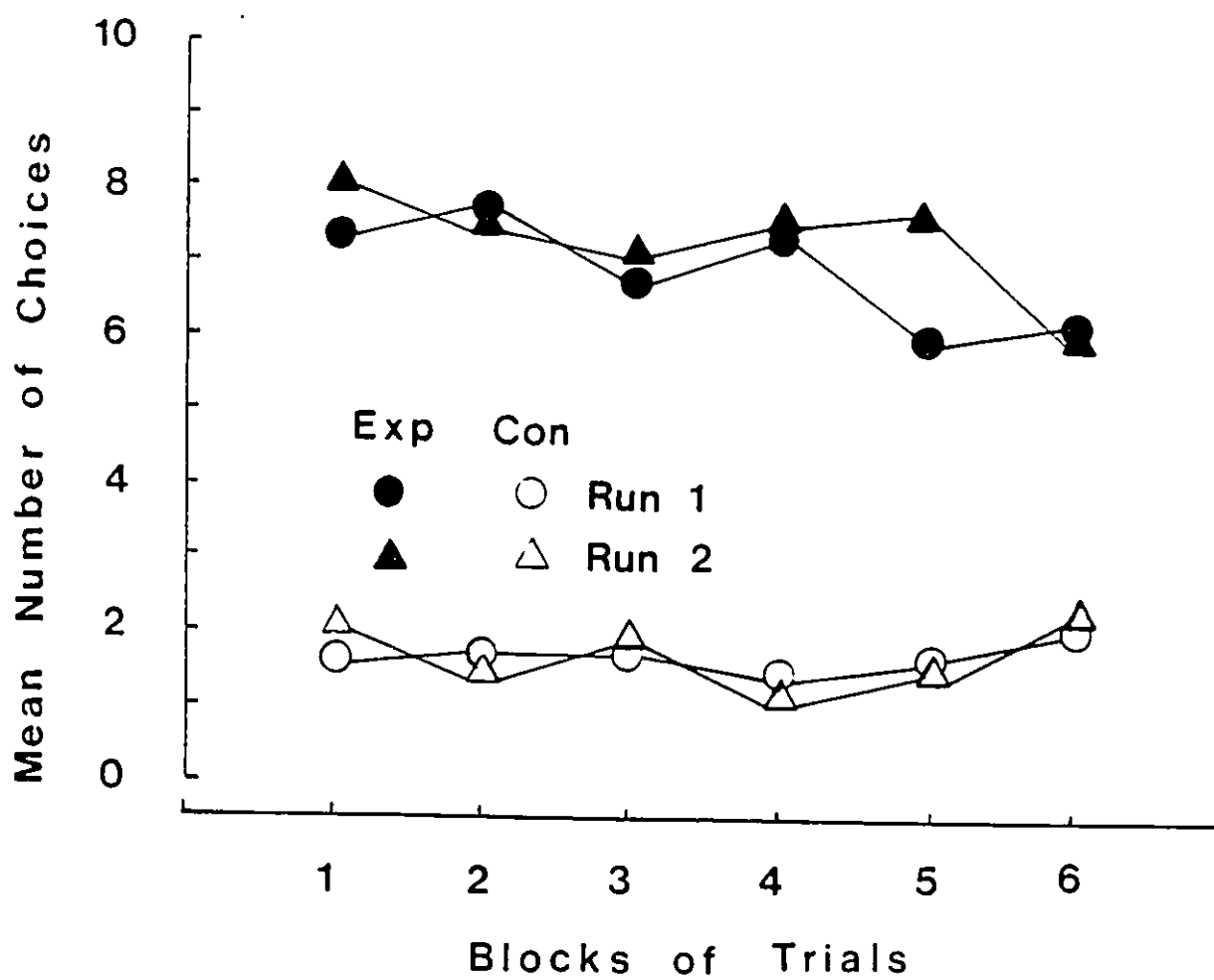Figure 8. Mean number of same arm runs for the free choice test.

Figure 9. Mean number of same arm choices for the first and second runs for the free choice test.

(F(2,10)=428.97 p<.0001) was found. The experimental group made significantly more choices in the first and second runs than the control group.

