THE NATURE OF COGNITIVE CHUNKING PROCESSES IN RAT SERIAL PATTERN LEARNING

A dissertation submitted to Kent State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy

by

Karen E. Doyle

December, 2013
Dissertation written by
Karen E. Doyle
B.A., Kalamazoo College, 2006
M.S., Villanova University, 2008
Ph.D., Kent State University, 2013

Approved by

____Stephen B. Fountain_______, Stephen B. Fountain, Ph.D.
Chair, Doctoral Dissertation Committee

____David C. Riccio___________,David C. Riccio, Ph.D.
Member, Doctoral Dissertation Committee

____Janis H. Crowther__________, Janis H. Crowther, Ph.D.
Member, Doctoral Dissertation Committee

____Marilyn A. Norconk________, Marilyn A. Norconk, Ph.D.
Member, Doctoral Dissertation Committee

____Eric M. Mintz______________, Eric M. Mintz, Ph.D.
Graduate Representative and Moderator,
Doctoral Dissertation Committee

Accepted by

____Maria S. Zaragoza__________, Maria S. Zaragoza, Ph.D.
Chair Department of Psychology

____Janis H. Crowther__________, Janis H. Crowther, Ph.D.
College of Arts and Sciences

ii
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>vii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>EXPERIMENT 1</td>
<td>22</td>
</tr>
<tr>
<td>Methods</td>
<td>24</td>
</tr>
<tr>
<td>Results</td>
<td>29</td>
</tr>
<tr>
<td>Discussion</td>
<td>52</td>
</tr>
<tr>
<td>EXPERIMENT 2</td>
<td>56</td>
</tr>
<tr>
<td>Methods</td>
<td>57</td>
</tr>
<tr>
<td>Results</td>
<td>62</td>
</tr>
<tr>
<td>Discussion</td>
<td>87</td>
</tr>
<tr>
<td>GENERAL DISCUSSION</td>
<td>93</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>112</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1  An octagonal operant chamber equipped with nose-poke receptacles on each wall, receptacle walls are numbered clockwise 1 – 8.  ....................................................................................................................................................... 13

Figure 2  Acquisition curves for the interleaved pattern in Experiment 1 for (A) the target subpattern and (B) the interleaved subpattern over 70 days of acquisition. Daily mean errors were averaged across all elements of the pattern. The y-axis represents mean proportion errors and the x-axis represents combinations of errors seen over 48 pattern repetitions. Filled circles, open circles, and filled triangles represent groups No Cue S, Cue S, and Cue R respectively. Error bars: ± SEM.  ....................................................................................................................................................... 32

Figure 3  Mean trial x trial incorrect response rates for both the target and interleaved subpatterns in Experiment 1 for (A) No Cue S, (B) Cue S, and (C) Cue R subpattern averaged over 70 days of acquisition. The y-axis represents mean proportion errors and the x-axis represents pattern sequence elements ........................................................................................................................................... 38
Figure 4  Performance curves for transfer of the interleaved pattern in Experiment 1 for (A) the target subpattern and (B) the interleaved subpattern over 10 days of transfer. Daily mean errors were averaged across all elements of the pattern. The y-axis represents mean proportion errors and the x-axis represents combinations of errors seen over 48 pattern repetitions. Filled circles, open circles, and filled triangles represent groups No Cue S, Cue S, and Cue R respectively. Error bars: ± SEM.  

Figure 5  Mean trial x trial incorrect response rates for both the target and interleaved subpatterns in Experiment 1 for (A) No Cue S, (B) Cue S, and (C) Cue R subpattern averaged over 10 days of transfer. The y-axis represents mean proportion errors and the x-axis represents pattern sequence elements.  

Figure 6  Acquisition curves for the interleaved pattern in Experiment 2 for (A) the target subpattern and (B) the interleaved subpattern over 48 days of acquisition. Daily mean errors were averaged across all elements of the pattern. The y-axis represents mean proportion errors and the x-axis represents combinations of errors seen over 48 pattern repetitions. Filled circles, open circles, filled triangles, open triangles, and filled squares represent groups No Cue SS, No Cue CS, Cue CS, Cue SS and Cue R respectively. Error bars: ± SEM.  
Figure 7  Mean trial x trial incorrect response rates for both the target and interleaved subpatterns in Experiment 2 for (A) No Cue SS, (B) No Cue CS, (C) Cue SS, (D) Cue CS and (E) Cue R subpattern averaged over 48 days of acquisition. The y-axis represents mean proportion errors and the x-axis represents pattern sequence elements. .......................... 73

Figure 8  Performance curves for transfer of the interleaved pattern in Experiment 2 for (A) the target subpattern and (B) the interleaved subpattern over 6 days of transfer. Daily mean errors were averaged across all elements of the pattern. The y-axis represents mean proportion errors and the x-axis represents combinations of errors seen over 48 pattern repetitions. Filled circles, open circles, filled triangles, open triangles, and filled squares represent groups No Cue SS, No Cue CS, Cue CS, and Cue SS respectively. Error bars: ± SEM. ................................. 79

Figure 9  Mean trial x trial incorrect response rates for both the target and interleaved subpatterns in Experiment 2 for (A) No Cue SS, (B) No Cue CS, (C) Cue SS, and (D) Cue CS subpattern averaged over 6 days of transfer. The y-axis represents mean proportion errors and the x-axis represents pattern sequence elements................................. 86
ACKNOWLEDGEMENTS

I am grateful to my advisor Dr. Stephen Fountain, under whose supervision I developed and conducted the research in this dissertation project. I would like to not only thank him for his mentorship and maddeningly obsessive eye for detail, but also for his friendship and constant flow of “funny” jokes that have made the last 5 and a half years such a joy. I would also like to thank the members of my dissertation committee: Dr. David Riccio, Dr. Janis Crowther, Dr. Marilyn Norconk, and Dr. Eric Mintz. I am grateful for the time and energy that they have invested on this dissertation project. I would also like to thank Pat Mlynar, Hollace Yeary, and the army of unusually patient and dedicated undergraduate research assistants that have assisted in this research.

I am indebted to my husband, Fletcher, for his support and understanding during the countless hours I have spent achieving this goal. He will never know how thankful I am that he has stood with me all these years. I grateful to my parents, Michael and Gail Doyle for their encouragement and unconditional support. They put my feet on the path I currently travel. To my brother, Michael Doyle, I suggest to “take it easy”.

Finally, this dissertation is dedicated to Benjamin and Orrin Liverance. Neither of them were very much help in this project, but they definitely made life more interesting during the process. To them, I advise: get comfortable with being uncomfortable…and then take another step.
The Nature of Cognitive Chunking Processes in Rat Serial Pattern Learning

Patterned sequences are prevalent in many every day cognitive activities such as typing, language production and navigation. They are also central to many complex motor functions such as driving, food preparation, and tying a shoelace. Non-human animals must also use sequences of behavior in order to ensure safety from predators, produce and care for offspring, and fulfill basic daily physical needs such as hunger and comfort. Mastery of many, sometimes simultaneously presented patterned sequences are required for survival and it is thus adaptive to be able to track and organize the individual elements of the sequence in a way that allows the behavior to be produced without taxation of working memory. Above and beyond, it is advantageous to be able to organize simultaneously presented sequences so that complex behaviors may be produced concurrently.

The adaptation to organize behavior requires the use of cognitive processes. Stimulus-response associative chains are not versatile enough to deal with the complexities of the patterned sequence (Lashley, 1951; Restle & Brown, 1970a; 1970b). Cognitive processes for the organization of sequential behavior have been found in various species such as humans (e.g., McLean & Greg, 1967; Restle & Brown, 1970a; 1970b; Simon, 1974), primates (Bryne & Russon, 1998), pigeons (Terrace, 1987; 1991), and rats (e.g., Hulse & Dorsky, 1977; Fountain, Henne, & Hulse, 1984; Fountain, 1990).
One such cognitive strategy that is utilized for the organization of information is *chunking*.

**Chunking as a Cognitive Strategy**

A term coined by Miller (1956), “chunking” is a cognitive process that recodes novel information into meaningful portions of information, termed *chunks*. Reorganization of this novel information into familiar chunks allows for a decrease in the amount of information required in short term memory (STM) by increasing how much information may be held in the chunk.

Miller (1956) demonstrated the limits of STM through a discussion of various experiments which presented subjects with sets of initially arbitrary unidimensional bits of information (e.g. a set of tone frequencies or various light wavelengths). When presented with stimuli, Miller argued, humans demonstrated an absolute STM capacity limit of 7 (plus or minus 2) bits of information. Singular bits of information could then be recoded into complex chunks of information, which allowed the participants to overcome the limits initially displayed. From results discussed by Miller, by restructuring information into complex and familiar chunks, human STM could be expanded to fit a number of chunks of information in a way that the complexity of the chunk was only dependent on the familiarity of the material and not the limit of memory load. Interestingly, a wide variety of research has since indicated that material in short term memory load may actually be limited to 4 chunks of information if the information is novel and long term memory storage has not yet been activated (Cowan, 2001).
The question of the limit of information that could be organized into one chunk was presented in Simon (1974). Information, argued Simon, may be experienced in any dimension (e.g. visual stimuli such as digits or colors, odors, tactile, auditory stimuli, navigation) and so the capacity of human working memory for complex information along with the capacity of the chunk to reorganize the information was examined. In order to demonstrate the importance of working memory load and chunk size, Simon (1974) presented a list of words to be processed for later recall: “Lincoln, milky, criminal, differential, address, way, lawyer, calculus, Gettysburg.” (p. 7). When the words were presented in a random order with no associations between the stimuli, acquisition of the list were quite difficult with recall limited to around 7 (plus or minus two) words. When these same stimuli were presented in a more familiar format with strong associations between the words:

“Lincoln’s Gettysburg Address
Milky Way
Criminal Lawyer
Differential calculus”

recall of the information occurred quickly and easily. Limits in recall appeared when information in the chunk increased. Smaller chunks such as the multiple 2-3 word phrases as presented previously resulted in the ability to form multiple chunks. Increasing chunk size to include complete sentences or paragraphs resulted in a limited number of chunks that were recalled. Thus, although an unlimited long term memory (LTM) store has been
suggested (e.g. McLean & Gregg, 1967), there is a finite nature to the amount of information that may be held in short term memory (STM) (Cowan, 1995).

In human experimental research, the chunking strategy has traditionally been examined through goal-oriented tasks such as presentation of linguistic stimuli with a required auditory recall which taxes STM (e.g. McLean & Greg, 1967; Cowan, 2001). Evidence of chunking has also been examined in more automatic and continuous tasks such as perceptual tasks (Chase & Simon, 1973; Simon, 1974) and sequential learning tasks (e.g. Cleeremans & McClelland, 1991; Sakai, Kitaguchi & Hiosaka, 2003; Perlman, Pothos, Edwards & Tzelgov, 2010) which include examination of both STM and LTM processes. Above and beyond a simple chunking strategy, humans have demonstrated the ability to organize and reproduce complex and concurrently appearing information by employing a hierarchically structured chunking strategy.

Evidence of Hierarchically Structured Chunking in Humans

McLean and Gregg (1967) examined the role of LTM and organizational processes in chunking of serial lists of 24 letters. Participants were required to learn and reproduce lists of 1, 3, 4, 6 or 8 groupings of letters and after mastery, were required to reproduce these lists backwards. Participants in this task were able to recall more stimuli when employing the “stimulus grouping” or chunking strategy with chunk sizes being most stable at 3 to 4 items. Grouping occurred not only within chunk, but also between chunks, creating a hierarchy of chunks. McLean and Gregg (1967) argue that at the lower level, participants used within-chunk cues to create strings of responses, and at a higher
level used between-chunk cues to be able to navigate from one chunk to the next. Since acquisition of serial lists was so easily manipulated by the organization of letters into chunks and not individual order in which the letters were presented, this behavior cannot be described by either associative or serial motor learning alone.

Another popular area of study in human sequential chunking involves study of memory capabilities in perception of chess moves by chess players ranging from Class A to Masters (Chase & Simon, 1973; Gobet & Simon, 1998). In these studies, participants were required to perform copy and recall tasks using displays of chess pieces on a computer simulated board. Participants were required to either copy a set of 24 to 30 chess pieces from the available simulated board to a new board, or recall from memory a similar set of chess pieces with no available external cueing. From the results, it was evident that Chess Masters were much more adept not only in the number of chunks of pieces that could be memorized, but also the size of theses chunks as well.

Gobet and Simon’s (1998) examination of chess strategies not only demonstrate a chunking strategy to organize complex patterns of information, but also augment and further define the process of chunking. The authors argued that chunking not only involves the process of maximizing the amount of items that may be maintained in STM, but also creates a series of “templates” in LTM to organize large patterns of information that can be recalled as a singular chunk. These templates also allow for faster acquisition of future data as they contain “slots” which results in rapid acquisition of new stimuli (Gobet & Simon, 1998). This may then be comparable to the hierarchical chunking of
McLean & Gregg (1967) as lower level within-chunk elements may be combined together and incorporate new material, but there is also evidence that between-chunk cueing is involved as the player must process available moves from one turn to the next.

 Chunking has also been explored through human visuomotor sequence learning (Cleeremans & McClelland, 1991; Sakai et al., 2003; Perlman et al., 2010). In these types of tasks, participants are required to learn a set of movements that, when combined, create a motor sequence. These movements may be organized into chunks of movements in order to expand limited STM capacity. In Sakai et al. (2003), participants were required to press buttons arranged in a 4x4 matrix. Correct responding required pressing 10 sets of 2 buttons each, which participants were required to discover by trial and error. Participants in this study represented the motor sequence required as chunks of motor movements that would make up the sequence. This was evident due to longer pauses within the sequence at these proposed chunk boundaries. These longer pauses also demonstrated a hierarchically represented series of chunks where processing occurred not only within the chunk that were made up of a set of movements, but also between chunks that cued the beginning of the next chunk.

 Evidence of Chunking in Non-human Animals

 The major tenants of comparative cognition research are first to demonstrate cognitive ability in non-human animals and then to explore the comparative nature of non-human animal studies to human cognitive research. Chunking must then be
demonstrated in non-human animals in a way that is similar to phenomenon seen in humans as previously discussed.

One issue with comparative chunking research is the methodology of human cognitive research. Human cognitive research in the field of chunking depends heavily on goal based tasks with a linguistic component (e.g. McLean & Greg, 1967; Cowan, 2001). Participants are given instructions on how to complete a task and then may be required to give a verbal response. This type of research does not translate easily into non-human research as animals cannot respond verbally on the mental processes being used. Instead, researchers must rely on nonverbal behavioral tasks to demonstrate similar cognitive phenomenon.

