Formal structure and pattern length in serial pattern learning by rats

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When rats learn to anticipate a sequence of stimulus events, such as a serial pattern of different food quantities, they are sensitive to the rule-based formal structure relating the magnitude of successive stimuli. Earlier research has shown that if formal structure is simple (e.g., if a single "less than" rule relates the size of each successive quantity), patterns are learned faster than if formal structure is complex (e.g., if two or more rules such as "less than" and "greater than" relate successive pattern quantities). Two experiments tested the hypothesis that pattern length modulates the role of pattern complexity. We predicted that pattern length and pattern complexity interact in determining pattern difficulty. That is to say, long complex patterns should be learned more slowly than short complex patterns. However, long simple patterns should be learned faster than short simple patterns. In Experiment 1, rats ran a straight runway to receive repeated sequences of food quantities. The long-monotonic group received a formally simple 18-10-6-3-1-0 pattern, in which each number represents a quantity of food pellets. The long-nonmonotonic group received a formally complex 10-1-3-6-18-0 pattern. Similarly, the short-monotonic and short-nonmonotonic groups received 18-1-0 and 1-18-0 patterns. Pattern tracking—fast and slow running in anticipation of large and small quantities of food, respectively—was taken as an index of pattern learning. In Experiment 2, comparable patterns were used, but rats leverpressed in a discrete-trial procedure; response latencies measured pattern tracking. In both experiments, rats learned formally simple patterns faster than they did formally complex patterns. In Experiments 1 and 2, but less clearly in Experiment 2, the predicted interaction was obtained. The results support and generalize the idea that rats encode and use some representation of the formal rule structure of serial patterns as they learn them.

Until recently, theoretical accounts of serial learning in animals were expressed in terms of stimulus-response chains or other associative processes (Hull, 1931; Skinner, 1934). In a recent series of studies, cognitive theory for serial pattern learning has been applied for the first time to study how nonhuman animals such as rats respond to stimuli arranged in sequential order. In the earliest of these studies, Hulse and Dorsky (1977) demonstrated that rats, like people, found formally complex patterns harder to learn than formally simple patterns. Later work has shown further functional parallels between rats and humans. For example, rats generalize a simple rule structure from one set of pattern elements to another, applying a previously learned rule to facilitate learning a similar but new pattern (Hulse &

Dorsky, 1979). Similarly, rats can extrapolate a well-learned, formally simple rule to extend a sequence and anticipate a novel pattern element (Fountain & Hulse, 1981). In the present research, we continue to explore pattern learning in rats by studying sequences that vary in length and formal complexity. In this case, we are unaware of any direct counterpart to the work in the literature based on human subjects.

One prediction that emerges from a cognitive, rule-learning hypothesis of rat serial learning is that the formal complexity of serial patterns and their length ought to interact to determine pattern difficulty. If patterns are formally simple, for example, are described by a single rule, then a long pattern should be easier to learn and remember than a short pattern; the learner experiences more instances of the pattern's single rule with each repetition of a long pattern, and this, in turn, should lead to more efficient encoding of the pattern's overall formal structure. If patterns are formally complex, requiring relatively more rules for an adequate formal description, however, then long patterns should be more difficult to learn than short ones. Without any consistent rule to relate neighboring elements, the learner is reduced to memorizing a list of pattern

Portions of this article are based on a dissertation submitted in partial fulfillment of the requirements for the PhD degree by S. B. Fountain. Preparation of this article was supported by National Science Foundation Research Grant BNS 8014137 to S. H. Hulse and National Institutes of Health Research Service Award MH 08759 from the National Institute of Mental Health to S. B. Fountain. Requests for reprints should be sent to Stephen B. Fountain, Department of Environmental Health Sciences, Division of Toxicology, The Johns Hopkins University, 615 North Wolfe Street, Baltimore, Maryland 21205.

elements, element by element, and pattern difficulty should grow rapidly with the length of the list. Finally, of course, an interaction between length and complexity implies that formally simple patterns should be easier to learn than formally complex patterns—as a great deal of research with both human and animal subjects has shown (Hulse, 1978; Hulse & Dorsky, 1977, 1979).

