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Re-examining the role of context in implicit sequence learning

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ABSTRACT

Implicit sequence learning typically develops gradually, is often expressed quite rigidly, and is heavily reliant on contextual features. Recently we reported results pointing to the role of context-specific processes in the acquisition and expression of implicit sequence knowledge (D'Angelo, Milliken, Jiménez, & Lupiáñez, 2013). Here we examined further the role of context in learning of first-order conditional sequences, and whether context also plays a role in learning second-order conditional structures. Across five experiments we show that the role of context in first-order conditional sequences may not be as clear as we had previously reported, while at the same time we find evidence for the role of context in learning second-order conditional sequences. Together the results suggest that temporal context may be sufficient to learn complementary first-order conditional sequences, but that additional contextual information is necessary to concurrently learn higher-order sequential structures.

1. Introduction

Sequential knowledge is important in our everyday lives. Drivers are able to coordinate a number of actions in sequence while attending to the roads, and often while also maintaining a conversation. The idea that sequential knowledge about one activity can be accessed while attention is directed to another activity is an important one in experimental psychology. In particular, it suggests that access to sequential knowledge can occur without intention, or automatically. Indeed, the implicit learning of sequences is now a well-studied laboratory phenomenon.

Implicit sequence learning is typically studied using the serial reaction time (SRT) task. In the most common variant of this task a single target appears on every trial at one of four marked locations. In this task, participants are instructed to respond to the location of the target on every trial by pressing a button corresponding to the target's current location. Unbeknownst to participants, the location of the target is predicted by a relatively complex sequence on the majority of the trials. Participants who are incidentally exposed to this structure are often unable to describe the underlying sequential structure. Despite this lack of awareness, participants show a gradual speeding of responses on trials where the target's location is predictable based on a training sequence (Nissen & Bullemer, 1987). Further evidence for sequence learning comes from the cost

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to participants' performance in responses made to a target when its location is either randomly selected (e.g., Cohen, Ivry, & Keele, 1990) or is generated by a control sequence (e.g., Schvaneveldt & Gomez, 1998).

A broad question in the implicit sequence learning literature that is beginning to receive attention is whether the representations that drive such effects are context-free or context-sensitive. Without systematic study of this issue, it seems that a reasonable argument can be made either way. Specifically, one might imagine that the representations supporting the learning of a predictable sequence of motor movements could be separate from the context-rich representations that we retrieve explicitly (e.g., Reber & Squire, 1994; Sanchez & Reber, 2013). Alternatively, one might view implicit sequence learning effects as being a product of the same representations that support explicit remembering, with differences in awareness attributed to processing differences associated with how those representations are accessed (e.g., Jamieson & Mewhort, 2009b). The broad aim of the research reported here was to examine whether implicit sequence learning is supported by context-dependent processes.

2. Context-dependent implicit sequence learning

One of the first studies to point to the context-dependence of sequence learning was reported by Jiménez, Vaquero, and Lupiáñez (2006). They trained a group of intentional and a group of incidental learners on a second-order conditional sequence over a series of training blocks in which a single target item appeared alone on every trial. During the training blocks, the location of the target item was selected based on the training sequence on the majority of trials (80%) and was selected based on a control sequence on the remaining 20% of trials. Following the training blocks, participants completed a transfer block in which the target item appeared among three distracting items. Importantly, the location of the target item in the transfer block continued to follow the training sequence on 80% of the trials. Although intentional learners continued to express sequence knowledge in the transfer block, the same was not true for incidental learners, who showed no evidence of sequence knowledge in the transfer block. One explanation of this effect is that the presence of distractors in the transfer block signals a change in context, which prevents the recruitment of previous learning episodes to support current performance, and thereby disrupts the expression of sequence learning.

More direct support for the notion that sequence learning is tied to context comes from work by Abrahamse and Verwey (2008). In a series of experiments, Abrahamse and Verwey trained participants on a sequence over a series of training blocks in one context. For example, participants would be trained on a sequence as they responded to the location of a target triangle that appeared along the top of the screen on a white background. Later, participants completed a transfer block in which the location of the target continued to be selected based on the trained sequence on all trials, but the context was shifted such that participants now responded to the location of a target rectangle that appeared along the bottom of the screen on a grey background. Participants showed learning in the training blocks, as evidenced by a gradual improvement in performance. However, performance suddenly slowed in the transfer block, when the context shifted, despite the fact that the target's location was still predicted by the training sequence. This decrement in performance when the context was changed constitutes evidence of the context-dependency of sequence learning. Abrahamse and Verwey's results are consistent with other work showing that the expression of motor skills can depend on the reinstatement of both incidentally and intentionally learned contextual features that were present during acquisition (e.g., Ruitenberg, Abrahamse, De Kleine, & Verwey, 2012; Ruitenberg, De Kleine, Van der Lubbe, Verwey, & Abrahamse, 2012; Wright & Shea, 1991).

Although work described above has provided initial support for the idea that the expression of implicit sequence learning is dependent on context-specific processes, some questions remain. For example, it remains unclear whether context-specific processes influence the acquisition of learning, and if such processes lead to the formation of distinct learning episodes that would allow participants to represent sequence knowledge in the face of high levels of interference. In addition, although Jiménez and colleagues' results provide evidence for context-dependent learning in incidental learners, the role of context-specific processes in implicit sequence learning remains unknown, as previous work in this field has been inconsistent in how participants were tested for awareness of sequence knowledge, with most work using a free recall task or questionnaires (e.g., Abrahamse & Verwey, 2008; Ruitenberg, Abrahamse, et al., 2012; Ruitenberg, De Kleine, et al., 2012; Wright & Shea, 1991).

In a recent study we took a first step toward answering these questions by examining whether individuals could implicitly and simultaneously learn two orthogonal sequences as a function of distinct contextual cues (D'Angelo, Milliken, Jiménez, & Lupiáñez, 2013). In a series of experiments, participants were trained on two complementary (orthogonal) sequences using a noisy sequence presentation, in which the location of the target was selected using the training sequence on 80% of trials, and was selected using a control sequence on 20% of trials. The incorporation of control trials during the training phase provided us with an online measure of learning throughout the experimental session (Schvaneveldt & Gomez, 1998). Critically, the complementary sequences were presented on alternating blocks during the training phase and were associated with distinct contexts. Here and in our previous work we use the term context to refer to both incidentally and intentionally learned features that can aid participants in distinguishing between different sources of information, and which are in turn associated with different statistical structures. For example, in the training phase of Experiment 3 of our previous work, one sequence was presented on odd numbered blocks and required left-hand responses to red circles presented along the top of the screen. A complementary sequence was presented on even numbered blocks that required right-hand responses to blue circles presented at the bottom of the screen. Note that because we used complementary