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Learning without consciously knowing: Evidence from event-related potentials in sequence learning

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ABSTRACT

This paper investigated how implicit and explicit knowledge is reflected in event-related potentials (ERPs) in sequence learning. ERPs were recorded during a serial reaction time task. The results showed that there were greater RT benefits for standard compared with deviant stimuli later than early on, indicating sequence learning. After training, more standard triplets were generated under inclusion than exclusion tests and more standard triplets under exclusion than chance level, indicating that participants acquired both explicit and implicit knowledge. However, deviant targets elicited enhanced N2 and P3 components for targets with explicit knowledge but a larger N2 effect for targets with implicit knowledge, revealing that implicit knowledge expresses itself in relatively early components (N2) and explicit knowledge in additional P3 components. The results help resolve current debate about the neural substrates supporting implicit and explicit learning.

1. Introduction

The issue of whether people can learn without conscious knowledge has been widely investigated in sequence learning (e.g., Destrebecqz et al., 2005; Fu, Fu, & Dienes, 2008; Hoffmann, Sebald, & Stöcker, 2001; Jiménez, 2003; Wilkinson & Shanks, 2004; Willingham, Wells, & Farrell, 2000). Typically, participants are presented a serial reaction time (SRT) task in sequence learning, in which the sequence of buttons to be pressed is structured and the participant is told which button to press by a corresponding location on a screen being indicated (Cleeremans, Destrebecqz, & Boyer, 1998; Nissen & Bullermer, 1987). Thus, the participant can in principle follow instructions without being aware that the sequence is structured. People come to respond faster when the sequence is maintained rather than switched, however, indicating that they have acquired sequential knowledge. Subjects can often recognize or generate the sequence after being trained on it, therefore, it has been argued, people must have been conscious of the sequence (e.g., Cleeremans & McClelland, 1991; Perruchet & Amorim, 1992; Shanks, Wilkinson, & Channon, 2003). However, being discriminatively sensitive to the sequence in recognition and generation tests does not mean a person is conscious of their knowledge of the sequence (Dienes, 2008a; Rosenthal, 2002, 2005). Indeed, other SRT studies have argued that people are often not conscious of their knowledge of the sequence because subjects often deny that there was a sequence, they cannot freely report it, or if they can generate the sequence, they cannot control its generation, or else they claim to be using only intuition in generating the sequence (e.g., Destrebecqz &

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Cleeremans, 2001, 2003; Fu, Dienes, & Fu, 2010; Fu et al., 2008; Goschke & Bolte, 2007; Willingham, Nissen, & Bullemer, 1989; Willingham et al., 2000; Ziessler, 1998). In general, such objective measures as recognition and generation tests do not in themselves indicate conscious knowledge, but may be passed by using the same knowledge that allows performance in the SRT task (Berry & Dienes, 1993).

Destrebecqz and Cleeremans (2001, 2003) adopted the process dissociation procedure (PDP), to measure the conscious status of knowledge acquired in the serial reaction time (SRT) task. The PDP takes the ability to control as the measure of whether knowledge is conscious or not (cf. Higham, Vokey, & Pritchard, 2000). Destrebecqz and Cleeremans found that participants came to respond faster when the sequence was consistently structured rather than switched in the training phase. However, when participants were asked to freely generate a sequence same as or different from the one they were trained on (i.e., using an inclusion or exclusion test, respectively), there was no difference in the number of chunks from the trained sequence under inclusion and exclusion when the response stimulus interval (RSI) was zero, suggesting that participants lacked control over the use of their knowledge. Fu et al. (2010) showed that whether subjects were conscious of knowing the sequence as shown by confidence ratings was strongly related to Jacoby's PDP estimates of ability to control the use of the knowledge in the SRT task. This paper will further explore the relation between conscious knowledge (as measured by the PDP method) and event-related brain potentials (ERPs).