Figure 10 shows the number of correct choices per session over blocks. Experimental rats made slightly more correct choices than the control rats over the first 8 trials. A main Group effect F(1,11)=6.55 p<.02) lent support to this observation.

The total number of AA, BB, and BA entries are depicted in Figure 11. It should be noted that the entry types are from the animals' true Set A and Set B and are not arbitrarily labelled. There was a significant Group effect (Wilk's .099, F(3,9)=27.17 p<.0001) which was accounted for by the control animals making significantly more BA entries but significantly fewer BB entries than the experimental animals. In other words, the control animals consistently returned to previously visited arms in Set A while the experimental animals continued to search arms in Set B.
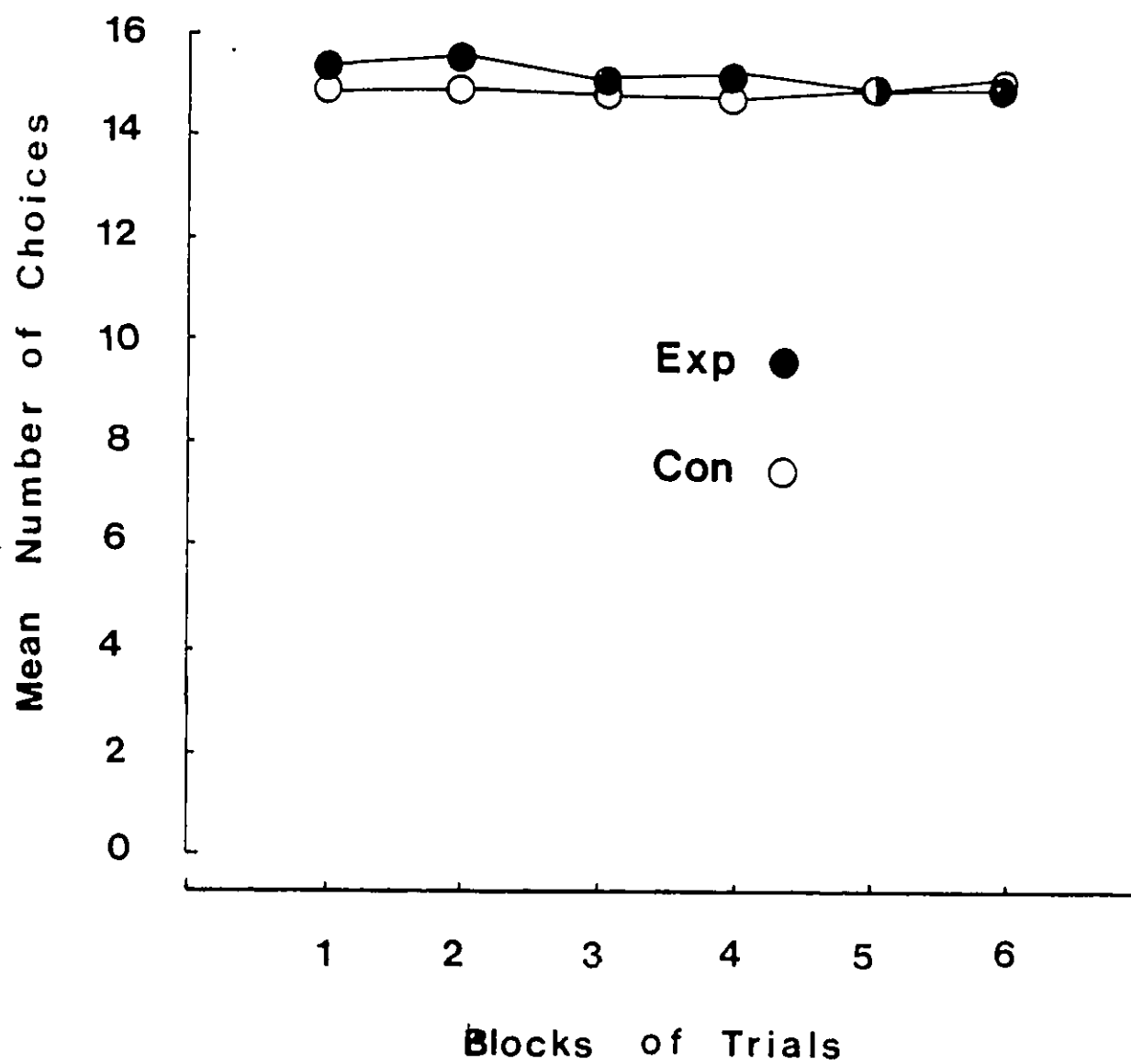
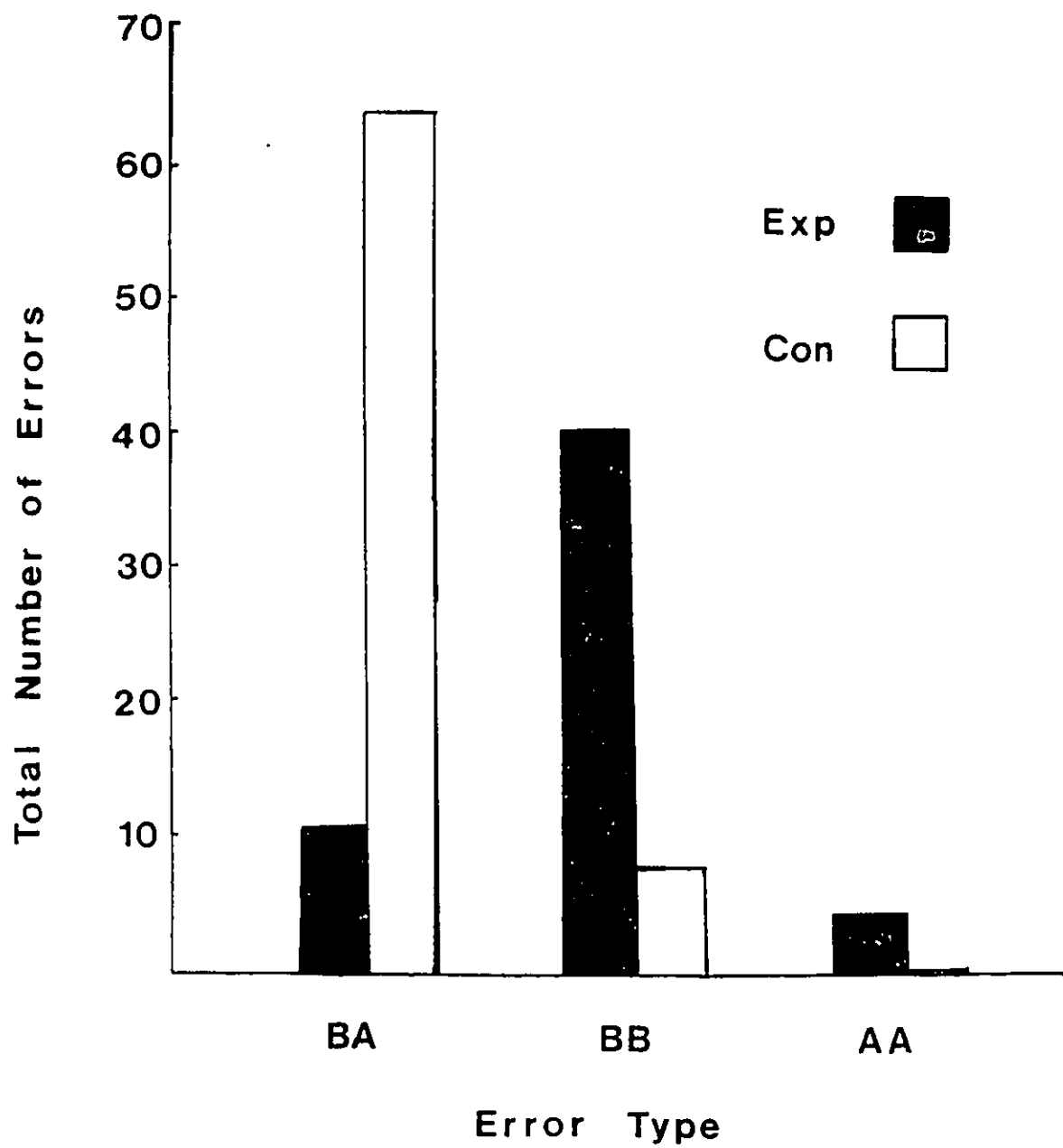Figure 10. Mean number of correct choices the free choice test.

