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SCIENCE BRIEF

Picking up patterns in language

Implicit learning helps guide the acquisition of linguistic rules and regularities.

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Laura Batterink is a postdoctoral fellow at Northwestern University. She earned her BA in neuroscience from Middlebury College in 2007 and her PhD in cognitive neuroscience from the University of Oregon in 2012. Her research focuses on the contribution of implicit and explicit mechanisms to language acquisition and related forms of learning. This research has implications for understanding why language acquisition becomes more effortful later in life; a related goal is to provide insight into the external learning conditions that are optimal for the acquisition of different aspects of language, particularly in adult non-native language learners.

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> "Have you ever wondered why we say fiddle-faddle and not faddle-fiddle? Why is it ping-pong and pitter-patter rather than pong-ping and patter-pitter? Why dribs and drabs, rather than vice versa? Why can't a kitchen be span and spic? ... The answer is that the vowels for which the tongue is high and in the front always come before the vowels for which the tongue is low and in the back" (Pinker, 1994).

As this quote illustrates, language contains countless regularities or patterns, many of which are seemingly arbitrary, even to a native speaker. Patterns exist at virtually every level. For example, in English, nouns that refer to more than one thing usually end in "s" (morphology). Articles such as "the" or "my" are usually followed by nouns, and never by verbs (syntax). And certain sounds commonly co-occur (e.g., *pl* or *sl*) while other sound combinations are never found (e.g., *tl*; phonology).

Regularities in language can be extremely subtle while still influencing online processing. For example, nouns and verbs differ in terms of phonological characteristics such as syllabic complexity, stress position and number of syllables (Kelly, 1992; Kelly & Bock, 1988). If a word is a less typical member of its category (e.g., a verb-like noun such as "insect," rather than a noun-like noun such as "marble"), sentence processing is delayed (Farmer, Christiansen & Monaghan, 2006; Farmer, Monaghan, Misyak & Christiansen, 2011).

Our recent work is premised on the idea that picking up these sorts of linguistic patterns can be a form of implicit learning — which occurs incidentally, without intention to learn, producing knowledge that is inaccessible to awareness (A.S. Reber, 1967; P.J. Reber, 2013; Foerde, 2010; Frensch & Runger, 2003; Seger, 1994). Children acquiring their native language typically learn these regularities implicitly (Paradis, 2004; Ullman, 2004), whereas patterns in language may potentially be learned by adults either explicitly or implicitly. We are also investigating the related idea that language learning is shaped by implicit processing during sleep (e.g., Gomez, Bootzin & Nadel, 2006; Gaskell et al., 2014; Nieuwenhuis, Folia, Forkstam, Jensen & Petersson, 2013).

Can linguistic patterns be picked up in the absence of awareness of learning?

Patterns linking grammatical form and meaning

One type of pattern found in language is the systematic relationship between grammatical form and meaning. For example, in English, the morpheme "–s" at the end of a noun is used to denote plurality, while verbs that end in "–ed" refer to actions that happened in the past. An often-debated question is whether adults learning a second language can acquire these relationships without awareness of learning (e.g., Robinson, 1996; Robinson, Mackey, Gass & Schmidt, 2012; VanPatten, 1996, 2004, 2007; Leow, 2001; Schmidt, 1990, 2001; Tomlin & Villa, 1994; Williams, 2005).