The measures of awareness in the above studies were all applied after learning. Eimer, Coschke, Schlaghecken, and Stürmer (1996) first investigated whether ERPs could be used as an online-measure for knowledge acquisition during SRT learning itself. They combined the standard SRT task with a variation of the oddball paradigm, in which the locations were replaced by four capital letters. Whether subjects were conscious of the sequence was measured by a set of explicit tasks including recognition after learning. They found that participants showed a larger enhanced frontocentral N2 component (negative components peaking 250–300 ms after stimulus onset, see Folstein and Van Petten (2008) for a review) for deviant targets for subjects who passed the explicit tasks rather than those who did not. Thus, they suggested that the N2 enhancement might be regarded as an indicator of the amount of explicit knowledge, though this point remains moot given recognition tasks can be passed based on implicit knowledge. That is, implicit and explicit knowledge may have been confounded in the recognition measure, so subjects counted as having explicit knowledge may also have had implicit knowledge. Unlike other studies, they found no P3 effect, which usually follows an N2 effect, in Experiment 1, and only a small P3 effect in Experiment 2.

Rüsseler, Hennighausen, Münte, and Rösler (2003) compared differences on ERPs in sequential learning between subjects who were informed (intentional group) or were not informed (incidental group) of the presence of a repeating sequence. This manipulation enhanced people's ability to generate the sequence. They found that intentional learners showed enhanced frontocentral N2b- and P3b-components for deviant targets, but there were no such effects for incidental learners. They suggested that both N2b and P3b reflected conscious processing. However, using a similar manipulation, Ferdinand, Mecklinger, and Kray (2010) found a larger N2b for deviant stimuli in both intentional and incidental groups. They argued that the N2b might be related to a gradual development of knowledge about the sequence structure producing expectancies of the next stimulus. Therefore, although Eimer et al. (1996) and Rüsseler et al. (2003) established relations between recognition and generation performance and N2 and P3 components, this does not entail a relation between these components and distinctively conscious knowledge. The next two studies resolve this problem more satisfactorily by using PDP but have another problem we will come to.

Schlaghecken, Stürmer, and Eimer (2000), using PDP, divided what each participant learned into chunk-internal (i.e., explicitly learned) and chunk-external (i.e., implicitly learned) targets based on the inclusion and exclusion performance. They found that the amplitudes of N2b- and P3b-components were enhanced only for deviants of chunk-internal rather than chunk-external targets. Thus, they also suggested that the enhancement of N2b and P3b components could be used as an online measure of explicit knowledge. Moreover, the effect of deviants on reaction times (i.e., RT benefits for standard) did not differ between chunk-internal and chunk-external targets, revealing that people implicitly acquired some knowledge. Miyawaki, Sato, Yasuda, Kumano, and Kuboki (2005), using PDP, replicated the behavioral results but found only an enhanced N2 effect for chunk-internal targets.

The use of PDP is useful for measuring conscious knowledge. But there is still a caveat in interpreting their results: their studies may have lacked power to determine the ERP correlates of distinctively implicit knowledge because they did not make a distinction between the parts of the sequence that people had implicitly learned and those of the sequence that people did not learn at all. It is known that subjects do not uniformly learn all parts of a sequence (e.g., Wilkinson & Shanks, 2004). Whereas "chunk-internal" refers to parts of the sequence we know the subject has explicitly learned, "chunk-external" refers to a mixture of implicitly learned and unlearned parts of the sequence (cf. Schlaghecken et al., 2000). Thus, it is not surprising that it was difficult to detect ERP components for chunk-external positions. Therefore, it is still unclear to what extent the N2 and P3 components reflected explicit knowledge rather than implicit knowledge.

The purpose of the present study is to explore how implicit and explicit knowledge is reflected in ERPs in sequence learning, where explicit knowledge is measured by PDP. We will explore whether N2 and P3 components have different roles in the acquisition of explicit and implicit knowledge. Compared to previous studies we will both (a) isolate consciously known chunks by using PDP rather than by using just generation or recognition; and (b) increase power for detecting the ERP concomitants of implicit knowledge by identifying those parts of the sequence actually implicitly learned by subjects. Thus, we will eliminate confounds in previous studies.