<u>Figure 11</u>. The total number of BA, BB, and AA entries for the free choice test.

CHAPTER IV

Discussion

Results from the present experiment suggest that rats acquired a search-sequence rule in reference memory which facilitated working memory performance in the radial arm maze. The fact that the search sequence was largely maintained after the removal of the parsing cue further supports the belief that rats learned to chunk the maze into two sets of arms based on the intramaze cues. As well, the chunking rule did improve the search performance of the experimental animals. However, there was no evidence of spontaneous chunking by the control group.

That the rule was learned and maintained throughout the experiment was evidenced by the few number of returns to Set A by the experimental group after all the Set A arms were sampled (BA entries) (see Figures 2, 5, & 11). The small number of BA entries suggests that these animals were able to drop the Set A arms from memory after completing the set and concentrate fully on the remaining eight arms. Indeed, the experimental animals always surpassed the control animals in the number of choices before a possible return to Set A. The fact that the experimental animals fluctuated slightly below eight choices in Set B was a result of a reduced number of allowable choices in that set. The reason for the reduced choices was the greater number of choices in Set A because of a premature, anticipatory switches to Set B (AB entries). In comparison, the lower number of choices by

control animals in Set B could not be accounted for by increased choices in Set A. Responding by the control animals in Set A was very close to perfect responding (see Figures 3 & 6).

The parsing cue facilatated experimental animals' separation of arms into two different sets. As the cue became a marker for the completion of Set A, there was a great decline in the number of premature switches to Set B (AB entries). As well, the number of returns to Set A were also greatly reduced for the experimental animals (see Figures 2 & 3). The facilitative effect of the parsing cue found in the present experiment supported the claim that a cue which corresponds to a higher order rule transition promotes the use of a chunking strategy in humans (Bower & Springston, 1970,) and in rats (Fountain, Henne, & Hulse, 1984).

Of particular interest is the performance by the experimental group after the removal of the parsing cue. Despite a slight increase in AB entries, the animals were able to maintain the rule. Had the animals been operating on the simple associative principle held by Capaldi and his associates, then one would have expected a far greater disruption in performance. Specifically, a break in chunking behavior would have indicated that the experimental animals were learning new associations. Capaldi and Miller (1988) found that rats routinely count reinforcing events but with a limited capacity of three or four events.

Therefore, from an associative perspective, it would be expected that without the aid of a parsing cue the experimental animals would simply count the first three or four reinforced entries into Set A then switch to Set B.

However, the experimental animals continued to make at least seven choices in Set A after the removal of the parsing cue (see Figure 6). In fact, when the parsing and no parsing phases were compared, the experimental animals still made more AB entries under the parsing condition in the first two blocks. The experimental animals did make more AB entries under the no parsing condition in the last two blocks. Yet, this performance is not surprising because with the removal of the cue, the animals had to rely on some other strategy to determine if all Set A arms had been sampled. Thus, animals began to make anticipatory switches to Set B. In keeping with the rule-learning hypothesis, the AB entries could be considered a measure of prospective memory, that is, an anticipation within the reference rule (Hulse, 1980). Comparisons between parsing and no parsing phases for the control animals revealed improved performance in the second phase which could be attributed to a practice effect.

The results of the present study also support the notion that chunking facilitates in encoding and retrieving information from working memory. (Simon, 1974). For the parsing phase, the experimental animals initially made fewer correct choices than the control animals as they had to

respond under the constraints of the rule. However, by the last three blocks the experimental animals perhaps were able to create some internal representation of the rule and use the strategy to improve their performance above that of control animals. Moreover, the experimental animals continued to make the greater number of correct choices in the no parsing phase.

