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Implicit and explicit contributions to statistical learning

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ABSTRACT

Statistical learning allows learners to detect regularities in the environment and appears to emerge automatically as a consequence of experience. Statistical learning paradigms bear many similarities to those of artificial grammar learning and other types of implicit learning. However, whether learning effects in statistical learning tasks are driven by implicit knowledge has not been thoroughly examined. The present study addressed this gap by examining the role of implicit and explicit knowledge within the context of a typical auditory statistical learning paradigm. Learners were exposed to a continuous stream of repeating nonsense words. Learning was tested (a) directly via a forced-choice recognition test combined with a remember/know procedure and (b) indirectly through a novel reaction time (RT) test. Behavior and brain potentials revealed statistical learning effects with both tests. On the recognition test, accurate responses were associated with subjective feelings of stronger recollection, and learned nonsense words relative to nonword foils elicited an enhanced late positive potential indicative of explicit knowledge. On the RT test, both RTs and P300 amplitudes differed as a function of syllable position, reflecting facilitation attributable to statistical learning. Explicit stimulus recognition did not correlate with RT or P300 effects on the RT test. These results provide evidence that explicit knowledge is accrued during statistical learning, while bringing out the possibility that dissociable implicit representations are acquired in parallel. The commonly used recognition measure primarily reflects explicit knowledge, and thus may underestimate the total amount of knowledge produced by statistical learning. Indirect measures may be more sensitive indices of learning, capturing knowledge above and beyond what is reflected by recognition accuracy.

Introduction

Statistical learning refers to the process of extracting subtle patterns in the environment. This type of learning was first reported in 8-month-old infants, who were briefly exposed to a continuous stream of repeating three-syllable nonsense words. Following exposure, infants showed sensitivity to the difference between the three-syllable sequences and foil sequences made up of the same syllables recombined in a different order, demonstrating that they were able to use the statistics of the input stream to discover word boundaries in connected speech (Saffran, Aslin, & Newport, 1996). This finding revolutionized thinking on language acquisition by showing that humans can use generalized statistical procedures to acquire language (Bates & Elman, 1996; Seidenberg, 1997).

Since this seminal study, subsequent research has shown that statistical learning can also be observed in older children and adults (e.g., Fiser & Aslin, 2001, 2002; Saffran, 2002; Saffran, Johnson, Aslin, & Newport, 1999;

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Saffran, Newport, Aslin, Tunick, & Barrueco, 1997; Turk-Browne, Junge, & Scholl, 2005). In a typical auditory statistical learning experiment run in adults, learners are exposed to a stream of repeating three-syllable nonsense words, as in Saffran and colleagues' original infant study. Learning is then assessed using a forced-choice recognition test. On each trial, learners are presented with a pair of stimuli: a nonsense word from the exposure stream is played together with a nonword foil composed of syllables from the speech stream combined in a novel order. Learners are asked to judge which stimulus sounds more familiar based upon the initial familiarization stream. Statistical learning is inferred if performance on this recognition measure is greater than chance.

An important feature of statistical learning is that it can occur in the absence of instruction or conscious attempts to extract the pattern, such as when stimuli are presented passively without any explicit task (e.g., Fiser & Aslin, 2001, 2002; Saffran et al., 1999; Toro, Sinnett, & Soto-Faraco, 2005) or when participants are engaged in an unrelated cover task (Saffran et al., 1997; Turk-Browne, Scholl, Chun, & Johnson, 2009; Turk-Browne et al., 2005). In addition, participants in statistical learning studies seem to have little explicit knowledge of the underlying statistical structure of the stimuli when assessed during debriefing (e.g., Conway & Christiansen, 2005; Turk-Browne et al., 2005). These results led researchers to describe statistical learning as occurring "incidentally" (Saffran et al., 1997), "involuntarily" (Fiser & Aslin, 2001), "automatically" (Fiser & Aslin, 2002), "without intent or awareness" (Turk-Browne et al., 2005), and "as a byproduct of mere exposure" (Saffran et al., 1999).