To reach this goal, researchers have attempted to demonstrate cognitive chunking strategies in non-human animals by employing a variety of tasks including both natural behaviors such as food gathering (e.g. Byrne & Russon, 1998), and artificial laboratory tasks such as perceptual spatial memory (Dallal & Meck, 1990; Macuda & Roberts, 1995) and motor sequence learning (Fountain et al.1984; Terrace, 1987; Conway & Christensen, 2001).

Chunking, or the organization of behavior, was seen in foraging behaviors of wild African mountain gorillas (Byrne & Russon, 1998). Researchers report that gorillas would employ sequences of behavior using a hierarchical pattern in order to strip away any natural defenses developed by the plant. Demonstration of use of a chunking strategy in a natural setting is important as it demonstrates an animal’s ability to spontaneously
produce behaviors similar to those seen in humans. This strategy may be lacking, though, as researchers are limited to observable behaviors which may not accurately reflect mental processes. In order to more accurately explore the chunking phenomenon, artificial tasks designed for a laboratory environment allow researchers a more precise ability to measure chunking.

One such versatile area which allows for controlled exploration into the comparative nature of chunking is perceptual spatial memory. Much like work done with chess masters (Chase & Simon, 1973; Gobet & Simon, 1998), Macuda & Roberts (1995) examined rats’ memory of food reward in a spatial task using a 12-arm radial maze. Similar to studies done by Dallal & Meck (1990), rats were allowed to access food types of differing reward magnitude in fixed locations on the maze. Findings indicated that rats not only chunked information of desirable food locations, but did so hierarchically, with certain arms represented as more desirable than others. Rats, akin to the chess masters, were able to chunk information about spatial locations flexibly and change foraging strategies based off of changing information about the spatial map.

Sequence learning has also allowed for further exploration of chunking in non-human animals. Terrace (1987) presented pigeons with lists of 5 unrelated pictures which were either organized into chunked sets separated by a temporal pause or presented with no pause. Pigeons were required to choose these pictures in a correct order for reinforcement. Pigeons that were presented with the items phrased by a temporal pause were more accurate as compared to pigeons presented with the unphrased sets. Similar to
McLean and Gregg (1967), this may be evidence that the birds were chunking the phrased sequences in order to more quickly acquire the pattern.

Chunking of sequences was also demonstrated in rats by Fountain et al. (1984). Rats were required to travel a runway to receive a food reward. Each consecutive trial presented the rat with a decrease in the magnitude of the food reward so that rats would experience a pattern of food magnitude: 14-7-3-1-0. Rats in this experiment were presented with either a phrased cue (temporal or spatial phrasing) or no phrased cueing. Latency to the end of the runway was measured for the final element. The rule of decreasing food magnitude predicted no reinforcement on the last trial of the pattern, so rats with a grasp of the abstract rule would be able to predict a non-reinforcement trial and would demonstrate a much higher latency. Rats with the phrased patterns were able to predict the final non-reinforcement trial better than rats with no phrasing cues and thus had higher latencies of the non-reward trial as compared to rats with no phrasing cues. These rats may have also been demonstrating chunking of the food reward magnitudes in order to predict trials where no reward would be present.

Presentation of more sophisticated serial patterns and the resulting chunking of elements in order to better acquire a rule have also been demonstrated in the Serial Multiple Choice (SMC) task (e.g. Fountain et al., 2000; Fountain, 2008; Stempowski, Carman & Fountain, 1999). This task has led to a variety of findings which will be utilized for the currently proposed research.
SMC Task, Rule Learning, and Chunking

The SMC task is a versatile methodology which allows the experimenter to manipulate both the parameters of stimulus presentation as well as the sequence of presentation. This allows for comparative study of the cognitive processes behind sequential behavior while maintaining the basic structure of the task. In this task, subjects are simultaneously presented with multiple stimuli and must make a correct choice in order to receive reinforcement. These stimuli may be presented in a structured way so that the sequence of responses create a rule that may be utilized by the subjects in order to perform the sequence of behaviors that produce reward (Fountain & Rowan, 1995a; 1995b; Stempowski et al., 1999; Fountain & Benson, 2006).

In one version of the SMC task, rats were placed into an 8-sided octagonal operant chamber (Figure 1.) with a response manipulandum (either lever or nose-poke receptacle) on each wall of the chamber. Each of the manipulanda was paired with a single stimulus (presentation of the lever or activation of light in the back of the receptacle). A trial consisted of simultaneous activation of stimuli and rats were required to choose the correct response from the 8 nearly identical manipulanda. If the rats produced the correct response during the trial, all stimuli were removed and reinforcement (either brain stimulation reward or water droplets) was immediately delivered. After a brief temporal pause, all stimuli were presented once more for the next correct choice. Response errors made during the trial reflected understanding of the sequence and possible strategies the rats may have been using.
One strategy seen in acquisition of these serial patterns is rule-learning or organization of pattern elements into an abstract, possibly hierarchical, representation. Patterns which were structured into a hierarchy of rules were learned faster than patterns which incorporated random elements (Kundey & Fountain, 2010). Rats also seemed to be sensitive to the structural level of the rules such that the rules lower in the hierarchy were acquired faster than rules higher in the hierarchy.

Fountain & Rowan (1995b) presented rats in the octagonal operant response chamber with either a two-level hierarchically structured pattern with both first-order and second-order rules or a pattern with linear elements.
Figure 1: An octagonal operant chamber equipped with nose-poke receptacles on each wall, receptacle walls are numbered clockwise 1 – 8.
Hierarchical (H) Pattern: 123 234 345 456 567 678 781 812

Linear (L) Pattern: 123 234 543 456 567 876 781 812

The H pattern followed a set of nested rules such that elements making up the three element chunks follow a first-order rule and the organization of the chunks follow a second-order rule. Rules appearing lower in the hierarchy, or first-order rules, were structured so that the rules predict the order of required responses on an element by element level. This means that rats acquiring first-order rules would be able to predict how a response to one element would lead to the next response. Rats employing higher order rules (second-order, third-order, etc.) acquired rules to help predict how chunks or sets of elements interact with other chunks or sets. Thus, rats acquiring a first-order rule would learn the chunk 1-2-3 as seen in the H pattern above while a second-order rule would be the relationship between the chunks 123 – 234- 345. The third order rule then predicts how groups of chunks are organized, in this example the chunks are organized in a reflective manner. Rats were sensitive to this nested rule structure and learned the first-order rule faster than the second-order rule. This was reflected in the results as more errors were made at the elements which followed the second-order rule as compared to elements which followed the first-order rule. This was also demonstrated in the later experiments where adding still higher levels of hierarchical structure produced greater pattern-learning difficulty. First-order rules were always acquired before second-order rules which were always acquired before third- and fourth- order rules.
Another prediction from rule-learning theory was that rats would also be sensitive to violations to these nested rules. Thus, the chunks of the L Pattern which follow a linear pattern but violate the relationship between the other element chunks should be more difficult to acquire than elements in the pattern which follow that nested rule. This result was also seen first in the overall acquisition of the pattern such that the H Pattern was acquired faster and with fewer overall errors than the L Pattern; and also in the errors made on each element. Many more errors were made on the linear elements than elements following the nested order of rules.

Rats are also sensitive to violations of different rule sets (Fountain & Rowan, 1995a). Rats were presented with either “Run” patterns (as was discussed in Fountain & Rowan, 1995b) or “Trill” patterns with alternating numbers (e.g. 121 232 343…). When rats were presented with the patterns with the addition of violation elements within the pattern, they tended to make errors based off of the rules of the specific pattern so that rats anticipating a “Run” pattern would make errors based on that pattern whereas rats anticipating a “Trill” pattern would make different errors in the same position based on that trill. This is evidence for rule-learning theory as rats made errors based off of the next anticipated element as predicted by the rule and not an associative chain.

The rule-learning strategy has been demonstrated in rats, but the question still remains as to how rats learn these rules. Do rats cognitively abstract rules without incorporating mediating external stimuli or do rats use cueing as an aid to increase performance in the task? One strategy which has been demonstrated in rats is sensitivity
to the phrasing in the pattern (Fountain et al., 1984; Fountain, Benson, & Wallace, 2000; Fountain, Rowan, & Carman, 2007; Stempowski et al., 1999; Wallace, Rowan, & Fountain, 2008). Stempowski et al. (1999) presented groups of rats with a hierarchically structured pattern (akin to the H pattern discussed previously) with groups receiving a short temporal pause between chunks of 3 elements, a long temporal pause, or no temporal phrasing cue. Rats that received a temporal pause acquired the pattern more quickly and made fewer errors over all as compared to rats that did not receive a temporal pause. The length of the temporal pause also affected acquisition as rats with a shorter temporal phrasing cue made fewer errors on the first element of each 3-element chunk as compared to rats with a longer temporal phrasing cue. Since rats are sensitive to phrasing cues within the pattern, they may be employing a hierarchical chunking strategy akin to strategies seen in human cognitive research in order to better acquire a cognitive rule.

Chunking in “Interleaved” Serial Patterns

Rats have also demonstrated chunking in interleaved serial patterns or multiple non-adjacent serial patterns. Whereas in previously discussed experiments adjacent elements in a series followed the same rule, elements in an interleaved pattern do not represent one continuous pattern or rule, but instead are multiple patterns presented together. In order to successfully acquire the interleaved pattern, rats need to acquire multiple sets of rules individually (Fountain, Rowan, & Benson, 1999; Fountain & Benson, 2006). For example, if presented with a sequence of letters such as AMBNCODPE__ one would be able to predict that the next letter in the sequence is Q.
This is because one is able to separate the two subpatterns in the interleaved pattern of letters to ABCDE and MNOP, after which the task becomes simpler, employing the rule of one forward in the alphabet.

Fountain et al. (1999) presented rats with an interleaved serial pattern consisting of a hierarchical serial pattern (the H Pattern) interleaved with responses in the spatial location 8. Rats were required to track both serial patterns during acquisition in order to receive reinforcement. Rats were presented with a either an interleaved serial pattern that followed a rule (structured) or an interleaved serial pattern that did not follow a rule (unstructured). The unstructured serial pattern was created by exchanging 4 elements (seen in underline) from the structured pattern. The middle chunk 384858 (bolded) appeared in both patterns for easy group comparison.

Structured/repeating pattern (ST-R): 182838 283848 \textbf{384858} 485868 586878...

Unstructured/repeating pattern (UNST-R):185838 283868 \textbf{384858} 482868 584878

The prediction was that if rats were able to chunk the subpatterns of the interleaved pattern, then they should be sensitive to the rules of each subpattern. Sensitivity to the rule should allow for faster acquisition of the structured interleaved serial pattern as compared to the unstructured interleaved pattern.

Rats presented with a structured interleaved pattern acquired the hierarchal subpattern faster than rats with the unstructured subpattern. Within the pattern, rats with the structured target subpattern made fewer errors on pattern elements in the middle
384858 chunk as compared to the unstructured target subpattern rats. This is evidence that rats were able to distinguish between the subpatterns, chunk the subpatterns, and were thus able to learn the rule structure and make fewer errors on the interleaved serial pattern.

One criticism for the design of this experiment, though, may be the use of repeated responses in the spatial location 8 as a subpattern. The perceived ease with which a rat may recall the spatial location without acquiring any pattern rule but instead represent the repetition of 8 as the response to make in-between the hierarchical rule may mean that rats excelled at the structured pattern over the unstructured pattern because they viewed the elements as adjacent and the other subpattern was ignored. Chunking of a secondary subpattern therefore required a more complex set of elements.

A second experiment in Fountain et al. (1999) presented rats with two subpatterns with either structured or unstructured elements.

Structured/alternating pattern (ST-A): \(12837485768\)

Unstructured/alternating pattern (UNST-A): \(175837482768\)

Rats presented with the structured alternating interleaved pattern were presented with two interleaved subpatterns 123456 and 787878 and the rats presented with the unstructured alternating interleaved pattern were presented with the two subpatterns 153426, where the 2 and 5 elements were switched to create an unstructured pattern, and 787878. If rats were chunking the two subpatterns and sensitive to the rule structure of the serial pattern,
then acquisition of the structured pattern would be faster than acquisition of the unstructured pattern.

The results of this experiment did indicate that rats were chunking the subpatterns as there were different acquisition rates for the elements of the two subpatterns. The structured rats produced fewer errors and acquired the pattern 123456 faster than the unstructured rats acquired the pattern 153426. Not predicted by chunking theory, though, the structure of the second subpattern did not improve acquisition so that for the 787878 pattern the unstructured rats actually made fewer errors and acquired the subpattern faster than the structured rats. Thus, while there is evidence of a chunking strategy in interleaved patterns, it is unclear to what extent the subpatterns are individually chunked.

Aim of Current Experiments

Rats are sensitive to the structure of serial patterns (Fountain & Rowan, 1995a; 1995b). They are able to acquire a set of rules in order to produce the serial pattern efficiently and do not do so when the pattern is unstructured. Rats are able to hierarchically chunk elements in a serial pattern to reduce working memory load and have trouble when patterns are not chunked or phased in an ideal way (Fountain et al., 2000; Stempowski et al., 1999). Rats appear to use a cognitive strategy during the presentation of interleaved patterns where two distinct subpatterns are interleaved within one another (Fountain et al., 1999). However it is unclear how these distinct subpatterns are cognitively represented.
If rats are chunking the elements of the subpatterns, could it be that the rats are able to completely separate the two interleaved subpatterns presented simultaneously, and if so, do they represent each subpattern as a hierarchal set of rules, or as completely separate patterns? For example, rats in Fountain et al. (1999) were presented with the two subpatterns 123456 and 787878 and acquired each subpattern at individual rates. Could this be an example of chunking the subpatterns so that rats were learning both a +1 rule and an alternating rule separately, switching from one pattern rule to the other and if so, how does this affect working memory? Or are the rats representing 172837485768 as one complex pattern with a hierarchical set of rules. If so, the differences in acquisition of the subpatterns may be due to hierarchical level of the subpattern rule so that one rule is considered a “lower” order rule and a second rule is considered a “higher” order rule. Differential acquisition would then be explained by acquisition of a perceived hierarchy and not of independent subpatterns.