Experimental animals continued to maintain a chunking strategy in the 16 arm free choice test. They made significantly fewer runs than the control animals (see Figure 8). The experimental animals did exhibit a slight tendency to move away from a "two-chunk" strategy in blocks 5 and 6. However, the small number of chunks (the range was between 2 and 5 chunks with 5 chunks made only twice over all trials) indicated that chunking predominated during this phase. These results also indicated that the greatest number of choices occurred in the first and second chunks for the experimental animals which again supports the chunking hypothesis.

The free choice test allowed the experimental animals to experience sampling the arms without the constraint of the "two sets" reinforcement procedure. During this phase the experimental animals were able to discover that entering Set B after not fully completing Set A now resulted in reinforcement and that they could then return and complete Set A. Thus, the discriminative value of the intra-maze pattern (white and striped) declined as both sets come to

represent immediate reinforcement. An associative view would have predicted an extinction of the search sequence pattern of choices.

Performance on the free choice test in terms of number of correct choices was still slightly better for the experimental group (see Figure 10). It was not unexpected to find improved performance by the control animals because of the learning effects over time. As well, Olton, Collison, and Werz (1977) found that searching a 17 arm maze is not difficult for rats. An increase in number of arms to 24 may provide a better indicator of working memory performance.

There was also the interesting occurence of more BB errors for the experimental group and more BA errors for the control group for the free choice test (see Figure 11). The control group's BA errors are easily explained in terms of working memory overload. As more arms are sampled it is expected that retention of locations of earlier sampled arms will be lost from working memory (Honig, 1978). Therefore, the control animals would be more prone to make an error of returning to an earlier sampled arm. As mentioned earlier, the fewer BA errors made by the experimental group indicated that the animals were able to use the chunking rule and reduce their load on working memory of Set A arm locations after completing the set. Therefore, BB errors may simply be a result of the rule confining the experimental animals' responses.

However, the question still remains as to why the animals make more BB errors and very few AA errors. It is possible that the salient extra-maze cues, each of which shared one pair of the intra-maze cues, created some type of interference in the rat's working memory. Kraemer, Gilbert, and Innis (1983) previously found that rats preferred extra-maze cues over intra-maze cues. Therefore, the rats may have encoded intra and extra-maze cues separately. Further research addressing this area is necessary.

Finally, the lack of spontaneous chunking by the control animals suggests some interesting parallels with cognitive development in humans. To date, studies have found that animals when presented with some type of specific pattern are capable of forming some type of internal representation (Hulse & Dorsky, 1977, 1979; Fountain, Henne, & Hulse, 1984; Terrace, 1987). However, for the animal to successfully utilize the rules or categories to improve performance often an additional cue is needed. Kobasigawa and Middleton (1972) noted similar performance when they examined the ability of children to categorize items. Specifically, they found that grade 5 subjects could categorize without help to aid recall, but that grade 3 subjects first needed the items presented in the categories to aid recall. Kindergarten children even with the extra help had difficulty grasping the grouping of the categories. Kobasigawa and Middleton suggested the possibility that the size of the categories was too large for the kindergarten

subjects.

The size of the chunks to be remembered is an issue to consider in animal memory studies. Olton and Samuelson (1976) reported that the rat easily searched an eight arm maze. However, the question remains of how does the animal remember how many location have been sampled. As mentioned earlier, Capaldi and Miller (1988) found that the rat was capable of counting up to three or four items. Future research could examine the possible interaction of counting ability and chunking ability in animals.

The present study provides a methodology for further studies of animal learning and cognition. The present evidence which supports the phenomenon of chunking should serve as an impetus for future investigations. Certainly, there is a need for a better understanding of the interaction between associative and rule-learning processes. Furthermore, the cognitive processes involved in the formation of internal representations of the rat are as yet unclear. Over the past ten years, debates concerning the processes involved in human categorization and concept formation have emerged (Halpern, 1986; Martin & Caramazza, 1980). Specifically, Martin and Caramazza have investigated the type of rule abstraction employed when subjects were presented with well defined and ill defined categories. Strategies vary from searches for a feature by feature relationship to searches for a general rule. Comparable animal research in the radial-arm maze may also be used to

investigate similar questions.

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