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Rats abstract rules from a response series lacking a consistent motor pattern

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ABSTRACT

Two experiments examined whether rats could learn a rule-based response sequence when prevented from performing a consistent motor pattern. In a serial multiple-choice procedure, rats chose from an 8-lever array mounted on the walls of an octagonal operant chamber. In Experiment 1, rats learned to choose levers in proper order according to one of two patterns, a structured pattern, 1-2-3-4-5-6-7-8, or an unstructured pattern, 1-7-3-5-6-4-2-8, where digits indicate the clockwise position of correct levers in the circular array. These patterns were interleaved with random elements consisting of levers drawn from the set of all 8 possible positions in the array. Rats in the structured group learned their pattern, indicating that they were not limited to learning response sequences based on a consistent motor pattern. Furthermore, rats learned the structured pattern much faster than the unstructured pattern, indicating that pattern structure facilitated learning. To test the notion that the random elements of Experiment 1 may have slowed learning by creating structural ambiguity caused by irrelevant structural relations, in Experiment 2 irrelevant relations were minimized by ensuring that the correct pattern- and random-element responses were spatially distant from one another. Rats again learned the structured pattern faster than the unstructured pattern and, additionally, faster than the structured pattern in Experiment 1. The results of both experiments indicate that even when prevented from performing a consistent motor pattern and irrelevant relationships are present between pattern elements, rats abstract and encode rules describing structured sequential patterns.

Sequential learning has long prompted debate regarding the nature of learning, memory, and representation (e.g., Capaldi & Molina, 1979; Dallal & Meck, 1990; Fountain, Rowan, & Benson, 1999; Fountain, Rowan, & Carman, 2007; Haggbloom & Brooks, 1985; Hulse & Dorsky, 1977; Hulse & Dorsky, 1979; Jones, 1974; Martins, Miller, & Capaldi, 2008; Phelps & Roberts, 1991). This debate has often concerned whether animals such as rats can employ nonassociative symbolic processes like rule induction to learn about the structure of patterned sequences.

Early work by Hulse and colleagues on rats' learning of patterned food reward quantities in a runway paradigm supported the notion that rats represented the abstract rules describing the organization of patterned sequences (e.g., Fountain & Hulse, 1981; Fountain, Evensen, & Hulse, 1983; Hulse & Dorsky, 1977; Hulse & Dorsky, 1979; Jones, 1974). This view implies rats are not limited to employing chaining (e.g., Skinner, 1934) or associative strategies such as discrimination learning (e.g., Capaldi & Miller, 1988; Capaldi & Molina, 1979; Capaldi, Nawrocki, Miller, & Verry, 1985; Capaldi, Nawrocki, & Verry, 1983;

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Capaldi, Verry, & Davidson, 1980) when learning patterned sequences. Recent work examining rats' ability to learn patterns of responses in a spatial array also supports the rule learning view (e.g., Fountain, 1990; Fountain & Rowan, 1995a; Fountain & Rowan, 1995b). However, much evidence from this literature also supports the view that if rats learn about pattern structure, they also employ associative strategies for learning at least some aspects of sequences such as chunk boundaries and violations to pattern structure (Fountain & Benson, 2006; Kundey & Fountain, 2010; Stempowski, Carman, & Fountain, 1999).

Some of the best evidence for rule learning in rats comes from studies investigating their ability to detect relationships between nonadjacent pattern elements (e.g., Fountain & Annau, 1984; Fountain & Benson, 2006; Fountain et al., 1999; Macuda & Roberts, 1995). If, in an analogous task, humans are presented with the sequence AMBNCODP, they demonstrate sensitivity to the structural organization of the pattern by sorting it into two separate subpatterns that were never presented directly by the experimenter: ABCD and MNOP (Hersh, 1974). The human subject could then use this representation of the sequence to predict the next letter in the sequence, "E", as well as recognize the subpattern ABCD despite changes in the identity of the second subpattern (e.g., if MNOP were changed, say, to RRRR). Increasing evidence indicates animals too can detect such relationships in analogous tasks (e.g., Capaldi & Miller, 1988; Fountain & Annau, 1984; Fountain & Benson, 2006; Fountain et al., 1999; Menzel, 1973; Phelps & Roberts, 1991; Roitblat, Bever, Helweg, & Harley, 1991).