If representation of the two interleaved subpatterns is not separate, how does the structure of one subpattern affect acquisition of the other subpattern? In Fountain et al. (1999), manipulation of the structure of the pattern occurred to the structured or target subpattern but not the secondary interleaved subpattern. Would manipulation of the secondary pattern affect rats in a similar way?

In order to explore the nature of chunking in an interleaved pattern, rats were presented with manipulated interleaved serial patterns. I manipulated the structure and the phrasing of the secondary interleaved subpattern to determine whether chunking may be
affected. By manipulating the different portions of the interleaved serial pattern, the processes behind acquisition will be more apparent.
Experiment 1

Experiment 1 determined the extent to which rats may be chunking the subpatterns in an interleaved pattern. In order to most efficiently explore interleaved pattern acquisition strategies, a 2x2 group design was utilized with manipulations of structure and the cueing of the interleaved subpattern. All groups were presented with the same target subpattern 123456 akin to the second experiment of Fountain et al. (1999), but with differing structure and cueing of the interleaved pattern. The structure of the interleaved pattern was manipulated so groups received either a subpattern with a structured alternating rule 787878 or an unstructured interleaved subpattern of random presentation of 7 and 8 trials.

The other manipulation occurred in phrasing between the subpatterns so that the different subpattern trials were made more apparent. Groups were either presented with an uncued interleaved subpattern that required the rat to make a correct choice akin to the target subpattern trials, or a cued interleaved subpattern which did not require a choice but instead indicated the correct response for the rats. Although the current experiment utilizes a 2x2 design, presenting rats with a non-cued random element subpattern was not beneficial as it did not contribute to the theoretical questions proposed and would be very difficult for a rat to acquire. Thus, 3 groups were used: No Cue Structure (No Cue S), Cue Structure (Cue S) and Cue Random (Cue R).

If the rats are chunking the two subpatterns during acquisition as two separate sets of rules, then the acquisition of the target subpattern rule should not be moderated by the
interleaved subpattern. Manipulation of the interleaved subpattern structure should therefore not affect performance of the target subpattern as both sets of rules would be treated as different entities. Different acquisition rates would occur for each subpattern akin to Fountain et al. (1999). Since Stempowski et al. (1999) demonstrated sensitivity to external phrasing in serial pattern learning; external cueing was also manipulated to better allow for chunking of the subpatterns in the interleaved serial patterns. It was predicted that external phrasing would affect acquisition similar to Stempowski et al. (1999) and external cueing would allow the rats to chunk more successfully.

If, on the other hand, the rats did not independently chunk the two subpatterns, then structured interleaved subpatterns would result in faster acquisition of the target subpattern as compared to a random interleaved subpattern. An incomplete chunking strategy would be more affected by the overall structure of the interleaved pattern and would thus be affected negatively to a random presentation of elements as compared to an interleaved pattern with two rule subsets.

Once rats had acquired the interleaved pattern, a transfer pattern was presented to all groups in which the interleaved subpattern was altered from 787878 and random presentations of 7 and 8 to the subpattern 878787 with cueing remaining the same from the acquisition phase. Thus rats were presented with the interleaved pattern 182738475867. If the rats were independently chunking the two subpatterns, then performance on the target subpattern 123456 was expected not to change even when the interleaved subpattern was altered. On the other hand, rats not independently chunking
the two subpatterns would result in a performance change on the target subpattern as the overall structure of the interleaved pattern was affected.

Method

Subjects

Subjects were 15 adult male hooded rats (*Rattus norvegicus*) received from the Kent State breeding colony. Rats were initially water deprived for 36-48 hours (h) prior to beginning of testing. During testing, rats were given access to water both in the testing chamber and then for 5 minutes (min) following testing every day. Food was available ad libitum.

Apparatus

Rats were initially shaped in a 15 x 30 x 30 cm shaping chamber which includes a shaping nose-poke receptacle (2.5-cm diameter PVC pipe end caps painted flat black) centered on one end wall 5.0 cm above the floor. The nose-poke receptacle was equipped with an infrared emitter-detector pair to detect nose-poke responses. A white LED light was positioned at the rear of the receptacle and a silicone tube fastened through a hole in the bottom of the receptacle delivered water. A 0.025 ml/droplet of distilled water was delivered via solenoid fastened to an outer chamber wall following each correct response. Testing occurred in one of six octagonal operant chambers constructed of clear Plexiglas (15 cm wide x 30 cm tall walls with 40 cm between opposite walls), stainless steel wire mesh flooring, and a nose-poke receptacle described above centered 5.0 cm above the floor on each chamber wall.
Chambers were enclosed by external sound-attenuating boxes with 10-ml syringes affixed to an internal wall of the enclosure. The syringes were connected by Tygon tubing (VWR Scientific, Performance Plastics 1/32-inch, #R-3603) to solenoids (General Valve Corp. Vac. 20 psig. 24 volts) and then to the receptacles. The solenoids controlled the delivery of water droplets to the nose-poke receptacles. Background white noise masked extraneous noise. Shaping and testing chambers were controlled by a computer and an interface (Med Associates interface; Grayson Stadler power supply Model E 783 DA) from an adjoining room. Rats in the shaping and testing chambers were monitored from the computer room via closed circuit cameras mounted inside the sound attenuating enclosures.

Procedure

Shaping. Adult rats were deprived of water for 36-48 h prior to the start of the experiment to increase motivation for shaping purposes. After 36-48 h, subjects were initially shaped to nose poke a water receptacle for water reinforcement in a shaping chamber. Shaping occurred over two shaping trials separated by a 24 h break. On the first day, rats were required to nose poke the water receptacle for water with no inter-trial interval (ITI) for 240 responses. On the second day, rats were required to nose poke the receptacle an additional 240 times with an ITI so that the receptacle light turned off for a 1 s interval after each reward delivery. Responses were rewarded only when the receptacle light was illuminated.
Acquisition. After shaping was complete, training occurred in a dark chamber with the only light stimuli being from the receptacle lights. On successive trials, rats were presented with 8 possible choices and were required to nose poke the receptacles in a certain order in order to receive water reinforcement. As shown in Table 1, rats received one of three patterns of elements in the testing chamber determined by random group assignment.

In Group No Cue Structure (No Cue S), rats received two subpatterns of elements interleaved with one another. The overall pattern was a target subpattern of 123456 and an interleaved subpattern 787878, where each number in the pattern corresponded to a specific nose-poke receptacle in the octagonal chamber. Thus the resulting interleaved pattern was 172837485768. No Cue S rats were required to choose each element of the pattern from 8 possible choices and thus no cue was given for any of the elements.

In group Cue Structure (Cue S), rats received the same two patterns of elements as previously described in No Cue S, but the 787878 subpattern was cued so that Cue S rats were required to choose elements of 123456 out of 8 possible choices, but only the correct choice was illuminated on 7 and 8 trials and Cue S rats were required to make a response at that correct choice location in order to continue the task.

In the Cue Random group (Cue R), rats received the 123456 target subpattern but interleaved by random presentations of 7 and 8 so that interleaved subpattern elements were not predictable. As for Cue S rats, 7 and 8 trials were cued such that only the correct
choice were illuminated and Cue R rats were required to make a response at the correct choice location in order to continue the task.

At the beginning of each trial, appropriate light receptacles were activated. If a rat made a correct choice, reinforcement was delivered and the lights were deactivated for an ITI of 1 s. When the rat chose incorrectly, the correct choice was flashed at a rate of 20 flashes/min in the chamber and the rat had to make that response in order to proceed with the task. This was repeated for every element of the pattern until the pattern was complete. Rats were presented with 48 repetitions of the pattern every day for a criterion of 70 days.

**Transfer.** On the 71st day, rats were transferred to a new pattern, interleaved 7 and 8 elements presented as 878787 for all groups. Thus rats in the No Cue S received the pattern 182738475867 with no cueing, and rats in Cue S and Cue R were presented with a structured pattern of 182738475867 where the 8-7 pattern was still cued. Beyond this, treatment of the rats and procedure remained the same. Rats were run as before for a criterion of 10 days.
Table 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Acquisition</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Cue Structure (8-7)</td>
<td>172837485768</td>
<td>182738475867</td>
</tr>
<tr>
<td>Cue Structured (8-7)</td>
<td>172837485768</td>
<td>182738475867</td>
</tr>
<tr>
<td>Cue Random (8-7)</td>
<td>1x2x3x4x5x6x</td>
<td>182738475867</td>
</tr>
</tbody>
</table>
Results

Acquisition of Subpatterns

Analyses were planned to determine whether rats acquired the target and interleaved subpatterns in an interleaved pattern at different rates when presented with specific combinations of cue and structure manipulation. To test this, a group x day (3 x 70) repeated measures analysis of variances (ANOVA) was conducted on rats’ daily mean error response rates for each element type across the 70 days of the experiment for both the target subpattern (123456) and the interleaved subpattern (787878) across groups. Main effects and interactions were considered significant if $p < .05$.

Acquisition curves of the target subpattern, the subpattern that remained constant across groups, are shown in Figure 2 (A). In the analysis of target subpattern acquisition, a group x day (3 x 70) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in a comparison between groups, $F(2, 69) = 9.038$, $p < .05$. Thus, rats acquired an identical target subpattern at different rates when presented with a differentially manipulated interleaved subpattern. Statistically significant main effects were also found for day, $F(2, 69) = 99.51$, $p < .05$, as well as a statistically significant group x day interaction $F(69, 138) = 1.95$, $p < .05$. Planned comparison based on the statistically significant group x day interaction demonstrated that groups with the same interleaved subpattern structure but with differences in cue presentation (No Cue S) and (Cue S) differed on days 3, 29, 31-34, 40, 56, 67 with rats
that received a cued interleaved subpattern acquiring the target subpattern faster and with fewer errors than rats that did not receive the cueing.
Figure 2: Acquisition curves for the interleaved pattern in Experiment 1 for (A) the target subpattern and (B) the interleaved subpattern over 70 days of acquisition. Daily mean errors were averaged across all elements of the pattern. The y-axis represents mean proportion errors and the x-axis represents combinations of errors seen over 48 pattern repetitions. Filled circles, open circles, and filled triangles represent groups No Cue S, Cue S, and Cue R respectively. Error bars: ± SEM.
In a comparison of rats that received the same cueing presentation but differed on pattern structure (Cue S and Cue R), rats differed on days 2-59, 61, 63, 66-67, with rats that received a structured interleaved subpattern acquiring the target subpattern faster and with fewer errors than rats that did not receive the structured interleaved subpattern. Differences were also seen in a comparison of groups No Cue S and Cue R which differed in both cueing and structure manipulation on days 25, 32, 36, 38, 41, 43, 44, 46-50, 53, with rats in No Cue S acquiring the target subpattern faster and making fewer errors than those rats with a cued but unstructured interleaved subpattern.

Acquisition curves of the interleaved subpattern, the subpattern that was manipulated across groups, are shown in Figure 2 (B). In the analysis of interleaved subpattern acquisition, a group X day (3 x 70) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, \( F(2, 69) = 16.57, p < .05 \). Thus, rats acquired the interleaved subpattern at different rates when presented with manipulations of cue and structure. Statistically significant main effects were also found for day, \( F(2, 69) = 35.38, p < .05 \), as well as a statistically significant group x day interaction \( F(69, 138) = 9.64, p < .05 \). Planned comparison based on the statistically significant group x day interaction demonstrated that groups with the same interleaved subpattern structure but with differences in cue presentation (No Cue S) and (Cue S) differed on days 1-45, 47-57, 59-60, 62-67, with rats receiving a cued interleaved subpattern acquiring the interleaved subpattern faster and with fewer errors than rats that did not receive the cueing. In a comparison of rats that received the same cueing presentation but differed on pattern structure (Cue S and
Cue R), rats differed on days 2-4, 7-14, 16-22, 24-70, with rats acquiring the structured interleaved subpattern faster and with fewer errors than rats that did not receive the structured interleaved subpattern. Differences were also seen in a comparison of groups No Cue S and Cue R which differed in both cueing and structure manipulation on days 2-34, 36, 39, 42, 70, with rats in No Cue S acquiring the interleaved subpattern faster and making fewer errors than those rats with a cued but unstructured interleaved subpattern.

Comparison of both target and interleaved subpattern acquisition was also analyzed for each group to determine any differences of acquisition between subpatterns. A subpattern x day (2 x 70) repeated measures ANOVA was conducted for groups No Cue S, Cue S, and Cue R. Once again, main effects and interactions were considered significant if \( p < .05 \).

For acquisition of target and interleaved subpatterns of group No Cue S, a subpattern x day (2 x 70) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect for day, \( F(2, 69) = 48.07, p < .05 \). Comparisons of subpattern and subpattern x day interactions resulted in a \( p > .05 \). Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 11-19, 26, 39 with rats acquiring the interleaved subpattern slightly faster and with fewer errors than the target subpattern.

For acquisition of target and interleaved subpatterns of group Cue S, a subpattern x day (2 x 70) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, \( F(1, 69) = 29.61, p < .05 \).
A statistically significant main effect was also found for day, $F(1, 69) = 43.62, p < .05$, as well as a statistically significant subpattern x day interaction $F(69, 69) = 13.85, p < .05$. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-53, 57, 59-60, 65-66, 70 with the interleaved subpattern being acquired faster and with fewer errors than the target pattern.

For acquisition of target and interleaved subpatterns of group Cue R, a subpattern x day (2 x 70) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, $F(1, 69) = 20.05, p < .05$. A statistically significant main effect was also found for day, $F(1, 69) = 40.74, p < .05$, as well as a statistically significant subpattern x day interaction $F(69, 69) = 19.06, p < .05$. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-54, 57.

**Trial x Trial Analyses**

Trial x trial analyses were conducted on the mean number of errors made on each individual element of the pattern throughout the experiment. Termed “trial-by-trial”, this analytic technique allows for better insight to the mean number of errors made on each element of the pattern for any day of the pattern across all groups. These analyses are done to better characterize and determine whether acquisition differences between groups are due to specific elements of the pattern. To look for differences in acquisition between groups on elements within the pattern, a group X element (3 X 12) ANOVA was conducted on rats’ trial-by-trial error response rates collapsed across all 70 days of
acquisition of the experiment for the interleaved pattern. Main effects and interactions were considered significant if $p < .05$.