In Experiment 1, we tested for the predicted interaction between pattern length and pattern complexity by training rats to run to sequences of different food quantities in a straight runway. Rats in a long-monotonic (LM) condition learned a formally simple 18-10-6-3-1-0 pattern of food pellets, and rats in a long-nonmonotonic (LN) condition learned a formally complex 10-1-3-6-18-0 pattern. Rats in a short-monotonic (SM) condition learned an 18-1-0 pattern, and those in a short-nonmonotonic (SN) condition learned a 1-18-0 pattern. The development of pattern *tracking*—running rapidly and slowly in anticipation of large and small quantities of food, respectively—was used as an index of pattern learning. Note that the long and short patterns contained equivalent amounts of food, whereas the two monotonic and nonmonotonic patterns, respectively, ended with a 1-0 and an 18-0 sequence. For the long patterns, we predicted that the formally simple monotonic pattern would be learned with greater facility than the formally complex nonmonotonic pattern. For the short patterns, we predicted the same result.

EXPERIMENT 1

Method

Subjects. The subjects were 32 naive female albino rats obtained from ARS/Sprague-Dawley, Inc., Madison, Wisconsin, at approximately 90 days of age. The rats were housed in individual cages and maintained at 85% of ad-lib weight throughout the experiment.

Apparatus. A straight enclosed runway, identical to that used by Hulse and Dorsky (1977), served as the apparatus. The runway was 92 cm long, with a 30-cm startbox and a 30-cm goal area separated from the runway by guillotine doors. The goal area included an 11-cm niche at a right angle to the runway. The niche contained a food cup (5 cm in diameter) fastened to the floor. The inside width of the runway and the niche was 10 cm, and the inside height was 11 cm. The start and goal areas were covered with hardware cloth. The apparatus was painted flat black, except for the start area, which was natural wood color. A timer started when the startbox door was raised and stopped when the rat activated a contact relay by bridging a gap between two metal plates located 20 cm into the goal area. Food reinforcement consisted of an appropriate number of 45-mg Noyes food pellets. A wooden holding cage (23 × 30 × 24 cm) with a hardware-cloth floor and a hinged Plexiglas lid housed rats between runs of the pattern.

Procedure. All rats received the same treatment for 5 days prior to the beginning of the experiment. The rats were tamed by being handled approximately 10-20 min each day and were reduced to 85% of normal ad-lib weight during this period. Exploration of the apparatus was allowed on the 2 days prior to experimental testing. On the 1st day of exploration, both guillotine doors

were open and individual animals were allowed to run through the apparatus for 10 min to obtain six food pellets scattered at random. On the 2nd day, both guillotine doors were open, and, during a 5-min exploration period, the rats could eat five food pellets from the cup. This procedure was repeated once, with the rats being returned to their home cages for a 15-sec interval between exploration periods.

On the day following exploration, the experiment proper began. The rats were randomly assigned to four conditions ($n=8$). The SM group received repetitions of a three-element pattern of 18-1-0 food pellets, while the SN group received repetitions of a 1-18-0 pattern of food quantities. Similarly, a LM and a LN group received repetitions of patterns containing, respectively, 18-10-6-3-1-0 and 10-1-3-6-18-0 food pellets.

Testing lasted for 15 days. The rats received two pattern repetitions on Days 1 and 2, three pattern repetitions on Day 3, and four pattern repetitions on Days 4 through 15. A pattern repetition began when the first rat was placed in the startbox of the runway. A "run" to the appropriate quantity began when the startbox and goalbox doors opened. The run ended when the rat entered the goal area and stopped the timer or when a nonresponse criterion of 120 sec had elapsed without the rat's entering the goal area. Goalbox confinement lasted until all the food had been eaten or, in the case of the 0-pellet quantity, for 20 sec. If the nonresponse time elapsed, the rat was removed immediately from the runway and placed in the holding cage to await the next run. Runs continued in this fashion until all the quantities of a given pattern repetition had been obtained. The rat was then returned to its home cage for a period of 10 to 15 min to await the next pattern repetition. During this interval, other rats were tested. Water was freely available in the home cage, but not in the holding cage.

