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# Hierarchical organization in serial pattern learning

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ABSTRACT

Theorists have long hypothesized how organisms represent the organized sequences of stimuli that they encounter. Such models often posit that the items that are encountered are not coded individually, but instead that the organism constructs an abstract representation of the sequence based upon their experience. Later, this representation can be drawn upon to reconstruct the entire sequence. However, the nature of that representation continues to be debated. Through two experiments with human undergraduates in a pattern production paradigm, we consider whether one popular model, the hierarchical model (Restle, 1972; Restle & Brown, 1970), accurately describes such learning. The hierarchical model predicts that humans should form an abstract representation of the sequence with which they are presented that is the simplest possible in order to reduce memory load. It posits a nested organization of relationships in which the highest-order rules relate the largest number of pattern elements and sets of elements while the lower-order rules are nested within this higher-order structure; the lowest-order rules relate individual pattern elements. However, our results indicate that participants did not abstract the simplest representation of the sequence available, contradicting the prediction of the hierarchical model. This suggests that the hierarchical model does not fully account for the learning of patterned sequences in humans.



Each day, organisms encounter multiple stimuli, some of which show patterns in their occurrence. When encountering such sequences, humans and nonhuman animals do not merely link together the elements of the string of stimuli as they encounter them (e.g., Fountain & Rowan, 1995; Fountain, Rowan, & Benson, 1999; Hersh, 1974; Jones, 1981, 1984; Jones & Zamostny, 1975; Kundey & Fountain, 2011; Kundey et al., 2013; Restle, 1970, 1972; Restle & Brown, 1970; Simon, 1972; Simon & Kotovsky, 1963). Instead, they appear to generate an abstract representation (i.e., a rule) of the sequence's structure based upon experience that describes how the stimuli are organized within the sequence (e.g., Jones, 1974; Restle, 1970, 1972; Simon & Kotovsky, 1963). Subsequently, the organism can use this representation to generate the entire sequence (e.g., Palmer & Pfordresher, 2003). Models geared towards explaining sequential learning phenomena often propose that the items within a sequence are not encoded in their entirety but are encoded into chunks. Chunking allows organisms to compress information into a form that lessens memory demands. Although a variety of models have been proposed (e.g., Jones, 1974; Simon & Kotovsky, 1963), the most successful remains the hierarchical model (Restle, 1970).

The hierarchical model (Fountain & Rowan, 1995; Restle, 1970; Restle & Brown, 1970), posits that the representation that the organism ultimately abstracts from the sequence will be the simplest possible that accurately encodes the sequence (e.g., Restle, 1972; Restle & Brown, 1970). That is, organisms will use a systematic relationship or set of relationships among rules to relate pattern elements. Such structure could include repeatedly performing a single rule (e.g., press a particular

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lever repeatedly) or a set of rules always occurring in the same order (e.g., press lever 1 followed by lever 2, then repeat). This representation could include lower-order rules, which relate individual pattern elements (e.g., press lever 1 followed by lever 2), as well as higher-order rules (e.g., repeat the lower-order rule just performed), which relate the chunks of information created by the lower-order rules. Importantly, this allows for a nested organization in which the highest-order rules relate the largest number of pattern elements and sets of elements (e.g., Fountain & Rowan, 1995; Restle, 1970, 1972) while the lower-order rules are nested within this higher-order structure. Within this model, organisms must be able to relate the individual pattern elements within a chunk (lower-order rule), as well as relate the chunks to each other (higher-order rule).

Proponents of the hierarchical model argue that this model is advantageous because it reduces memory load by allowing organisms to remember a particular patterned sequence without remembering every individual element and every connection between those elements (e.g., Restle, 1972; Restle & Brown, 1970). In other words, the model suggests that the number of relationships that must be memorized decreases when abstract rules are employed.

For example, Fountain and Rowan (1995) explored rats' and humans' learning of hierarchical patterns. Humans and rats were presented with patterned sequences composed of 24, 30, or 36 elements with a 2-level (123 234 345 456 567 678 781 812), 3-level (123 234 345 456 567 678 876 765 654 543 432, or 4-level (123 234 345 432 321 218 765 654 543 456 567 678) hierarchical structure in analogous serial multiple-choice paradigms. Rats pressed levers in a circular array while humans selected spatial locations from a circular array on a computer screen. The digits indicate the clockwise position of the correct choice (lever or spatial location) within the circular arrays.