Mean trial x trial error response rates for groups No Cue S (A), Cue S (B), and Cue R (C) over all 70 days of acquisition are shown in Figure 3. Generally, the results show that fewer errors are made both on the target and interleaved subpatterns when rats are presented with both a structured and cued interleaved pattern. When either the structure or the cue is removed from the interleaved pattern, errors on the target subpattern will increase.
Figure 3: Mean trial x trial incorrect response rates for both the target and interleaved subpatterns in Experiment 1 for (A) No Cue S, (B) Cue S, and (C) Cue R subpattern averaged over 70 days of acquisition. The y-axis represents mean proportion errors and the x-axis represents pattern sequence elements.
A. 
Interleaved Serial Pattern
1 7 2 8 3 7 4 8 5 7 6 8
Mean Proportion Errors

B. 
Interleaved Serial Pattern
1 X 2 X 3 X 4 X 5 X 6 X
Mean Proportion Errors

C. 
Interleaved Serial Pattern
1 X 2 X 3 X 4 X 5 X 6 X
Cueing of the interleaved subpattern also results in low error rates on the interleaved subpattern elements. The group X element (3 X 12) ANOVA indicated statistically significant main effects for group, \( F(2, 11) = 19.88, \ p < .05 \), element, \( F(2, 11) = 27.78, \ p < .05 \). A statistically significant group x element interaction was also found \( F(11, 22) = 381, \ p < .05 \). Planned comparisons of groups that shared a structured interleaved subpattern but differed in cueing (No Cue S and Cue S) showed differences in performance during acquisition on elements at serial positions 2 -10 and 12 with rats in group No Cue S producing more errors than rats in group Cue S. This indicates that the addition of cueing in the interleaved subpattern affected performance on both elements in the target and interleaved subpatterns.

Planned comparisons of groups that shared a cued interleaved subpattern but differed in structure (Cue S and Cue R) showed differences in performance during acquisition on elements at serial positions 1-3, 5, 7, 9-12 with rats with the structured interleaved subpattern producing fewer errors on the target subpattern elements as compared to the group with no structure in the interleaved subpattern. Serial positions where no difference was seen were all in the interleaved subpattern and may be due to the cued nature of the pattern.

Planned comparisons of groups that differed in both cueing and structure of the interleaved subpattern (No Cue S and Cue R) showed differences in performance during acquisition on elements at serial positions 1, 4, 6, 8, 11, and 12. Although these serial positions are primarily in the interleaved subpattern where rats in Cue R produce fewer errors than No Cue S, and thus due to cueing, there are differences on serial positions 1
and 11 where No Cue S rats do produce fewer errors on the target subpattern as compared to Cue R. The reduction of errors at the beginning and end of the target subpattern in group No Cue S may indicate that these groups are experiencing a different interleaved pattern and may thus be using different learning strategies based off of the elements presented.

Transfer of Interleaved pattern

Analyses were also planned to determine whether performance on target subpattern performance would be interrupted by further manipulation of the interleaved subpattern from 7-8 to 8-7. A group x day (3 x 2) repeated measures analysis of variance (ANOVA) was conducted on rats’ mean error response rates for each element type for the final day of acquisition and the initial day of transfer for both the target subpattern (123456) and the transferred interleaved subpattern (878787) across groups. Main effects and interactions were considered significant if $p < .05$.

In the analysis of target subpattern performance, a group x day (3 x 2) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, $F(2, 1) = 43.45, p < .05$. Thus, performance of an acquired target subpattern was altered when the interleaved subpattern was initially transferred. Statistically significant main effects were also found for day, $F(2, 1) = 352.5, p < .05$, as well as a statistically significant group x day interaction $F(1, 2) = 73.85, p < .05$. Planned comparison based on the statistically significant group x day interaction demonstrated that groups with the same interleaved subpattern structure but with
differences in cue presentation (No Cue S) and (Cue S) differed between acquisition Day 70 and transfer Day 1, with errors increasing on transfer Day 1.

In the analysis of interleaved subpattern performance, a group x day (3 x 2) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, $F(2, 1) = 20.12, p < .05$. Statistically significant main effects were also found for day, $F(2, 1) = 101.468, p < .05$, as well as a statistically significant group x day interaction $F (1, 2) = 82.21, p < .05$. Planned comparison based on the statistically significant group x day interaction demonstrated that No Cue S differed between acquisition Day 70 and transfer Day 1, with errors increasing on transfer Day 1.

To examine performance on the entire transfer, a group x day (3 x 10) repeated measures analysis of variances (ANOVA) was conducted on rats’ daily mean error response rates for each element type across the 10 days of transfer for both the target subpattern (123456) and the transferred interleaved subpattern (878787) across groups. Main effects and interactions were considered significant if $p < .05$

Performance curves of the target subpattern for the transfer are shown in Figure 4 (A). In the analysis of target subpattern performance, a group x day (3 x 10) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, $F(2, 9) = 51.47, p < .05$. Statistically significant main effects were also found for day, $F(2, 9) = 57.72, p < .05$, as well as a statistically significant group x day interaction $F (9, 18) = 9.45, p < .05$. Planned comparison based
on the statistically significant group x day interaction demonstrated that groups with the same interleaved subpattern structure but with differences in cue presentation (No Cue S) and (Cue S) differed on days 2, 4-10, with rats that received a cued interleaved subpattern performing the target subpattern faster and with fewer errors than rats that did not receive the cueing. In a comparison of rats that received the same cueing presentation but differed on pattern structure (Cue S and Cue R), rats differed on days 1-10, with rats that received an unstructured interleaved subpattern performing the target subpattern faster and with fewer errors than rats that did receive the structured interleaved subpattern.
Figure 4: Performance curves for transfer of the interleaved pattern in Experiment 1 for (A) the target subpattern and (B) the interleaved subpattern over 10 days of transfer. Daily mean errors were averaged across all elements of the pattern. The y-axis represents mean proportion errors and the x-axis represents combinations of errors seen over 48 pattern repetitions. Filled circles, open circles, and filled triangles represent groups No Cue S, Cue S, and Cue R respectively. Error bars: ± SEM.
Differences were also seen in a comparison of groups No Cue S and Cue R which differed in both cueing and structure manipulation on days 1-10, with rats in Cue R producing the target subpattern faster and making fewer errors than those rats in No Cue S.

Performance curves of the interleaved subpattern for the transfer are shown in Figure 4 (B). In the analysis of interleaved subpattern performance, a group x day (3 x 10) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, $F(2, 9) = 140.58, \ p < .05$. Statistically significant main effects were also found for day, $F(2, 9) = 23.89, \ p < .05$, as well as a statistically significant group x day interaction $F(9, 18) = 3.44, \ p < .05$. Planned comparison based on the statistically significant group x day interaction demonstrated that groups with the same interleaved subpattern structure but with differences in cue presentation (No Cue S) and (Cue S) differed on days 1-10, with rats performing the interleaved subpattern faster and with fewer errors than rats that did not receive the cueing. In a comparison of rats that received the same cueing presentation but differed on pattern structure (Cue S and Cue R), rats differed on day 1, with rats that received an unstructured interleaved subpattern performing faster and with fewer errors than rats that did receive the structured interleaved subpattern. Differences were also seen in a comparison of groups No Cue S and Cue R which differed in both cueing and structure manipulation on days 1-10, with rats in Cue R producing the target subpattern faster and making fewer errors than those rats in No Cue S.
Comparison of both target and interleaved subpattern performance was also analyzed for each group to determine any differences of performance between subpatterns. A subpattern x day (2 x 10) repeated measures ANOVA was conducted for groups No Cue S, Cue S, and Cue R. For group No Cue S, a subpattern x day (2 x 10) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, \( F(1, 9) = 8.29, p < .05 \). Statistically significant main effects were also found for day, \( F(1, 9) = 51.30, p < .05 \), as well as a statistically significant subpattern x day interaction \( F(9, 9) = 8.06, p < .05 \). Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-7 with rats making fewer errors on the interleaved subpattern as compared to the target subpattern.

For group Cue S, a subpattern x day (2 x 10) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, \( F(1, 9) = 89.32, p < .05 \). Statistically significant main effects were also found for day, \( F(1, 9) = 31.68, p < .05 \), as well as a statistically significant subpattern x day interaction \( F(9, 9) = 14.80, p < .05 \). Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-10 with rats making fewer errors on the interleaved subpattern as compared to the target subpattern.

For group Cue R, a subpattern x day (2 x 10) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, \( F(1, 9) = 32.43, p < .05 \). Statistically significant main effects were also found for day, \( F(1, 9) = 4.69, p < .05 \). A subpattern x day analysis to
determine whether there was an interaction resulted in \( p > .05 \). Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-10 with rats making fewer errors on the interleaved subpattern as compared to the target subpattern.

**Trial x Trial Analyses**

Trial x trial analyses were also conducted on the mean number of errors made on each individual element of the pattern throughout the transfer. A group X element (3 X 12) ANOVA was conducted on rats’ trial-by-trial error response rates collapsed across all 10 days of acquisition of the experiment for the interleaved pattern. Main effects and interactions were considered significant if \( p < .05 \).

Mean trial x trial error response rates for groups No Cue S (A), Cue S (B), and Cue R (C) over all 10 days of transfer are shown in Figure 5. Generally, the results show that fewer errors were made both on the target and interleaved subpatterns by group Cue R, meaning that rats in Cue R were not affected by the transfer and may then be the only rats to chunk the target and interleaved subpatterns. Cueing of the interleaved subpattern also results in low error rates on the interleaved subpattern elements. The group X element (3 X 12) ANOVA indicated statistically significant main effects for group, \( F(2, 11) = 123.81, \ p < .05 \) and element, \( F(2, 11) = 15.12, \ p < .05 \). A statistically significant group x element interaction was also found \( F(11, 22) = 5.87, \ p < .05 \). Planned comparisons of groups with that shared a structured interleaved subpattern but differed in cueing (No Cue S and Cue S) showed differences in performance during acquisition on
elements at serial positions 1, 4, 6, 7, 8, and 10 with rats in group No Cue S once again producing more errors than rats in group Cue S.

Planned comparisons of groups that shared a cued interleaved subpattern but differed in structure (Cue S and Cue R) showed differences in performance during acquisition on elements at serial positions 1, 3, 5, 7, 9, and 11 with rats with in the Cue R group producing fewer errors on the target subpattern as compared to rats in the Cue S condition.
Figure 5: Mean trial x trial incorrect response rates for both the target and interleaved subpatterns in Experiment 1 for (A) No Cue S, (B) Cue S, and (C) Cue R subpattern averaged over 10 days of transfer. The y-axis represents mean proportion errors and the x-axis represents pattern sequence elements.
Serial positions where no difference was seen were all in the interleaved subpattern were due to the cued nature of the pattern.

Planned comparisons of groups that differed in both cueing and structure of the interleaved subpattern (No Cue S and Cue R) showed differences in performance during acquisition on elements at serial positions 1, 3, and 4 -11. Rats in Cue R produced both the target subpattern and most of the interleaved subpattern more accurately than rats in group No Cue S. This may be due to a combination of successful chunking in the acquisition phase of the experiment by Cue R rats and cueing of the novel interleaved subpattern.
Discussion

Generally, after 70 days of acquisition rats were able to learn and produce an interleaved pattern consisting of two subpatterns with distinctive rules. Acquisition occurred faster and with fewer errors when rats presented with a cued and structured interleaved subpattern, thus group Cue S acquired the interleaved pattern (both the target and interleaved subpatterns) faster than groups No Cue S and Cue R. Acquisition of both the target and interleaved subpatterns were negatively affected when either the cueing or structure manipulation was removed, with the structure of the interleaved subpattern playing a more important role in the acquisition of the target subpattern and the cueing manipulation playing a more important role in the acquisition of the interleaved subpattern. Thus, for the target subpattern, group No Cue S excelled over Cue R, and for performance of the interleaved subpattern, group Cue R excelled over No Cue S, although this comparison must be very limited due to differences in the complexity of the task presented for groups No Cue S and Cue R. These findings are consistent with a chunking strategy as performance improved when the interleaved pattern was manipulated in a way that was easier to chunk and worsened when the interleaved pattern was manipulated in a way that was more difficult to chunk.

Overall comparisons of acquisition of the target and interleaved subpatterns resulted with faster acquisition of the interleaved subpattern as compared to the target subpattern. For group No Cue S, where rats were required to learn each subpattern in an identical way, transitive but statistically significant differences were seen with the
interleaved subpattern being learned slightly faster than the target subpattern. Differences in acquisition of non-cued interleaved patterns is a main finding in Fountain et al. (1999) with the interleaved alternating subpattern being acquired more quickly than the target subpattern. The replication of Fountain et al. (1999) allows for the consideration that the same mechanisms at work in the earlier experiment may also play a part in Experiment 1.

In comparison of errors made on pattern elements through trial x trial analysis, results once again demonstrate the importance of both cueing and structure as group Cue S made fewer errors overall on each element as compared to groups No Cue S and Cue R. An intriguing result came from the comparison of groups No Cue S and Cue R which differed in both cueing and structure manipulation of the interleaved subpattern but did share an identical target subpattern. Overall, Cue R made fewer errors, which may be accounted for by the random and cued nature of the interleaved subpattern. The interesting difference, though, was increased errors on the first and last elements of the target subpattern for group Cue R as compared to No Cue S. This result may be interpreted in one of two ways. First, rats in No Cue S may have been able to make fewer errors on the first and last elements of the target subpattern because they had more opportunity to use rule abstraction and therefore were more easily able to employ a rule early on in acquisition, which would allow for better performance on the target subpattern. Although a reasonable explanation, a more likely one when paired with the poor performance in the No Cue S group during transfer may be that the No Cue S group was more able to predict ordinal positions 1 and 11 in the pattern because it was not completely chunking the interleaved pattern and was thus able to use the interleaved
subpattern elements as cues for the elements in the target subpattern. Since the Cue R group were not given these same predictors, more errors were made during acquisition but eventually resulted in stronger acquisition of the target subpattern.

As mentioned previously, the transfer of the interleaved subpattern from 787878 to 878787 was clarifying as to whether rats were completely chunking the interleaved pattern as two distinct rules and subpatterns. By altering one pattern and examining the effect this change had on the other acquired and unaltered subpattern, it became clear that groups No Cue S and Cue S, the groups with the prior superior performance were not completely chunking the interleaved pattern. The transfer of the target subpattern, the pattern on which No Cue S and Cue S made fewer errors as compared to Cue R, resulted in deficits for these same structured groups where no such deficit was seen for group Cue R. Since no deficit was seen in Cue R even with the addition of the now structured interleaved subpattern, it becomes clear that chunking did occur between the two subpatterns in at least one group, but this chunking resulted in slower acquisition and needed to be dramatically different in order for the chunking to take place. Rats required both the cueing between the two subpatterns and a lack of structure on one subpattern to force the rat to chunk these subpatterns as two distinct learning experiences. Once the chunking had occurred, the resulting performance was more permanent as one would expect from a rule abstracted and chunked pattern.