Running times, the amounts of time required for the rats to run from the startbox to the goalbox, were recorded to the nearest 0.1 sec. A 120-sec running time was recorded for runs in which the rat met the nonresponse criterion.

Results

The rats in all conditions learned to track their serial patterns, running fast to large quantities and slowly to small ones, especially the 0-pellet quantity. As an index of the relative rate of learning to track, running times on 0-pellet runs were compared with running times on 18-pellet runs for each day, and for each group the 1st day on which running times for these two quantities were significantly different was determined. The results indicated that the formally simple monotonic patterns were learned in fewer trials than were the formally complex non-monotonic patterns. Both the LM and SM conditions generated reliable tracking by Day 3. The SN condition failed to generate reliable tracking until Day 10, and the LN condition failed to do so until Day 12. Thus, as measured by the training required to first generate tracking, the predicted interaction between pattern length and pattern complexity was obtained in that (1) LM and SM patterns were learned in fewer trials than were LN and SN patterns, and (2) SN patterns were learned in somewhat fewer trials than LN patterns. The prediction that LM patterns would be learned faster than SM patterns was confirmed in the limited sense that the rats in the LM condition learned to track a six-element pattern just as fast as the rats in the SM

condition learned to track a three-element pattern. Learning, as measured by the trials-to-begin-tracking index, was so rapid in both instances, however, that ceiling effects may have precluded demonstration of the predicted result.

Figure 1 illustrates the magnitude of tracking, as measured by the mean running-time latencies for the several quantities for Day 5, the 1st day in which rats in the LM condition tracked reliably better than rats in other conditions. Planned comparisons showed that rats in the LM condition ran reliably slower to the 0-pellet quantity than to any other quantity of their pattern ($p < .05$). They also ran reliably slower to the 0-pellet quantity than rats in other conditions ran to any quantity ($p < .05$). In particular, running times to 0 pellets were longer in the LM than in the SM condition. Furthermore, rats in the SM condition ran slower to 0 pellets than rats in other conditions ran to any quantity ($p < .05$). Although rats in the SN condition learned to track reliably on an earlier day (Day 10) than those in the LN condition (Day 12), this fact is not reflected in the running-time data shown in Figure 1 for Day 5; at that time the SN and LN conditions generated about the same running times. As measured by latency differences among the quantities on Day 5, then, the predicted interaction appeared, in that the LM pattern produced better tracking than either the SM or the LN pattern.

Figure 2 shows latencies for the several food quantities averaged over the last 3 days of the experiment. By this time, the rats in all conditions tracked their patterns, as measured by slow running to 0 pellets, but those in the LM group slowed their running

Figure 1. Mean running times to the several food quantities on Day 5 of Experiment 1. On each trial, the rats received the food quantities in the order indicated on the abscissa. The group designations are, respectively, long monotonic (LM), short monotonic (SM), long nonmonotonic (LN), and short nonmonotonic (SN).

Figure 2. Mean running times to the several food quantities over the last 3 days of Experiment 1. On each trial, the rats received the food quantities in the order indicated on the abscissa. The group designations are, respectively, long monotonic (LM), short monotonic (SM), long nonmonotonic (LN), and short nonmonotonic (SN).

times to 0 pellets more than did rats in any other group ($p < .05$). There was no indication of a difference between the SN, LN, and SM groups, however; all other differences between and within groups were not significant ($p > .05$). By the end of the experiment, the predicted interaction between pattern length and complexity appeared primarily in the long-pattern conditions. There was no indication of relative superiority between the short patterns.

