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Responses as phrasing cues in serial pattern learning with rats and humans

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ABSTRACT

Researchers investigating how organisms learn patterns of information have dedicated much attention to determining how sequences that can be meaningfully organized are parsed during learning. Results have indicated that cues, often termed phrasing cues, from many domains, including visual, auditory, temporal, and spatial, can influence how patterns of information are interpreted and learned. For example, the sequence of numbers 123234345456 is made easier to learn when the cues imposed by experimenters (here, spaces) match the transitions between groups of related elements (i.e., chunks) in the sequence (i.e., 123 234 345 456). When such cues do not match the natural transitions of the pattern between chunks (i.e., 12 323 43 45 456), performance is not facilitated and instead is often hindered. Additionally, the placement of such cues can affect how the same sequence is encoded (i.e., runs: . . .234 345 456. . . vs. trills: . . .232 343 454. . .). Through four experiments, we explored the effect of incorporating responses as spatial phrasing cues on humans' and rats' pattern production. The results indicated that the spatial phrasing cues were interpreted as phrasing cues rather than as part of the structure of the pattern and that they facilitated performance when placed congruent to the natural structure of the sequence. Additionally, rats and humans appeared to use their own responses as phrasing cues.

All organisms encounter sequences of information each day, with some occurring in related and predictable ways. Learning about, predicting, and executing such sequences offers many advantages. For humans, one does not have to search extensively to appreciate the importance of such abilities – from grammatical constructions in our speech to baking to tying our shoelaces (Lashley, 1951), predictable sequences surround us. Such sequences are also important for other species, for example in predicting when food will next become available. Humans and nonhuman animals (hereafter, animals) are sensitive to the structure of such sequences (for review, see Fountain, 2008), and researchers have devoted much attention to understanding how such sequences are learned, including how sequences that can be meaningfully phrased are broken into smaller amounts of information that can be more easily remembered than the sequence as a whole (e.g., Bower, 1970; Capaldi, Verry, Nawrocki, & Miller, 1984; Fountain, Henne, & Hulse, 1984; Fountain, Rowan, & Carman, 2007; Restle, 1972,

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1973, 1976; Restle & Brown, 1970; Simon, 1974; Stempowski, Carman, & Fountain, 1999; Terrace, 1987, 1991; Terrace & Chen, 1991a; Terrace & Chen, 1991b).

In these efforts, researchers have investigated how cues affect the learning of such sequences. These cues can provide guidance as to how the sequence should be phrased or can draw the organisms' attention to a specific feature of the pattern that would be helpful in interpreting its organization. Such phrasing cues refer to those cues (e.g., tone, time, light) within a sequence that set apart a series of elements from other elements within the sequence (e.g., Fountain et al., 1984; Restle, 1972). When appropriately placed, they often improve performance (e.g., Fountain et al., 1984; Restle, 1972). Debate, however, remains regarding why such cues often facilitate performance, with researchers suggesting, for example, that they potentially serve as discriminative cues, increase processing time for stimuli, and/or highlight the sequence's structure by indicating that a transition in the sequence is soon to occur (e.g., Capaldi, Birmingham, & Miller, 1999; Capaldi et al., 1984; Fountain et al., 1984, 2007; Restle, 1972). Such investigations are useful in that understanding the nature of phrasing cues in sequential learning provides a foundation for greater understanding of sequential learning more generally, as well as the many tasks where sequential processes are important to successful performance. Additionally, such basic work in sequential learning and memory creates opportunities for a more nuanced understanding of conditions affecting sequential processing and production (e.g., Kundey, De Los Reyes, & Taglang, 2011; Willingham, 1999).

To date, the phrasing cues investigated in sequence learning have been exteroceptive in nature and whether learning is helped or hindered by such cues appears to relate to the cues' placements within the sequence (e.g., Fountain et al., 1984; Restle, 1972; Stempowski et al., 1999; Terrace, 1991). When the cues correspond to the transitions between chunks in the patterned sequence, the cues facilitate performance (e.g., Fountain et al., 1984; Restle, 1972). Additionally, these phrasing cues can bias how organisms perceive and encode the sequences, leading them to group the sequence elements into chunks (i.e., groups of related elements) as indicated by the cues' positions within the sequence, even when the sequence itself (without the cues) is structurally ambiguous and thus could be interpreted in multiple ways (e.g., Bower, 1970; Restle, 1972, 1976; Restle & Brown, 1970; Simon, 1974; Stempowski et al., 1999).