The overall results of Experiment 1 led to a three-fold conclusion: rats are sensitive to the structure of subpatterns and will acquire and produce the interleaved
pattern faster when it is completely structured, rats are sensitive to the differences in the cued and non-cued subpatterns and will acquire the interleaved pattern more efficiently when given this distinction, and although rats excel with theses manipulations complete chunking of the subpatterns does not occur under these conditions. Instead, complete chunking occurs only in the more difficult to acquire unstructured condition.
Experiment 2

In Experiment 1, rats were presented with two interleaved subpatterns with the intention of examining chunking. Although it was predicted that rats presented with two structured interleaved subpatterns would chunk each subpattern, the only evidence of chunking occurred in group Cue R. If rats in groups No Cue S and Cue S were able to acquire the interleaved serial pattern, but were not completely chunking the subpatterns, then what strategy was being used to acquire what could be perceived as a very complex pattern? One possibility is that rats are using multiple concurrent cognitive learning strategies in order to learn the rules of the pattern. If this is true, then acquisition of the target subpattern should be dependent on structure of the interleaved pattern. Another possibility is that rats could be utilizing motor and discriminative learning strategies in order to memorize a pathway in the octagonal chamber in order to predict where the next element will be. If this is the case, rats should not be affected by the structure of the interleaved subpattern and thus the complexity of the pattern rule.

An additional experiment was completed to determine whether acquisition of an interleaved pattern was affected not only by the structure of the interleaved subpattern, but also the complexity of that interleaved subpattern. For experiment 2, the previous experiment was replicated with the addition of a more complex interleaved subpattern. If rats were sensitive to and utilized a rule-learning strategy in order to predict the next element in an interleaved serial pattern, then it was predicted that rats should be sensitive to the complexity of the interleaved subpattern and a structurally simpler subpattern
(787878) should allow for faster acquisition as compared to a structurally more complex subpattern (788778). If, on the other hand, rats were dependent on another learning strategy such as motor or kinesthetic memory, then it was predicted that rats should not be sensitive to the cognitive complexity of the rule structure as any motor pathway will remain unchanged. Any change to the spatial cue or motor component of the pattern, then, should result in a detriment in performance.

Method

Subjects

The subjects were 33 adult male hooded rats (Rattus norvegicus) received from Kent State breeding colony and treated the same as Experiment 1. Rats were assigned to one of five groups: No Cue Simple Structure (No Cue SS), No Cue Complex Structure (No Cue CS), Cue Simple Structure (Cue SS), Cue Complex Structure (Cue CS), and Cue Random (Cue R).

Apparatus

The same apparatus as was described in Experiment 1 was utilized for Experiment 2.

Procedure

Shaping. The same shaping procedure as was use in Experiment 1 was also used in Experiment 2.
Acquisition. After shaping was completed, training occurred in a dark chamber with the only light stimuli being from the receptacle lights. On successive trials, rats were presented with 8 possible choices and were required to nose poke the receptacles in a certain order in order to receive water reinforcement. As shown in Table 2, rats received one of five patterns of elements in the testing chamber determined by random group assignment.

In Group No Cue Simple Structure (No Cue SS), rats received two subpatterns of elements interleaved with one another. Thus, the overall pattern was a target subpattern of 123456 and an interleaved “simple” subpattern 787878. The resulting interleaved pattern was 172837485768. No Cue SS rats were required to choose each element of the pattern from 8 possible choices and thus no cue was given for any of the elements.

In the No Cue Complex Structured (No Cue CS), rats received two subpatterns of elements interleaved with one another, but with a more “complex” subpattern that included two “violations” to the alternating rule. Thus, the overall pattern was a target subpattern of 123456 and an interleaved “complex” subpattern of 788778. The resulting interleaved pattern was 172838475768. No Cue CS rats were required to choose each element of the pattern from 8 possible choices and thus no cue was given for any of the elements.

In group Cue Simple Structure (Cue SS), rats received the same two patterns of elements as previously described in No Cue SS, but the 787878 subpattern was cued so that Cue SS rats were required to choose elements of 123456 out of 8 possible choices,
but only the correct choice was illuminated on 7 and 8 trials and Cue SS rats were required to make a response at that correct choice location in order to continue the task.

In group Cue Complex Structure (Cue CS), rats received the target subpattern and the “complex” interleaved subpattern, but were cued so that Cue CS rats were required to choose elements of 123456 out of 8 possible choices, but only the correct choice was illuminated on 7 and 8 trials and Cue S rats were required to make a response at that correct choice location in order to continue the task.

Finally, in the Cue Random group (Cue R), rats received the 123456 target subpattern but interleaved by random presentations of 7 and 8 so that interleaved subpattern elements were not predictable. As for Cue SS and Cue CS rats, 7 and 8 trials were cued such that only the correct choice were illuminated and Cue R rats were required to make a response at the correct choice location in order to continue the task.

The same acquisition procedure used in Experiment 1 were also be used in Experiment 2. Rats were run on 48 patterns a day. Acquisition for this second experiment was shortened to 48 days due to the asymptotic nature of performance for structured groups in the previous experiment starting at day 48.

Transfer. On the 49th day, rats were transferred to the next consecutive of six chambers so that rats trained in chamber 1 were transferred to chamber 2, chamber 2 were transferred to chamber 3… and chamber 6 were transferred to chamber 1. As the octagonal chambers vary in start position, rats were presented with the same interleaved
pattern but the start of the pathway along with any potential external cues was altered.

Rats were presented with an identical interleaved pattern in the new chamber for 10 days.
### Table 2

**Groups for Experiment 2**

<table>
<thead>
<tr>
<th>Group</th>
<th>Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Cue Simple Structured</td>
<td>172837485768</td>
</tr>
<tr>
<td>No Cue Complex Structured</td>
<td>172838475768</td>
</tr>
<tr>
<td>Cue Simple Structured</td>
<td>172837485768</td>
</tr>
<tr>
<td>Cue Complex Structured</td>
<td>172838475768</td>
</tr>
<tr>
<td>Cue Random</td>
<td>1x2x3x4x5x6x</td>
</tr>
</tbody>
</table>
Results

Acquisition of Subpatterns

Analyses were completed to determine whether rats acquired the target and interleaved subpatterns in an interleaved pattern at different rates when presented with specific combinations of cue and structural complexity. To test this, a group x day (5 x 48) repeated measures ANOVA was conducted on rats’ daily mean error response rates for each element type across the 48 days of the experiment for both the target subpattern (123456) and the interleaved subpattern (either 787878 or 788778) across groups. Main effects and interactions were considered significant if \( p < .05 \).

Acquisition curves of the target subpattern, the subpattern that remained constant across groups, are shown in Figure 6 (A). In the analysis of target subpattern acquisition, a group x day (5 x 48) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, \( F(4, 47) = 9.55, p < .05 \). A statistically significant main effect was also found for day, \( F(4, 47) = 208.22, p < .05 \). A statistically significant group x day interaction was also found, \( F(47, 188) = 1.51, p < .05 \). Planned comparison based on the statistically significant group x day interaction overall demonstrated that cueing once again improved acquisition as compared to non-cued groups, structured groups acquired the pattern faster than the non-structured group, and there were transitive differences in complex vs. simple structuring.

Planned comparisons of groups with no cueing and differing in complexity of structure
(groups No Cue SS and No Cue CS) rats showed differences in performance during acquisition of the target subpattern on days 24, and 27-31 with rats in group No Cue SS making fewer errors than group No Cue CS on those days. When cueing was present, (groups Cue SS and Cue CS) no differences were seen between groups for the entirety of the experiment. Complexity of the structure of the target subpattern did not affect acquisition overall in this experiment.

In a comparison of the effect of cueing of groups with the simple structure interleaved pattern (groups No Cue SS and Cue SS) rats showed differences in performance during acquisition of the target subpattern on days 4-7, 9-14, 16-32, and 34 with rats in the cued group acquiring the pattern more quickly and with fewer errors than those in the no cued group.
Figure 6: Acquisition curves for the interleaved pattern in Experiment 2 for (A) the target subpattern and (B) the interleaved subpattern over 48 days of acquisition. Daily mean errors were averaged across all elements of the pattern. The y-axis represents mean proportion errors and the x-axis represents combinations of errors seen over 48 pattern repetitions. Filled circles, open circles, filled triangles, open triangles, and filled squares represent groups No Cue SS, No Cue CS, Cue CS, Cue SS and Cue R respectively. Error bars: ± SEM.
A comparison of the effect of cueing of groups with the complex structure interleaved pattern (groups No Cue CS and Cue CS) showed differences in performance during acquisition of the target subpattern on days 3-23, 25-27, 30, 32-33, 35, and 37 with rats in the cued group once again acquiring the pattern more quickly and with fewer errors than those in the no cued group.

Planned comparisons of the interaction of cue and structure found differences in groups No Cue SS and Cue CS on days 4-13, 15-31, and 33-34 with the cued complex condition acquiring the target subpattern more effectively than the group with no cues. Differences were also found in a comparison of groups No Cue CS and Cue SS on days 4-18, 20-21, 25, 27, 30, 32, 37, and 42 with once again the cued condition acquiring the target subpattern more effectively than the group with no cues.

A comparison of the Cue R condition with cueing but no structure present demonstrated that rats acquired the target subpattern faster with a structured interleaved pattern no matter the complexity of the pattern. This replicated findings from Experiment 1 and allows for more clarity on the importance of structure in the overall interleaved pattern. Planned comparisons showed differences between Cue R and No Cue SS on days 8-26, 28, 31 -48; No Cue CS on days 9, and 12-48; Cue SS on days 4-48; and Cue CS on days 3-48.

Acquisition curves of the interleaved subpattern, the subpattern that was manipulated across groups, are shown in Figure 6 (B). In the analysis of interleaved
subpattern acquisition, a group X day (5x 48) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, F(4, 47) = 20.60, p < .05. A statistically significant main effect was also found for day, F(4, 47) = 105.24 , p < .05, as well as a statistically significant group x day interaction F (47, 188) = 11.70, p < .05.

Planned comparisons of groups with no cueing and differing in complexity of structure (groups No Cue SS and No Cue CS) rats showed differences in performance during acquisition of the interleaved pattern on days 2-4, 6, 14-18, 20, 22-23, 26-31, 34, and 36 with rats in group No Cue SS making fewer errors than group No Cue CS initially but group No Cue CS acquiring the interleaved pattern with fewer errors after day 14. This was not predicted at the start of the experiment. When cueing was present (groups Cue SS and Cue CS) no differences were seen between groups for the entirety of the experiment.

In a comparison of the effect of cueing of groups on the interleaved subpattern with the simple structure interleaved pattern (groups No Cue SS and Cue SS) rats showed differences in performance during acquisition of the target subpattern on days 1-38, and 42 with rats in the cued group acquiring the pattern more quickly and with fewer errors than those in the no cued group. A comparison of the effect of cueing of groups with the complex structure interleaved pattern (groups No Cue CS and Cue CS) rats showed differences in performance during acquisition of the target subpattern on days 1-28, 30-
31, 33, and 37 with rats in the cued group once again acquiring the interleaved subpattern pattern more quickly and with fewer errors than those in the no cued group.

Planned comparisons of the interaction of cue and structure found differences in groups No Cue SS and Cue CS on days 1-38 with the cued complex condition acquiring the interleaved subpattern more effectively than the group with no cues. Differences were also found in a comparison of groups No Cue CS and Cue SS on days 1-22, 23-27, 30-31, 37, and 40 with once again the cued condition acquiring the interleaved subpattern more effectively than the group with no cues. Planned comparisons showed differences between Cue R and No Cue SS on days 1-15, 35-37, 39, 40-44, 46-48; No Cue CS on days 1-13, 18, 29, 31, 32, 34-44, and 46-48; Cue SS on days 2-48; and Cue CS on days 2-3, and 5-48.

Comparison of both target and interleaved subpattern acquisition was also analyzed for each group to determine any differences of acquisition between subpatterns. A subpattern x day (2 x 48) repeated measures ANOVA was conducted for groups No Cue SS, No Cue CS, Cue SS, Cue CS and Cue R. Once again, main effects and interactions were considered significant if \( p < .05 \). For all groups, rats made fewer errors and learned the interleaved subpattern faster than the target subpattern regardless of cueing, structure, or complexity of the pattern.

For group No Cue SS, a subpattern x day (2 x 48) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect for day, \( F(1, 47) = 59.37, p < .05 \). Comparisons of subpattern and subpattern x day interactions
resulted in a $p > .05$. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 2-9, 11-13, 16-24, 26-30, with the interleaved subpattern being acquired faster and with fewer errors as compared to the target subpattern.

For group No Cue CS, a subpattern x day (2 x 48) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect for subpattern $F(1, 47) = 6.71, p < .05$, and day, $F(1, 47) = 100.11, p < .05$. Comparisons of subpattern x day interactions resulted in a $p > .05$. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 7-27, 30, 32, 35-38, with the interleaved subpattern being acquired faster and with fewer errors as compared to the target subpattern.

For group Cue SS, a subpattern x day (2 x 48) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, $F(1, 47) = 37.29, p < .05$. Statistically significant main effects were also found for day, $F(1, 47) = 67.62, p < .05$, as well as a statistically significant subpattern x day interaction $F(47, 47) = 21.03, p < .05$. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-28, 31-35, 37-38, 40, 43, with the interleaved subpattern being acquired faster and with fewer errors as compared to the target subpattern.

For group Cue CS, a subpattern x day (2 x 48) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in
comparison between subpatterns, $F(1, 47) = 188.80, p < .05$. Statistically significant main effects were also found for day, $F(1, 47) = 113.44, p < .05$, as well as a statistically significant subpattern $\times$ day interaction $F(47, 47) = 29.46, p < .05$. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-48, with the interleaved subpattern being acquired faster and with fewer errors as compared to the target subpattern.

For group Cue R, a subpattern $\times$ day $(2 \times 70)$ repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, $F(1, 69) = 20.05, p < .05$. Statistically significant main effects were also found for day, $F(1, 69) = 40.74, p < .05$, as well as a statistically significant subpattern $\times$ day interaction $F(69, 69) = 19.06, p < .05$. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-40, 45, with the interleaved subpattern being acquired faster and with fewer errors as compared to the target subpattern.