The reliability of the foregoing results was assessed by planned comparisons on the rats' daily mean running times for 18- and 0-pellet runs over the 15 days of the experiment. Planned comparisons were computed using the appropriate error term from a two-way analysis of variance on the same data. The analysis of variance showed significant main effects for pattern complexity [$F(1,28)=9.08$, $p < .01$], days [$F(14,392)=4.10$, $p < .01$], and quantities [$F(1,28)=96.46$, $p < .01$]. Significant two-way interactions included pattern length $\times$ pattern complexity [$F(1,28)=7.67$, $p < .01$], pattern length $\times$ quantities [$F(1,28)=5.15$, $p < .01$], pattern complexity $\times$ days [$F(14,392)=2.09$, $p < .05$], pattern complexity $\times$ quantities [$F(1,28)=34.53$, $p < .01$], and days $\times$ quantities [$F(14,392)=7.84$, $p < .01$]. Higher order interactions that were reliable included pattern length $\times$ pattern complexity $\times$ quantities [$F(1,28)=7.96$, $p < .01$] and pattern length $\times$ pattern complexity $\times$ days $\times$ quantities [$F(14,392)=2.86$, $p < .01$]. Planned comparisons in addition to those already mentioned revealed that the rats in all conditions tracked their patterns reliably each day following the 1st day of tracking ($ps < .05$). In

addition, the rats in the LM group ran reliably slower to the 0-pellet quantity than did the rats in any other condition from Day 5 until the end of the experiment. Running times to 0 pellets for the rats in the SM condition were slower than those for the rats in both the SN and LN conditions until Day 7, and the SN group ran reliably slower to 0 pellets than did the LN group on Days 10, 11, and 15 ($p < .05$).

Discussion

The results of Experiment 1 confirm the prediction that pattern length and pattern complexity interact in determining the facility with which rats learn to track serial patterns of food quantities. The rats in the formally simple LM and SM conditions tracked their patterns reliably sooner than did the rats in the formally complex LN and SN conditions, and the rats in the LM condition tracked their pattern with reliably longer running times to 0 pellets than did the rats in any other condition from Day 5 until the end of the experiment. There was good evidence that the rats in the LM condition tracked better than did the rats in the SM condition. Finally, the rats in the LN condition were slower to learn their pattern than were the rats in any other group. Although the rats in all conditions showed little or no differentiation of running times to food quantities other than 0 pellets, the results do not suggest that the 0-pellet quantity is somehow qualitatively unique as a pattern element. Hulse and Dorsky (1979), for example, showed that rats learned monotonic patterns reliably faster than they did nonmonotonic patterns when the patterns ended in a 1-pellet quantity, just as they did when the patterns ended in a 0-pellet quantity. The latter result, then, supports the contention that the 0-pellet quantity is perceived as part of an ordered *alphabet* (Hulse & O'Leary, 1982; Jones, 1974) of food quantities, not as an event qualitatively different from food quantity stimuli.

EXPERIMENT 2

Experiment 2 examined the generality of the results of Experiment 1 and earlier work. The rats were tested in an operant chamber with a discrete-trial procedure that required that they make a single leverpress to obtain each of a series of food quantities. The latency to leverpress was measured for each quantity, and the difference in latency between the largest and smallest quantity was taken as an index of pattern tracking.

The experiment incorporated two short, four-quantity patterns and three long, six-quantity patterns. Within each pattern length, formal pattern structure was either simple or complex. As in the previous experiment, we predicted an interaction between pattern length and pattern complexity.

Formally simple patterns should become easier to learn as pattern length increases, and formally complex patterns should become more difficult. The easiest pattern to learn should be the LM pattern, and the most difficult should be the LN pattern.

Method

Subjects. The subjects were 40 naive female albino rats obtained from ARS/Sprague-Dawley, Inc., Madison, Wisconsin, at approximately 90-100 days of age. The rats were housed in individual cages and maintained at 85% of ad-lib weight throughout the experiment.

