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Implicit sequence learning of chunking and abstract structures

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ABSTRACT

The current study investigated whether people can simultaneously acquire knowledge about concrete chunks and abstract structures in implicit sequence learning; and whether the degree of abstraction determines the conscious status of the acquired knowledge. We adopted three types of stimuli in a serial reaction time task in three experiments. The RT results indicated that people could simultaneously acquire knowledge about concrete chunks and abstract structures of the temporal sequence. Generation performance revealed that ability to control was mainly based on abstract structures rather than concrete chunks. Moreover, ability to control was not generally accompanied with awareness of knowing or knowledge, as measured by confidence ratings and attribution tests, confirming that people could control the use of unconscious knowledge of abstract structures. The results present a challenge to computational models and theories of implicit learning.

1. Introduction

Although implicit learning has been defined as the acquisition of unconscious complex knowledge (Jiménez, 2003; Reber, 1989; Sager, 1994), it remains controversial whether people acquire knowledge about concrete exemplars (i.e., chunks or fragments) or abstract structures (i.e., other rules or regularities) in implicit learning (e.g., Dominey, Lelekov, Ventre-Dominey, & Jeannerod, 1998; Goschke & Bolte, 2007). The abstraction of general rules from direct experiences allows for the flexibility and adaptability that are central to intelligent behavior (Wallis, Anderson, & Miller, 2001). The degree of abstraction that can be implicitly learnt has important consequence for computational models and theories of implicit learning.

Reber (1989), one of the founders of implicit learning research, argued that implicit learning is characterized by two critical features: It results in knowledge that is largely (1) unconscious; (2) abstract. The initial empirical evidence in support of this assumption stemmed primarily from transfer effects in artificial grammar learning. For example, in an artificial grammar learning (AGL) task, participants are exposed to a set of letter strings that are generated by a finite-state grammar in the training phase; when participants are presented with novel letter strings or novel tone sequences in the test phase, they can implicitly transfer or apply the grammatical knowledge to test sequences constructed out of the same or indeed a new vocabulary (e.g., Altmann, Dienes, & Goode, 1995; see Reber, 1989 for a review). Despite abundant evidence for people acquiring structural knowledge of artificial grammars, the interpretation of the learning as implicit or abstract has been questioned widely over the last twenty years (e.g., Dulany, 1997; Perruchet & Vinter, 2002; Shanks, 2004). For example, Perruchet and Pacteau (1990) demonstrated that classifying new letter strings as grammatical or ungrammatical may depend on fragmentary knowledge of the bigrams of the training letter strings rather than an

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unconscious abstract representation of the grammar. Gomez (1997) argued that simple learning, such as learning first-order dependencies (bigrams), could occur without awareness, but more complex learning, such as learning second-order dependencies, was linked to explicit knowledge. The debate regarding what is learned implicitly is far from resolved (contrast Dienes, 2012; Vadillo, Konstantinidis, & Shanks, 2016).

Many recent studies in implicit sequence learning have focused on whether people can implicitly acquire complex knowledge such as second-order conditional (SOC) structure, by adopting SOC sequences in a serial reaction time (SRT) task (e.g., Destrebecqz & Cleeremans, 2001, 2003; Fu, Fu, & Dienes, 2008; Norman, Price, & Duff, 2006; Norman, Price, Duff, & Mentzoni, 2007; Pronk & Visser, 2010; Wilkinson & Shanks, 2004). In the SRT task, participants are asked to respond to the target at one of four locations as accurately and as quickly as possible. Unbeknownst to participants, the stimuli may follow, for example, a SOC sequence. It has been demonstrated that people can implicitly acquire sequence knowledge about the SOC structure when the response-stimulus interval (RSI) is zero (Destrebecqz & Cleeremans, 2001; Fu, et al., 2008; see Wilkinson & Shanks, 2004 for inconsistent findings). These findings provided important evidence that people can unconsciously acquire complex knowledge such as second-order dependencies. Nonetheless, in the SRT task, the learning effect is mainly defined as shorter reaction times for the training sequence compared to the transfer or random sequence, which depends only on people acquiring concrete chunks or triplets of the training sequence rather than abstract structures. By contrast, in the AGL task, there is evidence of learning not only chunks or associations, but also relations that go beyond chunks or associations, namely patterns of repetitions independent of vocabulary (e.g. Brooks & Vokey, 1991; Tunney & Altmann, 2001) or symmetries (e.g. Ling, Li, Qiao, Guo & Dienes, 2016) or other supra-finite state structures (e.g., Rohrmeier, Fu, & Dienes, 2012).