_Trial $x$ Trial Analyses_

Trial $x$ trial analyses were conducted on the mean number of errors made on each individual element of the pattern throughout the experiment. To look for differences in acquisition between groups on elements within the pattern, a group $x$ element $(5 \times 12)$ ANOVA was conducted on rats’ trial–by-trial error response rates collapsed across all 48 days of acquisition of the experiment for the interleaved pattern. Main effects and interactions were considered significant if $p < .05$. 
Mean trial x trial error response rates for groups No Cue SS (A), No Cue CS (B),
Cue SS (C), Cue CS (D) and Cue R (E) over all 48 days of acquisition are shown in
Figure 7. Generally, the results replicated Experiment 1 such that when either the
structure or the cue is removed from the interleaved pattern, errors on the target
subpattern will increase. Cueing of the interleaved subpattern also results in low error
rates on the interleaved subpattern elements. Complexity of the interleaved subpattern
did not seem to have a lasting effect on the acquisition of the overall interleaved pattern.
The group X element (5 X 12) ANOVA indicated statistically significant main effects for
group, F(4, 11) = 13.02, p < .05, and element, F(4, 11) = 82.20, p < .05. A statistically
significant group x element interaction was also found F(11, 22) = 2.91, p < .05.

Planned comparisons of groups with no cueing and differing in complexity of
structure
(groups No Cue SS and No Cue CS) rats showed differences on serial positions 5 and 9,
which were elements 3 and 5 on the target subpattern. No Cue SS made fewer errors on
serial position 5 but No Cue CS made fewer errors on serial position 9, meaning that no
clear difference was seen between the groups. When cueing was present (groups Cue SS
and Cue CS) no differences were seen between groups for the entirety of the experiment.
Complexity of the structure of the target subpattern did not affect performance.
Figure 7: Mean trial x trial incorrect response rates for both the target and interleaved subpatterns in Experiment 2 for (A) No Cue SS, (B) No Cue CS, (C) Cue SS, (D) Cue CS and (E) Cue R subpattern averaged over 48 days of acquisition. The y-axis represents mean proportion errors and the x-axis represents pattern sequence elements.
In a comparison of the effect of cueing of groups with the simple structure interleaved pattern (groups No Cue SS and Cue SS) rats showed differences in performance during acquisition of the target subpattern on serial positions 7 and 9, which were elements 4 and 5 on the target subpattern with rats in the cued group making fewer errors than those in the no cued group. A comparison of the effect of cueing of groups with the complex structure interleaved pattern (groups No Cue CS and Cue CS) rats showed differences in performance during acquisition of the target subpattern on serial positions 3, 5, 7, 11, 12 which were elements 2, 3, 4, and 6 on the target subpattern and the final 8 on the interleaved subpattern. Rats in the cued group making fewer errors than those in the no cued group on both subpatterns. Overall, rats in the cued condition made fewer errors than rats in the non-cued condition, regardless of complexity of the interleaved subpattern.

Planned comparisons of the interaction of cue and structure found differences in groups No Cue SS and Cue CS on serial positions 7, 9, and 11, which were serial positions 4, 5, and 6 in the target subpattern. The cued complex condition made fewer errors than the group with no cues. Differences were also found in a comparison of groups No Cue CS and Cue SS on serial positions 3, 5, and 7, with once again the cued condition acquiring the target subpattern more effectively than the group with no cues.

Planned comparisons showed differences between Cue R and No Cue SS on serial positions 3, 7, 9, and 11; No Cue CS on serial positions 1, 7, 9, and 11; Cue SS on serial positions 1, 3, 5, 7, 9, and 11; Cue CS on serial positions 1, 3, 5, 7, 9, and 11. These
differences between group Cue R and the other structured groups indicates that the presence of the structured interleaved subpattern was integral for performance on the target subpattern, once again giving evidence that chunking may not be complete during the acquisition phase of the experiment.

Transfer of Interleaved Pattern

Analyses were also planned to determine whether performance on the target subpattern would be interrupted by altering the initial pathway and intra chamber cues. To test this, a group x day (4 x 2) repeated measures analysis of variance (ANOVA) was once again conducted on rats’ mean error response rates for each element type for the final day of acquisition and the initial day of transfer for both the target and interleaved subpattern across groups. Main effects and interactions were considered significant if \( p < .05 \).

In the analysis of target subpattern performance, a group x day (4 x 2) repeated measures ANOVA conducted on mean error rates revealed a trend towards a between group difference, but \( p > .05 \). Statistically significant main effects were found for day, \( F(3, 1) = 43.828, p < .05 \), but a group x day interaction was \( p > .05 \).

In the analysis of interleaved subpattern performance, a group x day (4 x 2) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, \( F(3, 1) = 20.15, p < .05 \). Statistically significant main effects were also found for day, \( F(3, 1) = 32.60, p < .05 \), as well as a statistically significant group x day interaction \( F(1, 3) = 8.1, p < .05 \). Planned
comparison based on the statistically significant group x day interaction demonstrated that groups No Cue CS and Cue CS differed between acquisition Day 70 and transfer Day 1, with errors increasing on transfer Day 1 for both groups.

To examine the entirety of the transfer, a group x day (4 x 6) repeated measures analysis of variances (ANOVA) was conducted on rats’ daily mean error response rates for each element type across the 6 days of transfer for both the target and interleaved subpattern across groups. Main effects and interactions were considered significant if \( p < .05 \).

Performance curves of the target subpattern for the transfer are shown in Figure 8 (A). In the analysis of target subpattern performance, a group x day (4 x 6) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, \( F(3, 5) = 7.99, p < .05 \). A statistically significant main effect was also found for day, \( F(3, 5) = 70.30, p < .05 \), as well as a statistically significant group x day interaction \( F(5, 15) = 2.41, p < .05 \).

Planned comparisons of groups with no cueing and differing in complexity of structure (groups No Cue SS and No Cue CS) rats showed differences in performance during transfer of the target subpattern on days 2 and 3 with rats in group No Cue CS making fewer errors than group No Cue SS on those days. When cueing was present (groups Cue SS and Cue CS) no differences were seen between groups for the entirety of the experiment.
In a comparison of the effect of cueing of groups with the simple structure interleaved pattern (groups No Cue SS and Cue SS) rats showed differences in performance during days 1-6 with rats in the cued group performing the target subpattern more quickly and with fewer errors than those in the no cued group. A comparison of the effect of cueing of groups with the complex structure interleaved pattern (groups No Cue CS and Cue CS) rats showed differences in performance on days 1-6 with rats in the cued group once again producing the target subpattern more quickly and with fewer errors than those in the no cued group.
Figure 8: Performance curves for transfer of the interleaved pattern in Experiment 2 for (A) the target subpattern and (B) the interleaved subpattern over 6 days of transfer. Daily mean errors were averaged across all elements of the pattern. The y-axis represents mean proportion errors and the x-axis represents combinations of errors seen over 48 pattern repetitions. Filled circles, open circles, filled triangles, open triangles, and filled squares represent groups No Cue SS, No Cue CS, Cue CS, and Cue SS respectively. Error bars: ± SEM.
Planned comparisons of the interaction of cue and structure found differences in groups No Cue SS and Cue CS on 1-6 with the cued complex condition producing the target subpattern more effectively than the group with no cues. Differences were also found in a comparison of groups No Cue CS and Cue SS on days 1-6.

Performance curves of the interleaved subpattern for the transfer are shown in Figure 8 (B). In the analysis of interleaved subpattern performance, a group x day (4 x 6) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between groups, $F(3, 5) = 50.60$, $p < .05$. A statistically significant main effect was also found for day, $F(3, 5) = 82.41$, $p < .05$, as well as a statistically significant group x day interaction $F(5, 15) = 19.72$, $p < .05$.

Planned comparisons of groups with no cueing and differing in complexity of structure (groups No Cue SS and No Cue CS) rats showed differences in performance during transfer of the interleaved pattern on days 3 and 5 with rats in group No Cue SS making fewer errors than group No Cue CS. A comparison of groups with cueing and differing complexity showed no difference during transfer.

In a comparison of the effect of cueing of groups on the interleaved subpattern with the simple structure interleaved pattern (groups No Cue SS and Cue SS) rats showed differences in performance during transfer of the interleaved subpattern on days 1-6 with rats in the cued group producing fewer errors than those in the no cued group. A comparison of the effect of cueing of groups with the complex structure interleaved pattern (groups No Cue CS and Cue CS) rats showed differences in performance during
transfer of the interleaved subpattern on days 1-6 with rats in the cued group producing fewer errors than those in the no cued group.

Planned comparisons of the interaction of cue and structure found differences in groups No Cue SS and Cue CS on days 1-6 with the cued complex condition producing the interleaved subpattern more effectively than the group with no cues. Differences were also found in a comparison of groups No Cue CS and Cue SS on days 1-6 with once again the cued condition acquiring the interleaved subpattern more effectively than the group with no cues.

Comparison of both target and interleaved subpattern performance was also analyzed for each group to determine any differences of performance between subpatterns. A subpattern x day (2 x 6) repeated measures ANOVA was conducted for groups No Cue SS, No Cue CS Cue SS, and Cue CS. For group No Cue SS, a subpattern x day (2 x 6) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect for day, $F(1, 5) = 78.76, p < .05$, analysis of subpattern and subpattern x day resulted in $p > .05$. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-5. Interleaved subpatterns were once again produced with fewer errors as compared to target subpatterns for all groups.

For group No Cue CS, a subpattern x day (2 x 6) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect for day, $F(1, 5) = 49.13, p < .05$, analysis of subpattern and subpattern x day resulted in $p > .05$. Planned comparisons of acquisition of target and interleaved subpattern showed
differences on days 3-6.

For group Cue SS, a subpattern x day (2 x 6) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, F(1, 5) = 63.97, p < .05. Statistically significant main effects were also found for day, F(1, 5) = 13.80, p < .05, as well as a statistically significant subpattern x day interaction F(5, 5) = 7.08, p < .05. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-6.

For group Cue CS, a subpattern x day (2 x 6) repeated measures ANOVA conducted on mean error rates revealed a statistically significant main effect in comparison between subpatterns, F(1, 5) = 215.4, p < .05. Statistically significant main effects were also found for day, F(1, 5) = 14.94, p < .05, as well as a statistically significant subpattern x day interaction F(5, 5) = 7.13, p < .05. Planned comparisons of acquisition of target and interleaved subpattern showed differences on days 1-6.

**Trial x Trial Analyses**

Trial x trial analyses were also conducted on the mean number of errors made on each individual element of the pattern throughout the transfer. A group X element (4 X 12) ANOVA was conducted on rats’ trial-by-trial error response rates collapsed across all 6 days of transfer for the interleaved pattern. Main effects and interactions were considered significant if p < .05.

Mean trial x trial error response rates for groups No Cue SS (A), No Cue CS (B), Cue SS (C), and Cue CS (D) over all 6 days of transfer are shown in Figure 9. Generally,
the results show major differences between the cue and no cue conditions, with some differences between the No Cue SS and No Cue CS groups near the end of the interleaved pattern. Groups were affected very differently based on cueing for a transfer that did not change the pattern. The group x element (4 X 12) ANOVA indicated statistically significant main effects for group, $F(3, 11) = 9.75, p < .05$ and element, $F(3, 11) = 21.60, p < .05$. A statistically significant group x element interaction was also found $F(11, 33) = 2.50, p < .05$.

Planned comparisons of groups with no cueing and differing in complexity of structure (groups No Cue SS and No Cue CS) rats showed differences on serial positions 9, 10, and 11 at the end of the interleaved pattern with group No Cue CS made fewer errors than No Cue SS. No differences were seen in a comparison of Cue SS and Cue CS. Groups differing in complexity thus were affected differently by the change in pathway and intra-chamber cues when no cueing occurred but were not as affected when cueing occurred.

In a comparison of the effect of cueing of groups with the simple structure interleaved pattern (groups No Cue SS and Cue SS) rats showed differences in performance in the interleaved pattern on serial positions 2-12 with rats in the cued group making fewer errors than those in the no cued group. A comparison of the effect of cueing of groups with the complex structure interleaved pattern (groups No Cue CS and Cue CS) rats showed differences in performance on serial positions 2-12 with once again rats in the cued group making fewer errors than those in the no cue group. Overall, rats in
the cued condition made fewer errors than rats in the non-cued condition, regardless of complexity of the interleaved subpattern.

Planned comparisons of the interaction of cue and structure found differences in groups No Cue SS and Cue CS on serial positions 2-12. The cued complex condition made fewer than the group with no cues. Differences were also found in a comparison of groups No Cue CS and Cue SS on serial positions 2, 4-12, with once again the cued condition producing the interleaved pattern more effectively than the no cue condition.
Figure 9: Mean trial x trial incorrect response rates for both the target and interleaved subpatterns in Experiment 2 for (A) No Cue SS, (B) No Cue CS, (C) Cue SS, and (D) Cue CS subpattern averaged over 6 days of transfer. The y-axis represents mean proportion errors and the x-axis represents pattern sequence elements.
Discussion

The overall goals of Experiment 2 were to: replicate findings of Experiment 1, to determine the role that cueing and structure complexity play in chunking and acquisition of the interleaved pattern, and to discover any other strategies that may be developed to acquire the interleaved pattern above and beyond that of chunking. Generally, the findings from Experiment 2 indicate that while rats are sensitive to the abstract and alternating rules that make up the interleaved pattern, other intra-chamber information can and will be incorporated with the cognitive strategy, producing a complex learning strategy.

Replication of Experiment 1 and Role of Cueing and Structural Complexity

In Experiment 1, rats were able to acquire the interleaved serial pattern within the 70 days of acquisition. Both cueing and structure affected acquisition so that removal of one manipulation (either cueing or structure) resulted in deficits in acquisition. Thus, group Cue S acquired the interleaved pattern faster and with fewer errors as compared to groups No Cue S and Cue R. Cueing and structure manipulations also affected subpatterns differently with structured groups acquiring the target subpattern faster than unstructured groups and cued groups acquiring the interleaved subpattern faster than no cue groups. Ultimately, although all groups demonstrated sensitivity to pattern structure and to the alternating nature of the interleaved subpatterns, only group Cue R demonstrated chunking during the transfer condition.
Rats in Experiment 2 demonstrated similar but not consistently identical findings when presented with these same conditions. All groups in Experiment 2 were able to acquire the interleaved pattern after 48 days of testing and once again excelled with the combination of cueing and structure manipulations with groups Cue SS and Cue CS acquiring the interleaved pattern faster than those groups whose manipulations did not include cueing/structure. Target subpattern acquisition was affected by both structure and cueing as cued and structured groups acquired the subpattern faster than no cue structured groups and structured groups acquired the target subpattern faster than the unstructured group, regardless of cueing. The new manipulation, the complexity of the structure of the interleaved subpattern had only a transitive difference in groups with no cueing (No Cue SS and No Cue CS) with differences leaning in favor of the No Cue SS group. Since differences between these two groups did not consistently favor the simpler structured interleaved subpattern, and since these effects do not appear in the cued condition, it is difficult to determine whether rats were affected by the complexity of the structure.