Apparatus. Scientific Prototype, Inc., operant boxes ($23.5 \times 21.5 \times 19.5$ cm) served as test chambers. The boxes were composed of metal end walls, Plexiglas side walls, and a floor made from stainless steel rods (0.3 cm in diameter) spaced 1.0 cm apart. One end wall was equipped with a Lehigh Valley Electronics, Inc., retractable level mounted 4.0 cm above the floor and 2.0 cm from the front side wall. A brass food cup was mounted on the opposite wall 2.0 cm above the floor. A Gerbrands feeder (Model D-1) delivered 45-mg food pellets to the food cup. The operant box and associated equipment were enclosed in a BRS/Foringer sound-attenuating hull ($90 \times 45 \times 60$ cm). A houselight (7.5 W) was centered on the ceiling of the hull, and two speakers produced white noise (approximately 80 dB SPL) from above and behind the wall on which the lever was mounted. The experiment was controlled from an adjoining room by a Digital Equipment Corporation PDP-8 minicomputer system.

Procedure. Each day, rats in five conditions received repetitions of patterns composed of successive quantities of food that were always presented in the same sequential order. The animals in the LM condition received an 18-10-6-3-1-0 sequence of quantities, in which successive quantities were delivered on successive trials of the pattern repetition. That is, a leverpress on the first trial of a pattern repetition produced 18 food pellets, a leverpress on the second trial produced 10 pellets, and so on through the 6 trials of a pattern repetition. Similarly, the rats in one LN (LN-10-0) condition received an 18-1-3-6-10-0 pattern of food quantities, and the animals in a second LN (LN-1-0) condition received an 18-3-6-10-1-0 pattern of food quantities. The two LN conditions were included to test for the effects of large (10 vs. 0) as compared with small (1 vs. 0) stimulus contrast in the last two elements of the pattern. The rats in two other conditions received shorter, four-element patterns. The SM condition received an 18-10-1-0 pattern, and a SN condition received an 18-1-10-0 pattern.

For 7 days prior to testing in the apparatus, the rats were tamed by daily handling and reduced to 85% of ad-lib weight. On the following 2 days, the rats explored the operant chamber. For the 1st day of exploration, each rat was placed in the chamber for 15 min. The houselight was on, and one food pellet was available in the food cup. On the 2nd day, each rat was placed in a dark chamber, and then the houselight was turned on. One food pellet was delivered automatically to the food cup after each minute of the 15-min session.

Two days of leverpress training followed the exploration phase. On the 1st day, the rats were shaped to leverpress using a discrete-trial, continuous-reinforcement procedure. The rats were placed in the darkened chamber to await the first trial, which began when the houselight was turned on for 10 sec, off for 1 sec, and then on again. Four seconds after the 1-sec light-out period, the lever was inserted into the chamber to remain until (1) the rat had pressed the lever, (2) the experimenter had reinforced an approximation of a leverpress, or (3) 20 sec had elapsed. A leverpress resulted in the delivery of one food pellet. A 15-sec intertrial interval began when the lever was withdrawn. The beginning of the next trial was signaled by a 1-sec light-out period that occurred 4 sec before the lever was inserted into the chamber. The rats received 150 trials (including those in which

leverpresses were shaped by the experimenter) on the 1st day of leverpress training. On the 2nd day, the same procedure was used, except that all rewards were obtained by leverpresses. To continue in the experiment, the rats were required to respond within 20 sec on 100 of 150 trials on this day. No rat failed to meet this requirement.

The experiment proper began on the day following leverpress training and lasted for 21 days. Each day, the rats were placed in the dark operant chamber before testing was begun. For each trial, a pretrial interval was arranged so that the house-light was on for 10 sec, off for 1 sec, and on again for 4 sec just before the lever was inserted into the testing chamber and became available for responding. The light remained on until the next trial. The first leverpress or the elapse of 20 sec without a response terminated the trial. A leverpress resulted in the immediate delivery of the appropriate quantity of food and the removal of the lever from the operant box. Food pellets were dispensed into the food cup at a rate of 1/150 msec. Following a response, the houselight remained on during time allotted for the rats to eat the food reward before the intertrial interval began. This procedure paralleled that of Experiment 1 and earlier studies, in which rats were allowed to remain in the goalbox of the maze until all food had been consumed. For a reward of 18 pellets, the rats were allowed 105 sec, for 10 pellets, they were allowed 75 sec, for 6 pellets, 30 sec, for 3 pellets, 15 sec, for 1 pellet, 5 sec, and for no reward (the 0-pellet quantity), 20 sec. These times had been shown to be sufficient by pilot work, and they paralleled those allowed for food consumption in Experiment 1. If a period of 20 sec elapsed without a response, the lever was retracted from the box, and the next 15-sec pretrial interval followed. The houselight was extinguished for a 5-min time-out between pattern repetitions. All animals received four repetitions of their respective patterns each day, throughout the experiment. Following testing, the rats were removed from the darkened chamber and returned to their home cages.

