Learning and Motivation 48 (2014) 1–13

Contents lists available at ScienceDirect

Learning and Motivation

journal homepage: www.elsevier.com/locate/l&m

# Human and rat encoding of structural ambiguity in serial pattern learning

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A R T I C L E   I N F O

*Article history:*
Received 25 April 2014
Received in revised form 8 August 2014

*Keywords:*
Sequential pattern learning
Serial pattern learning
Rats
Structural ambiguity

A B S T R A C T

Many have investigated how organisms detect and learn about the patterned sequences of stimuli that they regularly encounter. In some cases, a sequence of stimuli may be structurally ambiguous. That is, more than one rule might be generated in attempts to describe or organize the sequence in a meaningful way. Past studies exploring learning of such sequences have indicated that while subjects can learn about the rules describing such sequences, they often make errors in learning consistent with holding multiple representations of the sequence. Here, we examined the ability of humans and rats to perform runs and trills sequences over the same spatial locations in a pattern production task using a touchscreen (humans) or a circular operant chamber array (rats). One of two signals, presented immediately prior to the start of each trial, indicated which sequence to perform. The results indicated that both species were able to learn to produce runs and trills sequences at levels exceeding chance, which provides additional evidence that humans and rats may hold multiple representations of structurally ambiguous sequences.



As they navigate throughout their environment daily, all organisms encounter a variety of stimuli across diverse domains. Some of these events occur in ways that are both relatable and predictable across time and space. A variety of research indicates that humans and nonhuman animals (hereafter, animals) display sensitivity to the arrangement of these kinds of events when they are encountered in a series (for review, see Fountain, 2008).

Organisms' ability to detect and learn about such sequences has led many researchers to question how they parse the sequences that they encounter and how such parsing can affect overall learning about the sequence itself (e.g., Bower, 1970; Capaldi, Verry, Nawrocki, & Miller, 1984; Fountain, Henne, & Hulse, 1984; Fountain, Rowan, & Carman, 2007; Restle, 1972; Restle & Brown, 1970; Simon, 1972; Stempowski, Carman, & Fountain, 1999; Terrace, 1987, 1991; Terrace & Chen, 1991a, 1991b; Winzenz & Bower, 1970). In some cases, the structure of the sequence may not be immediately clear to the organism encountering it. That is, more than one 'rule' could be generated in attempting to describe the sequence. For example, the pattern of numbers . . .123234345. . . could be interpreted as a 'runs' sequence (123 234 345) or a 'trills' sequence (. . .1 232 343 45. . .).

In investigations involving these structurally ambiguous patterns, the errors committed suggest that the organisms attempting to learn about the sequences might hold multiple representations of the sequence to be learned (e.g., Fountain et al., 2007; Fountain & Rowan, 1995). This possibility is indicated by their tendency to emit responses consistent with

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http://dx.doi.org/10.1016/j.lmot.2014.08.001

these multiple representations. For example, Fountain et al. (2007) investigated rats' production of a structurally ambiguous sequence phrased either as a series of 'runs' (1234-3456-5678-7812-. . .) or a series of 'trills' (1212-3434-5656-7878-. . .), where digits represent adjacent levers within an octagonal chamber and dashes indicate phrasing cues, in a sequence production paradigm in a circular array. From eight extended levers, rats depressed the correct lever on each trial, as defined by their group assignment, to receive reinforcement.

The researchers found that the phrasing imposed on the pattern elements affected how rats' interpreted the structure of the pattern, which later affected how they remembered and/or produced the sequences. Additionally, the results suggested that sequences phrased as runs were easier to learn than those phrased as trills, which accords with prior work investigating serial pattern learning in humans (e.g., Fountain & Rowan, 1995; Restle & Brown, 1970). Additionally, these findings suggested that the rats represented the two versions of the sequence differently even though they involved the same spatial locations within the chamber in the same order. More specifically, while those learning the pattern phrased as runs learned quickly and made few errors consistent with trills phrasing, those learning the pattern phrased as trills showed increased rates of errors consistent with runs phrasing. That is, though one group was only ever reinforced for producing trills, they made numerous errors consistent with a runs representation. Thus, they appeared to hold a runs representation of the pattern, which was not reinforced, in addition to representing the trills structure, which was reinforced. These results suggest that rats might be able to hold multiple representations of a structurally ambiguous pattern concurrently and that it might be possible to cue the production of either representation.

Here, we further explored the notion of multiple representations of sequences in rats and humans by exploring their performance of both runs and trills sequences in a pattern production task. Rats performed sequences in an octagonal chamber while humans completed a computer analogue of the pattern production task. If humans and rats are capable of holding multiple representations of sequences in memory, we hypothesized that they would be able to perform the runs and trills pattern, as signaled by a cue at the beginning of each sequence, at a level better than expected by chance alone. Additionally, we hypothesized that when humans and rats committed errors in their sequence production, the errors would be consistent with either a runs or trills structure. This hypothesis was evaluated by examining errors on the third element of each chunk.

## Experiment 1

This experiment investigated whether humans could hold multiple representations of sequences by examining performance of runs and trills sequences within the same spatial array. Undergraduate students learned to perform both runs and trills sequences in a computerized pattern production task where eight small circles were arranged in a circular array on a computer screen, as described below. Prior to performing each sequence, a visual cue in the form of a single non-letter character (✒ or ✦) presented on the center of the computer screen indicated which sequence type (runs or trills) was to be performed. However, participants were never explicitly instructed regarding what the characters indicated. The visual cues were counterbalanced across participants. Participants' performance was examined for evidence of the ability to hold multiple concurrent representations of the sequence.

### *Method*

The procedure outlined below closely followed the paradigms employed by Fountain and Rowan (1995) and Kundey et al. (2013).

#### *Participants*

Undergraduate participants were recruited from undergraduate psychology courses via an announcement in classes from Hood College, a small mid-Atlantic liberal arts college. For agreeing to participate, they were given extra credit in the psychology course of their choosing or a candy reward. The participants included 10 undergraduates (3 male; *M* [*SEM*] = 20.22 [2.76] years; ages ranged from 18 to 22 years); one participant declined to report information regarding age.

#### *Apparatus*

Three IBM-compatible desktop computers with touchscreen monitors were used. Each computer was located on a separate computer desk in a classroom, with approximately 1.5 m between desks. Partitions were placed between computers to prevent potential visual distractions from the testing room. Additionally, participants wore headphones to minimize potential auditory distractions from the testing room.

#### *Procedure*

The procedure used was developed from earlier research in serial pattern learning (Fountain & Rowan, 1995). The Hood College Institutional Review Board approved all procedures. Upon arrival, participants read and signed informed consent forms. Research personnel were available to answer participants' questions. Then, they completed a sequential learning task, as described below. Following the pattern completion task, participants completed a demographic questionnaire and were debriefed regarding their participation.