To address whether people can acquire structure more abstract than memorized chunks in implicit sequence learning, Goschke and Bolte (2007) developed a new serial naming task (SNT), in which participants were asked to name line-drawings of concrete objects from one of four semantic categories. Unbeknownst to participants, the concrete objects were presented in a random order, but the sequence of semantic categories followed a repeating sequence (furniture–body part–animal– clothing–body part–animal). They found that the reaction times in the SNT were much faster for a repeating category sequence than a random category sequence but performance in a sequence reproduction task was not significantly greater than chance level, which was taken to indicate that people implicitly acquired knowledge about the repeating category sequence. As the acquired knowledge referred to sequential dependencies between semantic categories rather than specific exemplars, it was abstract in this sense (Compare Rebuschat & Williams, 2009, finding implicit learning of the order of grammatical type of word independent of the exact words used in an AGL paradigm). However, Dominey et al. (1998) investigated learning of abstract repetition structure in the SRT task and found that participants in the implicit group did not significantly learn the abstract structure. Nonetheless, in the Experiments 2 and 3 of Dominey et al. (1998), participants in the implicit learning condition also showed significant or marginally significant learning effects of the abstract structures, although it was argued that this abstract learning effect was due to single-item recency effects. Other researchers have also argued that abstract knowledge can be acquired only in explicit learning conditions (Boyer, Destrebecqz, & Cleeremans, 2005; Channon et al., 2002; Cleeremans & Destrebecqz, 2005; Johnstonem & Shanks, 2001).

Fu, et al. (2008) adopted two second-order conditional (SOC) sequences (SOC1 = 3-4-2-3-1-2-1-4-3-2-4-1; SOC2 = 3-4-1-2-4-3-1-4-2-1-3-2) in the training phase, in which one SOC sequence is the training sequence and its triplets occurred with a large probability and the other SOC sequence is the transfer sequence and its triplets occurred with a small probability. After the training, people were asked to complete two free generation tests according to the logic of the Process Dissociation Procedure (PDP, Jacoby, 1991; for bias of the PDP measure see Stahl, Barth, & Haider, 2015): in an inclusion test, participants were asked to generate a sequence that was same as the training sequence; in an exclusion test, participants were asked to generate a sequence that was different from the training sequence. They found that two types of knowledge were expressed in the explicit tests: (1) knowledge relevant to distinguishing training and transfer SOC sequences, i.e., chunking knowledge about concrete chunks or triplets; (2) knowledge concerning properties both training and transfer SOC sequences had in common, i.e., abstract structures about repetition patterns. They also found that the amount of noise and training influenced the conscious status of chunking knowledge and abstract knowledge in a different way, indicating that people can simultaneously acquire chunking and abstract knowledge in implicit sequence learning.

The abstract feature shared by training and transfer SOC sequences in Fu et al. (2008) is reversal frequency (Pronk & Visser, 2010). A reversal refers to a triplet in which the first and the third stimulus were the same, as found in ABA grammars (Marcus, 1999) or n-2 repetition (Koch, Philipp, & Gade, 2006). Reed and Johnson (1994) considered reversals as salient, and each of the SOC sequence (SOC1 = 3-4-2-3-1-2-1-4-3-2-4-1; SOC2 = 3-4-1-2-4-3-1-4-2-1-3-2) has only one reversal. That is, there is one reversal triplet in the training or transfer SOC sequence, while there are ten reversal triplets in the neither SOC sequence. To investigate the effects of reversal frequencies in probabilistic SOC sequence learning, Pronk and Visser (2010) trained one group of participants with the sequence that contained only a single reversal and one group of participants with the sequence that contained four reversals. They found that the reversal frequency in probabilistic SOC sequence learning influenced how people responded to reversals and non-reversals in the SRT task and which type of knowledge became explicit in the explicit test. Tanaka and Watanabe (2013, 2014) also showed that after learning a set of triplets in an SRT task, participants were particularly fast to the triplets with the elements in reverse order compared to other re-orderings, even in participants who claimed not to notice the pattern.

Interestingly, both simulation and experimental work indicate that rule learning in implicit learning is at least largely associatively-driven and extracting the statistical regularities in the sequence play a crucial role (e.g. Cleeremans & Dienes, 2008; Speiegel & McLaren, 2006). Few studies have investigated abstract learning in the SRT task because it is difficult to distinguish rule learning from associative learning.

To address this issue, we adopted three types of stimuli that differed in only the sequence location to detect the effects of associative learning and rule learning separately in the training phase in the present study. “Standard” stimuli refer to the stimuli that