Response latency, the amount of time elapsing between the insertion of the lever and the first leverpress, was recorded to the nearest 0.01 sec for each trial. A 20-sec response latency was recorded for trials in which no response occurred.

Results

As in the previous experiment, the rats in all groups learned to track their serial patterns, responding rapidly on 18-pellet trials and responding slowly, or not at all, on 0-pellet trials. The relative rate of pattern learning differed among groups, as indicated by the day on which reliable tracking first occurred. The day of onset of reliable tracking was determined for each group by conducting planned comparisons on daily mean response latencies for all quantities over the 21 days of the experiment. Using this index, the LM group first tracked reliably ($p < .05$) on Day 9, the SM group on Day 10, the SN group on Day 12, and both LN groups on Day 14. Once they had begun tracking, all groups continued to do so reliably until the end of the experiment, with the exception of Group LN-1-0, which failed to track reliably on Days 15, 16, and 17. Group differences were in the direction of the predicted interaction between pattern length and complexity—the LM pattern was learned in fewer days than was the SM pattern, and both the LN patterns were learned later than was the SN pattern. However, the 5-day span in the onset of

tracking for the several groups was not particularly striking.

To assess matters further, we analyzed the data, taken alone, for Day 9—the 1st day on which reliable tracking appeared for any group. Figure 3 shows mean response latencies for each quantity for all conditions. The figure indicates that the monotonic patterns generated better tracking as measured by latencies to 0 pellets than did the non-monotonic patterns, which showed little difference in latency to any quantity. Furthermore, there was a suggestion that latencies to 0 pellets were longer for the LM group than for the SM group. Two analyses of variance were performed on the response latencies to 0 pellets on Day 9. Both analyses included data from the LM, SM, and SN groups; one analysis included data from the LN-10-0 condition, and the other included data from the LN-1-0 condition. The analysis that included the LN-10-0 group revealed a reliable main effect for pattern complexity [$F(1,28) = 7.90$, $p < .01$]. The analysis that included the LN-1-0 group also revealed a reliable main effect for pattern complexity [$F(1,28) = 10.42$, $p < .01$]. No other effect in either analysis was significant ($p > .05$).

Halfway through the experiment, then, there was a reliable indication that formally simple patterns were easier to learn than were formally complex patterns. However, there was no reliable indication that pattern complexity interacted with pattern length.

Figure 3. Mean running times to the several food quantities on Day 9 of Experiment 2. On each trial, the rats received the food quantities in the order indicated on the abscissa. The group designations are, respectively, long monotonic (LM), short monotonic (SM), short nonmonotonic (SN), long nonmonotonic ending with a 10-0 pair (LN-10-0), and long nonmonotonic ending with a 1-0 pair (LN-1-0).

By the end of the experiment, all groups tracked with about the same level of proficiency. Planned comparisons on the data of Day 21 showed that the rats in all conditions responded reliably slower on 0-pellet than on 18-pellet trials. Analyses of variance such as those used on the data for Day 9, however, revealed no significant effects for pattern complexity, pattern length, or the interaction between the two variables ($p > .05$).