Differences in results between Experiments 1 and 2 were seen in the acquisition of the interleaved subpattern. In the prior experiment, while cueing and structure combined led to faster acquisition, rats in Cue R were able to acquire the pattern faster than rats No Cue S. In this current experiment, rats once again excelled when presented with a cued and structured pattern (regardless of complexity of subpattern), but this time rats in No Cue SS and No Cue CS ultimately acquired the interleaved subpattern faster than Cue R. Rats in group Cue R initially produced fewer errors. This may be another
indication that rats are sensitive to the structure of the interleaved pattern and were able to use that structure to acquire the pattern.

Overall comparisons of acquisition of the target and interleaved subpatterns in Experiment 1 resulted in faster acquisition of the interleaved subpattern as compared to the target subpattern, which was a replication of findings in Fountain et al. (1999). This result was once again replicated in Experiment 2, regardless of complexity of the interleaved subpattern.

In a comparison of errors made on pattern elements through trial x trial analysis, results once again demonstrate the importance of both cueing and structure as both cued and structured groups made fewer errors overall on each element as compared to groups with only one of these manipulations. An intriguing overall result indicates that most differences in performance occurred during the target subpattern regardless of cueing condition. For example, in a trial x trial comparison of groups No Cue SS and No Cue CS demonstrated differences (albeit inconsistent differences) on the target subpattern even though manipulations between the groups were primarily in the interleaved subpattern. One explanation for this may be that interleaved subpattern elements may have been used to predict the next response in the target subpattern, thus resulting in differences in performance on the target subpattern. Though, if this were the case, more consistent findings should have occurred between these two groups. Differences in target subpattern errors were primarily seen in all group comparisons regardless of cueing and
structure. Once again all groups made fewer errors on the pattern elements as compared to group Cue R.

**Strategies used in Interleaved Pattern Acquisition**

The other goal of this experiment was to determine other strategies rats were using to acquire an interleaved pattern. From Experiment 1, it was determined that while rats were able to cognitively chunk two interleaved subpatterns (group Cue R in transfer), this chunking strategy resulted in longer acquisition and did not actually include two structured interleaved patterns during acquisition. This group then is more akin to Experiment 1 of Fountain et al. (1999) and may thus be subjected to the same criticisms that rats were not per say experiencing a true interleaved pattern.

If rats are not completely chunking the interleaved subpatterns but are still able to acquire these subpatterns, then what possible strategies are they using to accomplish this task? To take a step forward in answering this question, rats in Experiment 2 participated in a very simple transfer task. Rats in all structured groups (group Cue R was not used in the transfer) were maintained on the same pattern manipulations but were put into chambers with a differing start location (spatial location 1 was on a different wall from the acquisition chamber) and a potential for different intra and extra chamber cueing. If rats had acquired the interleaved pattern using a cognitive strategy, then performance should remain constant regardless of the changes in spatial locations. If, on the other hand, rats were using a discriminative strategy along with a cognitive strategy that has already been demonstrated, then performance would be altered in transfer.
Results of the transfer condition show that a performance deficit does appear when rats were transferred to a new chamber, even when the already acquired pattern remained constant. Errors at the beginning of transfer increased but then were reduced after a few days into transfer. Rats in the cued conditions performed better than rats in the no cue conditions regardless of complexity of patterns and this can be seen in both performance curves and in trial x trial analysis. Two interesting results from the transfer of Experiment 2 are the comparison of performance on groups No Cue SS and No Cue CS and of trial x trial comparisons of cued groups versus no cued groups.

In a comparison of mean number of errors made during the transfer, group No Cue CS made fewer errors on the target subpattern as compared to group No Cue SS and differences were also seen on performance in the interleaved subpattern. This is inconsistent with errors seen during acquisition and may indicate that experiences learned in the complex interleaved subpattern resulted in different learning strategies or a different amount of retained information. Since finding between the No Cue SS and No Cue CS groups were inconsistent throughout Experiment 2, it is unclear what these differences in experiences may be.

Another interesting finding was the difference in trial x trial comparisons of cued and non-cued groups. Differences were seen in elements 2-12 for almost every group comparison between cued and non-cued groups with cued groups performing better on both the cued interleaved subpattern and the non-cued target subpattern. Rats in the cued conditions may have been relying on the cued elements as discriminative cues that not
only signaled the next correct interleaved subpattern element, but also the next correct target subpattern element as well.

A cued and memorized set of performance discriminations would then not be as affected by the transfer to the new chamber as compared to rats that were relying on a less cued pattern as was required by groups No Cue SS and No Cue CS. The lack of difference between the SS and CS manipulations in the cued groups is also telling that a movement strategy within the chamber was utilized in order to solve the problem of the interleaved pattern.
General Discussion

Experiment 1 was conducted to further explore evidence of chunking of two interleaved subpatterns as seen in Fountain et al. (1999). Rats were presented one target subpattern which remained constant across groups and one interleaved subpattern which was manipulated with cueing and structure. Acquisition and performance of the two subpatterns were compared across groups. The reasoning being that if rats were using a cognitive chunking strategy in order to acquire the interleaved pattern, then there should be differential acquisition of the subpatterns within groups but similar acquisition of the target subpattern between groups. Another prediction was that groups that were given manipulations that made chunking easier would excel over groups that did not have these same manipulations. A transfer of the interleaved subpattern was also incorporated to determine the extent of chunking. If rats had completely chunked the already acquired interleaved pattern, then a change in one pattern would not affect performance on the other pattern.

Generally, results from Experiment 1 indicated that rats, although sensitive to the structure of the interleaved pattern and the alternating set of rules, did not ultimately chunk the two interleaved subpatterns since transfer of the interleaved subpattern 787878 to 878787 not only affected performance on the interleaved subpattern, but also the target subpattern as well. This lack of complete chunking occurred in groups No Cue S and Cue S, both of which acquired a completely structured serial pattern. Chunking was evident in
group Cue R which acquired the interleaved pattern at the slowest rate in comparison of the three groups. When presented with the transfer, group Cue R performance on the target subpattern was not altered. This may be evidence of chunking and may mean that rats not given the extra cues are better at chunking simply because they have no other alternative.

One criticism to the evidence of chunking in group Cue R may potentially be that due to the random nature of the interleaved subpattern, rats in group Cue R may have instead utilized a different memory-based strategy to acquire the 6 responses in the target subpattern and thus did not actually acquire a rule-based pattern whatsoever. This would explain the slower acquisition and differential findings in the trial x trial analyses for acquisition.

Another criticism to the evidence of chunking in group Cue R may be that the group was not actually experiencing an interleaved pattern since the second interleaved subpattern was not actually made up of rule-based pattern. It may be that group Cue R instead was presented with a structured pattern 123456 surrounded by “noise” that the rats had to learn to ignore. Rats may have been acquiring the predictable elements of the structured pattern while using the random noise as a required observing response or response that triggers the next trial but is not predictive of any other responses or patterned rules. One counter to this criticism is the response errors evident on the interleaved subpattern. Although Cue R rats were presented with a cued random element, errors were still made during the interleaved subpattern as may be seen in the trial-by-trial analysis. If rats were learning to “ignore the noise” then simply responding to the
cued location would not result in errors at the interleaved subpattern element serial positions. Since these errors occurred, it may be that the rats were also attempting to gain a structure from the interleaved subpattern and were sensitive to the structure of the overall interleaved pattern.

From the results of Experiment 1, it was determined that although rats are able to chunk information in an interleaved pattern, they will use other information in order to acquire the pattern if that information is present. But what information are the rats using in order to acquire the interleaved pattern? Is the interleaved pattern being represented as one complex serial pattern and a purely cognitive strategy is being employed, or are rats using other discriminative cues in order to acquire and produce the interleaved pattern? Thus, the purpose of Experiment 2 was to determine the possible strategies employed by rats in an interleaved serial pattern learning task.

Rats were once again presented with an interleaved serial pattern with a constant target subpattern across groups and a manipulated interleaved subpattern. Groups were once again assigned interleaved subpatterns with structure and cueing manipulations, a new manipulation included was also the complexity of that structure. The reasoning for the complexity manipulation being that rats using a completely cognitive learning strategy presented with a complex or “violated” interleaved serial pattern would experience slower acquisition as compared to rats with a simple or “non-violated” interleaved serial pattern. Rats using other types of strategies would not be affected by
the complexity of the interleaved serial pattern and there would be no difference between
the SS groups and the CS groups.

A transfer manipulation was conducted after groups had acquired the interleaved
serial pattern in order to change the pathway and other possible discriminative cueing
occurring within the chamber. Rats were transferred to the next octagonal chamber (e.g.
rats in Chamber 1 transferred to Chamber 2…) so that the start position of the serial
pattern was changed along with any discriminative cues unintentionally present in the
octagonal chambers. Rats employing a purely cognitive strategy would not be affected as
the abstract cognitive rules would remain past removal of any other cues. If rats were
employing a more complex strategy, then any change in the pathway or chamber would
affect acquisition.

From the results of Experiment 2, a clear picture of interleaved pattern learning
strategy began to emerge. From acquisition of the interleaved serial pattern, groups No
Cue SS, Cue SS, and Cue R once again replicated findings from Experiment 1, but
groups No Cue CS and Cue CS did not behave in the predicted way. No differences were
seen between groups Cue SS and Cue CS for the entire experiment. While differences
were present between groups No Cue SS and No Cue CS, these differences were
transitive at best and did not consistently remain with group No Cue SS performing better
than group No Cue CS. Instead, rats in each group excelled during some points but not
others. This finding seems to indicate that rats were not affected by the complexity of the
interleaved subpattern and thus may not have been employing a purely cognitive learning
strategy. Instead, rats may have been employing a more complex learning strategy incorporating not only abstract cognitive rule-learning, but also using other cueing information present in the chambers.

This is also supported by findings from the transfer in Experiment 2. When rats were transferred to the next chamber and any possible discriminative stimuli were removed, performance on both the target and interleaved subpatterns were affected. Groups that did not receive a cueing manipulation were also more affected than those with a cued interleaved subpattern. This may mean that rats in the non-cued condition may have been more reliant on other non-predicted cues in order to solve the same interleaved pattern presented to the cued conditions.

Alternative Accounts for Interleaved Serial Pattern Acquisition

If rats are not exclusively employing a chunking strategy in order to acquire and produce an interleaved serial pattern, then what other possible strategies could explain how rats are able to perform this very complex task? Three possible explanations to be considered are the memorization of ordinal position, conditional discriminative learning and mediation of rule learning by a complex system of other environmental information. Each possibility will be explored in tandem with the results of the current experiments.

Ordinal Position Learning

One possible explanation of performance in rats presented with an interleaved serial pattern is the use of ordinal position as a memory strategy to recall unrelated items in a certain order (e.g. Chen, Swartz & Terrace, 1997). According to ordinal position
theory, rats not exclusively employing an abstract rule learning strategy may instead be memorizing a series of unrelated responses in order to receive reinforcement. In the current set of experiments, if using a serial position strategy, rats presented with the interleaved serial pattern 172837485768 would be required to memorize each successive response, linking them with their ordinal position, but not abstracting an overarching rule between the elements. Thus, rats would be required to memorize that spatial position 1 in Ordinal Position 1 is followed by 7 in Ordinal Position 2 which is followed by 2 in Ordinal Position 3, but rats would not be sensitive to the interleaved nature of the pattern, nor the N+1 rule making up the target subpattern or the alternating trill rule of the interleaved subpattern.

An example of ordinal position learning similar to the task currently used may be seen in Swartz and Himmanen (2002) where monkeys were trained to produce multiple lists of 4-items presented randomly on a screen. Monkeys were presented with lists of 2, 3, and then 4 items and were required to respond to the items in a serial order for reinforcement. An incorrect response immediately ended the trial and resulted in a time-out period for the animal. After the monkeys had successively mastered the 4-item lists, they were transferred to a new series of items in order to determine learning strategy.

The critical transfer involved the two top performing monkeys where the 4-item lists were mixed with either original ordinal position remaining consistent in the new list or being mixed. For example, a maintained list, or a list where original ordinal position of the items are maintained, may contain the first item A from list 2 (A2), second item B
from list 4 (B4), third item C from list 1 (C1), and the fourth item D from list 3 (D3), but these items stay in the same ordinal position as they were first experienced (A2→B4→C1→D3). A changed list, on the other hand, would not retain the original ordinal positions such that animals would experience the list (B3→A1→D4→C2). The two monkeys were presented with these lists demonstrated highly accurate performance with the maintained list but low accuracy for changed lists. Knowledge of, and sensitivity to, the original position may be considered more evidence for an ordinal position learning strategy.

Monkeys that were required to learn multiple lists of information and retain this information in reference memory demonstrated an ordinal position learning strategy. Since there is presence of many similarities between the current set of experiments and Swartz and Himmanen (2002), it may be possible that the rats were also employing an ordinal position learning strategy.

If the rats in the current experiments were employing an ordinal position strategy, then there should be sensitivity to the ordinal position so that any change in the position of a response in the list, such as seen in the interleaved subpattern transfer of Experiment 1, should affect all items in the list. Another sign of ordinal position learning is an extended acquisition period as memorization of a list is extremely taxing for the rat.

Evidence for the ordinal position learning strategy in the current set of experiments may be seen in the transfer of the interleaved pattern for groups No Cue S and Cue S (Figure 4(B) in Experiment 1 where rats had acquired a structured pattern.
which thus presented rats with elements in a stable ordinal position. Rats transferred from one ordered set of elements to a different order of elements suffered in performance at the beginning of transfer, making more errors not only on the transferred interleaved subpattern but also on the consistent target subpattern. This may indicate a sensitive to the ordinal position of all the elements so that changes for some elements in the order may have affected performance for all elements. One possible criticism to this argument comes from Swartz and Himmanen (2002) where monkeys faced with novel elements in a novel maintained list were able to acquire the series of pictures faster over a changed list. Seen in Figure 4 (A), rats in groups No Cue S and Cue S made more errors on the target subpattern transfer (which maintained ordinal position) compared to the interleaved subpattern transfer (which changed ordinal position). A possible explanation for the discrepancy of performance between the subpatterns may be conditional discrimination as discussed in the next section.