For example, Fountain and Annau (1984) observed that rats spontaneously sorted a sequence of reward quantities into chunks from nonadjacent serial positions. Rats learned patterns composed of varying quantities of reward, in this case, different numbers of pulses of hypothalamic brain stimulation reward (BSR) presented on successive trials. Some rats learned to lever press to receive a formally simple monotonically decreasing 25-18-10-3-1-0 pattern of BSR pulses presented on successive trials. The pattern is considered formally simple because it can be described by a simple rule structure, a single "less than" rule in this case. A three-element subpattern of BSR pulses, 6-6-0, separated the main pattern elements in the manner: 25 6-6-0 18 6-6-0 10 6-6-0 3 6-6-0 1 6-6-0 0, where dashes indicate short intertrial intervals and spaces indicate longer temporal intervals that served as "phrasing cues." Another group of rats learned a more complex nonmonotonic 25-3-10-18-1-0 pattern presented in the same manner with interleaved 6-6-0 subpatterns. The results showed that rats in the simple pattern group learned quickly to anticipate large versus small quantities of BSR. Rats in the more complex nonmonotonic pattern condition learned slower than rats in the monotonic pattern condition. These results indicate that when a simple structure is available, rats may be able to detect and encode relational rules from nonadjacent pattern elements. Unfortunately, the reward quantity tracking procedure used in Fountain and Annau (1984), like the food reward quantity anticipation procedure used in earlier studies, was methodologically weak in that conclusions regarding what rats might know about a sequence rely on interpreting response latency data, which fail to identify the specific reward quantities rats anticipated on a trial-by-trial basis.

One approach employed in later studies has considerably facilitated analysis of animal serial pattern learning involving long and more elaborate sequences. In this serial multiple-choice paradigm (see Fountain et al., 2006), rats learn patterns of spatial locations in a circular array of 8 levers or other manipulanda (e.g., nosepoke receptacles) located on the walls of an octagonal operant chamber. The rat's task is to learn to choose the levers in the proper sequential order to obtain BSR or other reward (e.g., water). Each lever is referred to by an integer, which reflects the clockwise position of the correct lever within the chamber. For example, the pattern 12345678 would indicate that the rat should begin at position 1 and depress levers around the box in a clockwise manner. At the beginning of each trial, all eight levers are extended. If the rat depresses the correct lever, it receives reinforcement and moves on to the next trial. If it does not choose the correct lever, then the incorrect levers are retracted and the correct lever remains extended. Thus, the rat must always depress the correct lever, for which it receives reinforcement, before it can move to the next trial. In this paradigm, the rat learns over a series of repeated patterns to produce the correct pattern of lever choices.

Fountain et al. (1999) used this paradigm to determine whether rats would learn interleaved subpatterns at different rates as a function of subpattern complexity. In one study, the goal was to determine if rats were sensitive to the organization of nonadjacent items from interleaved subpatterns when one subpattern was either highly structured or unstructured and the second subpattern was composed of a single repeating element. For the structured-repeating condition, a structured 123 234 345 456 567 subpattern was interleaved with repeating responses on lever 8. This resulted in the structured-repeating pattern, 182838 283848 384858 485868 586878. For the unstructured-repeating condition, an unstructured 153 236 345 426 547 subpattern composed of the same elements as the structured subpattern but reordered was interleaved with repeating responses on lever 8, resulting in the unstructured-repeating pattern, 185838 283868 384858 482868 584878. For both conditions, the integers reflect the clockwise positions of correct levers in the octagonal chamber on successive trials as described above and spaces represent pauses that served as phrasing cues (cf., Fountain & Rowan, 1995a; Fountain & Rowan, 1995b; Stempowski et al., 1999). The results indicated that simpler formal pattern structure facilitated pattern acquisition.

In a second experiment employing the same serial multiple choice methodology, rats learned two interleaved sequences created from sets composed of more than one lever. A structured or unstructured subpattern was interleaved with a subpattern of two alternating elements. For one group, the structured subpattern, 123456, was interleaved with the alternating subpattern, 787878, to create the structured-alternating pattern, 172837485768. For another group, the unstructured subpattern, 1<u>5</u>34<u>2</u>6, was interleaved with the same alternating subpattern, 787878, to produce the unstructured-alternating pattern, 17<u>5</u>83748<u>2</u>768. Here, the unstructured subpattern was formed by exchanging two items of the structured subpattern indicated by underlining. Consistent with the view that rats learn about