Discussion

The results of Experiment 2 parallel those of Experiment 1 in that there was good evidence that formally simple patterns were easier to learn, as indexed by pattern tracking, than were formally complex patterns. This result is important because it demonstrates, with new procedures and in an entirely new experimental situation, a familiar and well-documented result that has proved to be a basic demonstration of the capacity for serial pattern learning in rats (e.g., Hulse & Dorsky, 1977, 1979). Furthermore, as indexed by the amount of training required to first generate reliable tracking, the predicted interaction between pattern length and pattern complexity was obtained: LM and SM patterns were learned in fewer trials than were LN and SN patterns, and SN patterns were learned in somewhat fewer trials than were LN patterns. This latter conclusion must be hedged, however, due to our failure to detect a reliable interaction of pattern complexity and pattern length through the analysis of variance.

There are several possible reasons why we failed to obtain a robust demonstration of the predicted interaction. First, our hypothesis may have been in error; this seems unlikely in the most general case, because we obtained the predicted interaction in Experiment 1. Second, the short patterns of Experiment 2 were four elements long instead of three elements long, as they had been in Experiment 1. As Hulse (1980) remarked earlier, there is a priori reason to believe that the effects of pattern length should increase rapidly as patterns grow, given the rapid increase in the number of elements to be ordered sequentially. Perhaps, assuming the validity of comparing data across Experiments 1 and 2, the difference between patterns three and four elements long marks a threshold value for "short" as compared with "long" patterns.

GENERAL DISCUSSION

Both experiments showed a major feature of serial pattern learning that has been demonstrated repeatedly in rats: response latencies were longer to small (especially 0-pellet) than to large food quantities (rats tracked the patterns), and formally simple patterns were easier to learn than were formally complex patterns (Hulse & Dorsky, 1977, 1979;

Hulse & O'Leary, 1982). In addition, both Experiments 1 and 2 showed the predicted interaction between pattern length and pattern complexity, although the effect in Experiment 2 was much less robust. In Experiment 1, the effects were clear: the rats that received formally simple long patterns anticipated 0 pellets better than did the rats that received short patterns, and the rats that received formally complex short patterns learned their patterns faster than did the rats that received long patterns.

The data from both experiments also suggest that, even for short patterns, rats opted for a rule-learning strategy to learn and remember the formally simple patterns. The rats in the SM conditions tracked sooner than did those in the SN conditions, although differences in running times to all quantities were about the same by the end of the experiment. This being the case, however, we hedge the proposition that rule-learning strategies will always be adopted in learning short serial patterns (cf. Hulse, 1980). Capaldi and Molina (1979)—although they used rather different experimental conditions—found that rats tracked a three-element nonmonotonic pattern better than they did a three-element monotonic pattern, in the sense that differences in response speeds to large as compared with small quantities were greater at the end of their experiment. Their data were therefore in line with the associative, memory-of-prior-reward theory they proposed. Very short patterns provide an ambiguous case with respect to the general prediction that formally simple patterns will be easier to learn than will formally complex patterns. In the case of the formally simple pattern 18-1-0, as compared with the formally complex pattern 1-18-0, for example, it is uncertain whether the single "less than" rule of the formally simple pattern affords any appreciable (or measurable) simplification of the pattern as compared with learning the pair of associations 18-1 and 1-0 and putting them together in an associative chain. The ultimate strategy chosen, then, might well depend upon the relative discriminability of the successive stimuli, relevant past experience, and a host of other factors (Hulse, 1980).

Our results add to the growing body of literature that indicates a functional similarity between rat and human serial pattern learning. Rats, like people, find formally simple patterns easier to learn than formally complex patterns (Hulse, 1978; Hulse & Dorsky, 1977, 1979), extrapolate patterns to anticipate a new element implied by a pattern's formal structure (Fountain & Hulse, 1981), generalize a rule from one set of pattern elements to a new set (Hulse & Dorsky, 1979), and so on. In the present case, we have shown, for rats, an interaction between pattern length and pattern complexity predicted by a cognitive rule-learning view of serial pattern learning, an effect not yet demonstrated

with human subjects. It is encouraging that a rule-learning model can produce novel and testable hypotheses about rat serial pattern learning rather than merely suggesting replications of effects well established for humans.

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(Manuscript received July 1, 1982;
revision accepted for publication February 2, 1983.)