Evidence of ordinal position learning strategy may also be seen in the length of time required to acquire an interleaved pattern. As can be seen in Figure 2 for Experiment 1 and 6 for Experiment 2, acquisition of interleaved patterns takes an extremely long time with 2000-3000 repetitions of the interleaved pattern. Even in comparison to other hierarchically structured serial patterns (e.g. Fountain & Rowan, 1995a); interleaved patterns take a notoriously long time to acquire.

In Experiment 2, the absence of a difference between the cued simple and complex interleaved subpatterns (Figure 6 for acquisition curves, Figure 7, 8 and 9) may
also indicate the presence of a non-rule abstraction strategy. For both ordinal position learning and conditional discrimination theory, rats would not be sensitive to the complexity of the rule but would instead represent both the simple and complex structured lists as lists of arbitrary items to be memorized or interitem associations. Although it is unclear whether rats were employing an ordinal position strategy or conditional discrimination, it is clear that rats were not using a rule abstraction strategy for these interleaved patterns. If rats had been employing an abstract rule learning strategy, groups Cue SS and Cue CS should have acquired the interleaved pattern differently with the Cue SS group acquiring the interleaved pattern faster and with fewer errors as compared to group Cue CS. An ordinal position learning theory would predict the lack of difference between the two interleaved subpatterns because elements in an arbitrary list of items would have no overall meaning. Items would be memorized in the ordinal positions presented but no overlying abstract rule would predict (or not predict) the next item.

Although current findings do provide evidence which supports the ordinal position learning strategy, not all results are congruent with this theory. One result incongruent with the serial position theory is the differential rates of acquisition of the target and interleaved subpatterns. When comparing (A) and (B) in Figures 2 and 6, rats acquired the interleaved subpattern faster than the target subpattern in all conditions. In ordinal position learning, acquisition would be determined based on ordinal position in the list and not on subpattern. Rats using an ordinal position learning strategy should demonstrate similar rates of acquisition between the two subpatterns. Another
problematic finding appears in the results of the transfer for Experiment 2. Unlike the transfer from Experiment 1 which included a change in the interleaved subpattern, rats in Experiment 2 were not transferred to a different pattern but instead a different environment. Although rats were maintained on the same pattern with consistent ordinal positions, error rates increased on the target subpattern for all groups (see Figure 8 (A) and on the interleaved subpattern for groups No Cue SS and No Cue CS (see Figure 8 (B). As the ordinal position of these elements had not changed but performance did, rats may not be solely relying on an ordinal position learning strategy.

Performance by group Cue R in both Experiments 1 and 2 also may be presented as evidence against the ordinal position learning strategy due to the acquisition and retention of the target pattern even with random elements introduced into the interleaved pattern. Rats using an ordinal position learning strategy would be dependent on the ordinal position of the items, and thus may not have been able to learn this chaotic serial pattern as well as was seen in Cue R. The length of list should also be considered when approaching a serial position learning strategy as all items of the list must be maintained separately in memory. This means that rats were required to memorize and retain 12 individual items, which would be very taxing on memory if no other strategy was used. Although some findings do indicate a serial position learning strategy, the differential rates of acquisition between the subpatterns, the differential responding of Cue R and the length of the interleaved pattern suggests a different strategy above and beyond ordinal position learning.
Pairwise and Conditional Discrimination

First suggested by Hull (1943), discriminative learning posits that in order for an association to form between two (or sometimes more) responses, resulting in one response predicting or leading to the next response, reinforcement must occur between those two responses. According to the discriminative learning theory, a complex set of responses, such that is seen in an interleaved serial pattern task, may be explained by “interitem associations” or the previous response paired with reinforcement and not due to a cognitive learning strategy as was proposed in this set of experiments. The two types of discrimination learning considered were the more basic pair-wise discrimination learning theory which examines the association between two responses, and conditional discriminations which examines the association between multiple, perhaps configural, cueing which may allow for simplified acquisition of a complex task.

A model of associative learning for sequential behavior was first proposed by Capaldi (1967) and was later used as an explanation in regards to the sequential learning studies done by Hulse & Dorsky (1977). In this series of experiments, Hulse & Dorsky (1977) demonstrated that rats learned to anticipate the successive elements of a “simple” consistently decreasing pattern of food quantities faster than sequences with less structure. Rats presented with the consistently decreasing pattern of food amount 14-7-3-1-0 demonstrated consistently increasing run-time latency as compared to rats with a less structured pattern of 14-3-1-7-0. This, among other early studies was particularly strong evidence that rats presented with structured patterns were capable of abstracting rules
(Hulse & Dorsky, 1979; Fountain & Hulse, 1981). Capaldi & Molina (1979) argued in reaction to these early food quantity experiments that the distinctive quality of the food magnitude led to associations between the events and thus instead of rule abstraction, rats were using the event of being reinforced to predict the next likely event.

Although current serial pattern learning experiments no longer utilize food quantities but instead provide a uniform set of reinforcements for responses in a series of spatial locations, a similar associative argument could potentially still be considered. It is possible that reinforcement at one spatial location produces an association at the next correct location and thus rats are reflexively predicting the next correct response through the previous reinforcer.

For example, rats presented with the interleaved pattern 172837485768 would learn to produce the correct responses by a series of successive responses paired with reinforcement. The rats would be presented with the first trial, where the correct response is the spatial location 1. Once the rats had made this response reinforcement would be presented. This event of receiving reinforcement would be predictive of the correct response of spatial location 7 and thus the association between 1 and 7 has been created. These pairwise associations between all elements in the pattern would be the driving force behind what deceptively seems like complex executive functioning.

In consideration of a pairwise discriminative model of serial learning, one problematic issue arises. As the elements in the interleaved subpattern 7 and 8 are repeated in a trill structure, the act of making the response and the following reinforcers
creates a “branching” problem, or may be associated with multiple elements (Restle & Brown, 1970a, 1970b). Thus responding to spatial location 7 in this example pattern would lead to equal associations being made to spatial elements 2, 4, and 6 and responding to spatial location 8 would lead to equal associations being made to spatial elements 1, 3, and 5. In pairwise discrimination, rats would be unable to distinguish the next element for the target subpattern and should not have been able acquire the target subpattern. As all groups in both Experiments 1 and 2 were able to acquire this target subpattern, pairwise discrimination is considered unlikely as an explanation.

The problematic nature of pairwise discriminative learning leads to the consideration that associations may not be limited to a stimulus-response pair, but instead may create a configural cue of multiple-item associations paired with spatial chamber cueing. This may mean that rats are using an associative learning strategy in order to produce the interleaved pattern by using combinations of stimulus-response pairs to predict future responses. Although this type of associative learning solves any possible “branching” issues, the types of possible configural combinations for each element in the pattern becomes very large and thus specific conditional learning strategies become difficult to analyze.

For example, rats using a conditional discrimination strategy may pair the amount of reinforcement received at spatial location 8 with the next response so that one reinforcement will predict a response at 3, whereas two reinforcements will predict a response at 5. Rats instead may be pairing intra-chamber cueing with responses and reinforcement, or rats may be combining series of responses to predict the next response
so that reinforcement at 1-7-2-8- will lead to the next element 3. Conditional
discrimination, therefore, is a very complex strategy to demonstrate using behavioral
data.

One way to demonstrate a conditional discrimination learning strategy was used
in Fountain and Benson (2006) where errors in interleaved serial pattern learning were
presented that were inconsistent with a rule learning strategy. In Fountain and Benson
(2006), rats were presented with interleaved serial patterns with 0, 2, or 4 items which
violated the rules in one of the subpatterns. Overall, rats demonstrated both chunking and
rule-learning processes, as would be predicted from previous research. Interestingly, rats
also demonstrated conditional discrimination with multiple interitem associations in order
to produce the violating elements in the pattern. Since rats could still produce items that
violated the rule, it was apparent that they could concurrently use both cognitive and
associative strategies to produce the pattern. Since rule violating elements were not
included in Experiment 1, and only included in Experiment 2 in terms of a “complex”
subpattern, it becomes more challenging to analyze data for signs of conditional
discrimination. From data analysis, possible evidence of conditional discrimination may
be seen in the acquisition of simple and complex interleaved subpatterns in Experiment 2
and in the trial x trial analysis for the transfers in both Experiments 1 and 2.

As previously mentioned, rats in Experiment 2 did not differ in acquisition of
cued simple and complex interleaved subpatterns (Figure 6 for acquisition curves).
Although predicted by ordinal learning theory, this would also be predicted by
conditional discrimination learning theory as elements that maintained a predictable structure could potentially be predicted by a configural set of interitem cueing. Violations or complexity would not affect associative learning in the same way it would affect rule abstraction.

Evidence of conditional discrimination may also be seen in the transfer of Experiment 1. Rats in Experiment 1 were transferred from a 787878 interleaved subpattern to an 878787 subpattern. When groups with previous structured pattern experience, No Cue S and Cue S, were presented with this transfer, errors increased for the 123456 target subpattern. In the trial x trial analysis, it becomes apparent that more errors occurred during performance of the target subpattern as compared to the interleaved subpattern. In Figure 4, group No Cue S, which was most affected by the transfer of the interleaved serial pattern, made dramatically fewer errors on serial elements 2 and 12 (which are spatial elements 8 and 7 respectively). This is not predicted by rule learning theory as: 1. Group No Cue S had not previously experienced the transferred interleaved subpattern and did not have time to acquire the rule and 2. These decreases in errors did not stay consistent across the interleaved subpattern. Also discussed previously, ordinal position learning of these elements may be problematic as these specific elements did not maintain the same ordinal position and thus the rats would have needed to re-memorize the ordinal positions of these elements. Instead, these elements appear to be adjacent to the previous elements, meaning rats may have been using these interitem associations to make these specific responses.
Finally, evidence may also be seen in the transfer of Experiment 2 where rats were maintained on the same pattern but moved to a different environment and thus a different set of potential cues. When rats were presented with the same interleaved pattern but were transferred to a new chamber, performance initially decreased dramatically. This may be indicative of a dependency on intra-chamber cueing that may be considered associative in nature.

**Insights into Mediation of Pattern Learning**

As some evidence may be argued for rule learning, ordinal position, and discriminative learning strategies it may be that rats are utilizing a complex strategy which employed not only cognitive, rule-based learning, but also ordinal positioning of the items in the interleaved serial pattern and discriminative cueing that may have assisted in the difficult alternating nature of the interleaved serial pattern. Rats would be required to learn not only when to produce each rule-based pattern, but also what spatial and ordinal positions in order to produce the pattern. This would have resulted in a high taxation of working memory as rats were required to keep multiple pieces of information simultaneously. Although the strategy predicted was chunking of cognitive information in a way that would represent the interleaved serial pattern as two distinct subpatterns each with a distinct cognitive rule, it may be possible instead that while chunking was occurring, it may have been utilized to chunk multiple types of information above and beyond the abstract chunking initially suggested.
Rats may have instead been organizing multiple forms of cognitive, kinesthetic, spatial, and visual information in order to complete the task. When such information was not present (e.g. Cue R), rats would rely more heavily on other forms of information, but this change in strategy would result in slowed acquisition. Differences in performance between groups may have been the result of not only different representation of the interleaved serial pattern, but also the differential availability of other information.

One question that arises from these results is to what extent are rats using other information above and beyond the cognitive chunking strategy originally proposed. This topic was discussed in Muller and Fountain (2010) which explored the mediating factors in serial pattern learning in an octagonal chamber. In a series of three experiments, pattern learning strategy was examined in rats learning a 24-element serial pattern in an octagonal lever chamber akin to the octagonal nose-poke chamber used in this current set of experiments.

In this series of experiments, rats were initially required to learn a serial pattern with a violation to the rule placed in a part of the pattern. Rats were given information about either the serial position of the item in pattern, the spatial position (lever position), or both pieces of information. Rats that were presented with a combination of both serial and spatial information were able to acquire the violation error faster than groups with only one of the manipulations. Further manipulations in Experiments 2 and 3 also examined usage of a counting mechanism to determine a violation in ordinal position and
use of chunk boundaries in order to predict elements in the serial pattern, and rats were sensitive to both manipulations.

Ultimately, Muller and Fountain (2010) determined that although rats were sensitive to the pattern structure and had developed rules in order to learn a pattern, rats also incorporated other forms of information such as discriminative cueing, timing/counting of ordinal position, and item memorization in order to accurately produce the serial pattern. If rats are using multiple strategies in a structured serial pattern, it may be possible that some of these same strategies are also being employed during acquisition of an interleaved serial pattern.

Thus rats may be utilizing multiple partial strategies based on the information present during the manipulation. Evidence supports rule learning theory due to the differential acquisition of two rule-based subpatterns. A problem with rule-learning theory, though, may be seen in both transfers of Experiments 1 and 2 as performance is affected more strongly than would be predicted by rats employing an abstract rule learning strategy.

Evidence may also support the memorization of ordinal position. Rats acquired the interleaved serial pattern very slowly and rats were affected by the transfer in Experiment 1. Rats in Experiment 2 were also not affected by the complexity of the interleaved subpattern. All of these findings are predicted by ordinal learning theory. A complete ordinal position learning strategy was not evident, though, due to the differential rate of acquisition between the target and interleaved subpatterns and the
increase in errors seen in the transfer for Experiment 2, both of which was not predicted by ordinal position learning.

Finally, evidence may also support conditional discrimination based on results from the transfer of Experiment 2 where rats’ performance was negatively affected on an identical interleaved serial pattern task when placed into a new chamber. The problem with conditional discrimination is once again the differential rate of acquisition between the target and interleaved subpatterns, which would not be predicted by conditional discrimination.

Conclusions

The overall goal of the current studies was to create a clearer picture of cognitive strategies used in complex interleaved serial pattern learning and the factors controlling behavior in an octagonal SMC task. The evidence collected indicates that rats are sensitive to the structure of the interleaved serial subpatterns, and are thus employing a cognitive rule-abstraction strategy in order to solve the interleaved serial pattern. This rule-abstraction, though, is also mediated by other information such as ordinal position and discriminative cueing learning strategies.
References