Statistical learning bears some similarity to *implicit learning*, a term coined by Reber (1967) and defined as "the capacity to learn without awareness of the products of learning" (Frensch & Runger, 2003). Paradigms used to study implicit learning include the artificial grammar learning (AGL) task (Reber, 1967) and the serial reaction time (SRT) task (Nissen & Bullemer, 1987). Learning in these tasks is typically measured indirectly, without making direct reference to prior studied items. In the AGL task, participants memorize letter strings generated by a grammatical rule system, and are then asked to decide whether new strings either conform to or violate the grammar. Above-chance classification performance is taken as evidence that participants have successfully acquired the underlying grammar. In the SRT task, participants respond to visual cues that contain a hidden repeating sequence. Participants eventually respond more quickly and accurately to sequential trials than to random trials, indicating that they have learned the sequence. Thus, as in statistical learning, participants in implicit learning experiments are passively exposed to material that contains a hidden, repetitive structure. Learning proceeds as a consequence of exposure to positive examples, and in the absence of feedback or explicit instruction. In addition, both statistical learning and implicit learning are thought to be domain-general phenomena (e.g., Conway & Christiansen, 2005; Kirkham, Slemmer, & Johnson, 2002; Manza & Reber, 1997; Thiessen, 2011). The similarities between statistical learning and implicit learning have led some investigators to propose (or tacitly assume) that statistical learning and implicit learning arise due to the same general mechanism (e.g., Conway & Christiansen, 2005; Perruchet & Pacton, 2006; Turk-Browne et al., 2005).

In contrast to the statistical learning literature, the literature on implicit learning has focused on the nature of the representations formed during learning. These studies have sought to address whether the knowledge produced by implicit learning paradigms such as the AGL and SRT tasks is conscious (explicit) or unconscious (implicit). The use of confidence scales has been helpful in this regard. According to one widely accepted framework (Dienes & Berry, 1997), knowledge is implicit when participants lack meta-knowledge of what they have learned, either because they believe they are guessing when in fact they are above chance on a direct test of memory (*the guessing criterion*), or because their confidence is unrelated to their accuracy (*the zero-correlation criterion*). Thus, if participants perform above chance on a task when they claim to be guessing, or if they are no more confident when making correct responses compared to incorrect ones, knowledge is inferred to be implicit. In contrast, if participants perform above chance on the task, but their accuracy on guess responses is not higher than chance and/or they express greater confidence for correct responses compared to incorrect ones, knowledge is inferred to be explicit. These criteria apply only to *judgment* knowledge, defined as the ability to recognize whether a particular test item has the same structure as training items (Dienes & Scott, 2005). Judgment knowledge is distinct from *structural* knowledge, which is knowledge of the underlying structure of training materials and/or knowledge of the training items themselves. Judgment knowledge can be conscious even if structural knowledge is unconscious. In the present paper, we use the term "implicit knowledge" to refer to implicit judgment knowledge, as determined by the criteria of Dienes and Berry (1997).

Whether learning in AGL and SRT paradigms depends upon implicit knowledge has been a source of major contention in the literature. Original accounts of AGL concluded that learning in this paradigm is driven by the unconscious abstraction of information from the environment (e.g., Reber, 1967, 1976). According to this proposal, knowledge produced during the training phase was not accessible to awareness—participants acquired knowledge without realizing that they had acquired it. A number of subsequent studies supported this conclusion by showing that confidence ratings did not differ between correct and incorrect trials and that classification accuracy was better than chance even when participants claim to be guessing, collectively providing evidence of implicit judgment knowledge (Dienes & Altmann, 1997; Dienes, Altmann, Kwan, & Goode, 1995; Scott & Dienes, 2008; Tunney & Altmann, 2001). Similarly, in the SRT task, participants often show robust learning as measured by performance while simultaneously exhibiting poor explicit recall or recognition of the sequence, leading to the conclusion that sequence knowledge is implicit (e.g., Curran, 1997a, 1997b; Reber & Squire, 1994; Willingham & Goedert-Eschmann, 1999). Studies in amnesic patients provide additional support for this idea. Amnesic patients