For rats and humans, the complexity (i.e., the number of rules that needed to be remembered) of the pattern was associated with learning difficulty, as well as the number and types of errors committed. Groups learning patterns that were more complex (e.g., patterns with four levels of structure) made more errors than those learning patterns that were simpler (e.g., patterns with two levels of structure). It was also found that when inconsistencies (i.e., violations) in the hierarchical structure were inserted into the patterns to be learned, more errors were committed. Analysis of the errors committed indicated that the mistakes on violation elements were consistent with the rule describing the overall pattern. These outcomes suggest that rats and humans encode and use multilevel hierarchical structure representations in learning patterned sequences.

However, Fountain and Rowan (1995) only investigated violations of the first two levels in the nesting of the hierarchical structure. For example, Fountain and Rowan compared learning of a two-level perfect hierarchical pattern (123 234 345 456 567 678 781 812) to a similar pattern containing violations of pattern organization (123 234 <u>543</u> 456 567 <u>876</u> 781 812, underlining indicates violations). Here, the two-level perfect hierarchical pattern could be described by first indicating how to relate the elements within chunks (first-level rule: starting with the first element of the chunk, move one lever to the right twice) and then describing how to relate the chunks (second-level rule: move one lever to the left, then repeat the first-level rule). Importantly, note that only two three-element chunks were exchanged to create the violations. The insertion of these violations, however, significantly increased rats' error rates, suggesting disruptions in learning the first-level and the second-level rules describing the pattern. However, the effects of disrupting third-level or fourth-level rules were not addressed.

Moreover, the third-level and fourth-level sequences employed by Fountain and Rowan (1995) could be interpreted as having multiple pattern structures. That is, it is possible to interpret the three-level hierarchical pattern Fountain and Rowan (1995) employed (123 234 345 456 567 678 765 654 543 432 321 218) as one hierarchical pattern with three levels of hierarchical structure (consistent with Fountain and Rowan's interpretation). The sequence could be described by adopting these rules: starting with the first element of the chunk, move one lever to the right twice (first-level rule); then, move one lever to the left, and repeat the first-level rule five times (second-level rule); and reflect the second-level and first-level rules (third-level rule). However, this pattern could also be interpreted as two separate patterns that alternate (Pattern 1: 123 234 345 456 567 678; Pattern 2: 765 654 543 432 321 218), each with two levels of hierarchical structure. Pattern 1 could be described as: starting with the first element of the chunk, move one lever to the right twice (first-level rule); then, move one lever to the left, and repeat the first-level rule five times (second-level rule). Pattern 2 could be described as: starting with the first element of the chunk, move one lever to the left twice (first-level rule); then, move one lever to the right, then repeat the first-level rule five times (second-level rule).

Based on Fountain and Rowan's (1995) previous experiment, it is impossible to distinguish between these possibilities; that is, whether rats and humans encoded the three-level hierarchical sequence as having three levels of hierarchical structure or whether they encoded the sequence as consisting of two patterns with (individually) less complexity that alternated. If the latter were adopted during learning, this would suggest that organisms were not nesting rules in the way hypothesized by the hierarchical model. This would be because representing two rules that alternated would be structurally more complex, which violates the prediction of the hierarchical model (e.g., Fountain & Rowan, 1995; Restle, 1970, 1972). In this paper, we address this issue with humans by employing the computer pattern production paradigm previously used by Fountain and Rowan (1995).

## Experiment 1

We compared people's learning of a three-level hierarchical pattern, similar to that employed by Fountain and Rowan (1995), with and without a violation. Half of the participants learned a three-level hierarchical pattern without a violation, and the remaining half of participants learned a pattern with a violation in the second half of the pattern:

Perfect runs pattern: 123 234 345 456 567 678 781 812 321 218 187 876 765 654 543 432

Violation runs pattern: 123 234 345 456 567 678 781 812 321 218 187 876 765 <u>456</u> 543 432