Phrasing cues' effects are most apparent in these structurally ambiguous sequences because without the cues, it is unclear how the sequences' structure should be interpreted (e.g., Restle, 1976). For example, if presented with the sequence of numbers . . .323434545656. . ., it could be difficult to determine whether the sequence is a series of runs (234 345 456. . .) or a series of trills (343 454 565. . .). The presence of a phrasing cue, here a space, is instructive in clarifying how to interpret the sequence. While the shorthand of 'runs' and of 'trills' is more familiar within a musical context, their use is analogous here, with items drawn from a stimulus alphabet of numbers, spatial locations, or lights of varying intensity to replace musical notes (e.g., Hulse & O'Leary, 1982).

Comparative work with animals (e.g., Fountain et al., 1984; Stempowski et al., 1999; Terrace, 1991) and humans (e.g., Bower, 1970; Restle, 1972, 1976; Restle & Brown, 1970; Simon, 1974) suggests that phrasing cues appear to affect the learning of structured sequences similarly across species. Studies with humans indicate that the insertion of cues into sequences biases the way in which they group the individual pattern elements into larger chunks of information (e.g., Bower, 1970; Restle, 1972, 1976; Restle & Brown, 1970; Simon, 1974).

For example, Restle (1972) investigated humans' abilities to reproduce sequences of illumination generated by turning on lights in a particular order from an array of six lights arranged horizontally in succession after watching several sequence examples. The phrasing cue was a temporal interval between the lights that composed the sequence. Congruent phrasing involved placing pauses between portions of the sequence sharing a similar structure (12–65–12–65–12–65–23–54–23–54, where digits represent the spatial location of lights and dashes represent temporal breaks). Non-congruent phrasing, in contrast, involved placing pauses between portions of the sequence that did not share a similar structure (126–512–652–354–235–4). The results indicated that congruent phrasing facilitated recall relative to non-congruent phrasing, leading Restle to conclude that congruent phrasing facilitated recall because it helped the participants to divide the sequence into parts rather than because it enabled them extra time to process the information that they had encountered.

Similarly, research with animals indicates that they are also sensitive to phrasing cues (e.g., Fountain et al., 1984; Stempowski et al., 1999; Terrace, 1991). For example, Fountain et al. (1984) investigated rats' learning of food quantity sequences in a T-maze. First, rats encountered a sequence of decreasing food quantities (14–7–3–1–0, where digits indicate number of food pellets) that repeated several times within a session. Between sequence repetitions, some encountered no phrasing cues, while others encountered spatial, temporal, or both spatial and temporal phrasing cues. All cues improved learning relative to no phrasing. In a second experiment, cue positioning within the sequence was evaluated. Some rats learned a sequence with phrasing cues positioned at the chunk boundaries (i.e., positioned congruently between quantities 0 and 14). Others learned the same sequence with either no phrasing cues or the phrasing cues placed within the middle of the chunk boundaries (i.e., positioned non-congruently between quantities 3 and 1; unphrased group). The congruent group performed better than the no phrasing group, which performed better than the unphrased group. Fountain et al. (1984) concluded that rats were sensitive to phrasing cue placement.

Other studies indicate similarities in how phrasing cues affect humans' and rats' parsing of structurally ambiguous sequences that can be interpreted in multiple ways without the addition of phrasing cues (e.g., Fountain & Rowan, 1995a; Restle, 1976; Stempowski et al., 1999). For example, Stempowski et al. (1999) explored the effects of phrasing on rats' learning of a runs (e.g., 123–234–345–456, etc., where digits represent adjacent levers within an octagonal chamber and dashes indicate phrasing cues) or a trills (e.g., 121–232–343–454, etc.) pattern in a sequence production paradigm. From among eight extended levers arranged in a circle, rats were required to depress the correct lever, as defined by their group