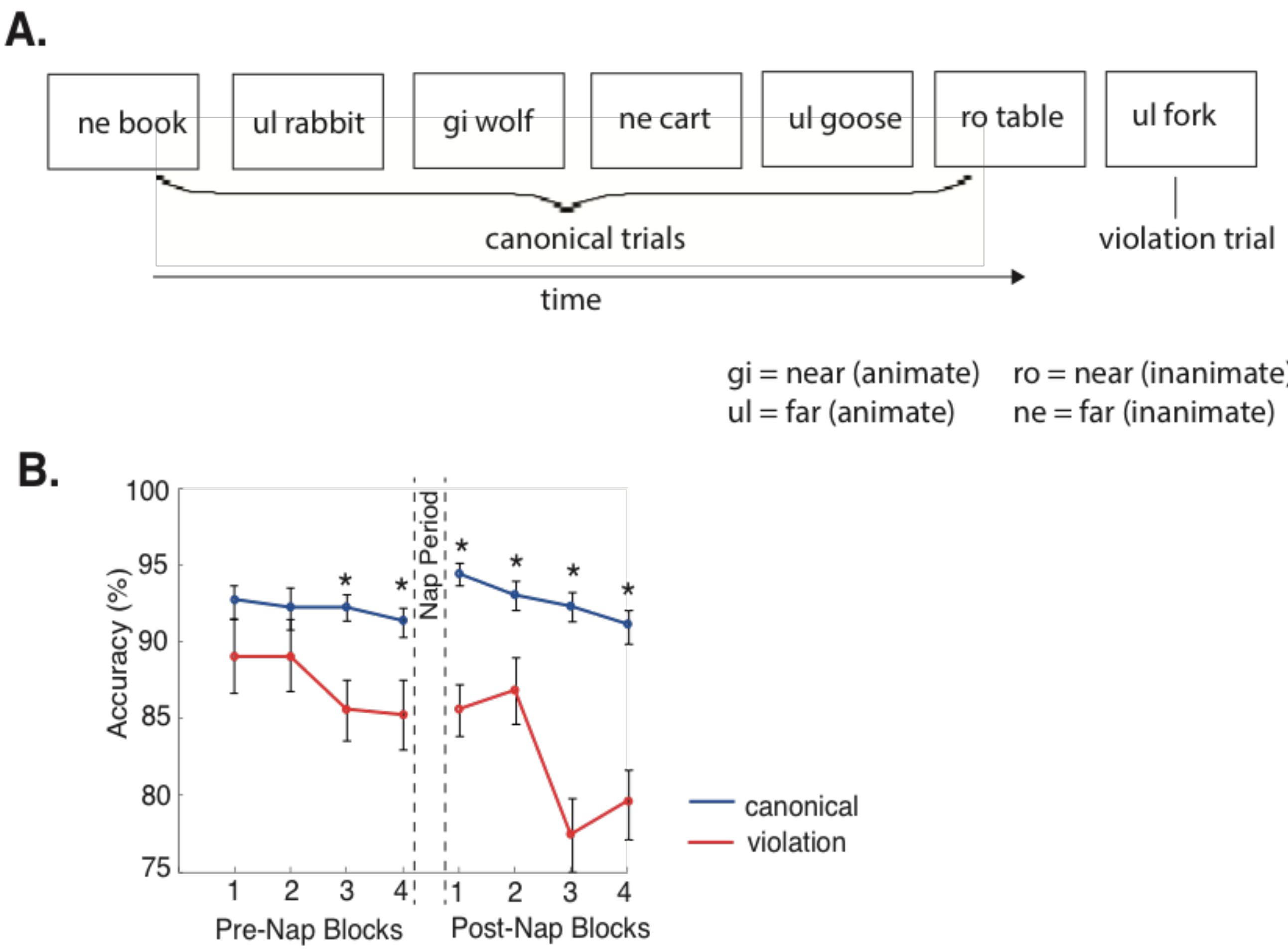

Figure 1: Illustration of task used to examine learning of hidden novel grammatical pattern. Participants were required to respond to each phrase, indicating first whether the noun was living or non-living (the hidden rule) and second whether it was near or far (the overt rule). Accuracy for violation phrases declined as learning progressed, and this pattern was present both for participants who were explicitly aware of the rule and for those who were not.

To examine this question, we exposed adults to a novel hidden linguistic rule (Batterink, Oudiette, Reber & Paller, 2014), building upon a paradigm developed by Leung and Williams (2012, 2014). Participants were presented with a large number of two-word phrases, each including a noun preceded by one of four novel words that functioned as an article (e.g., *gi* rhino). These novel articles were introduced as obeying an explicit rule: two words (*gi* and *ro*) were used to indicate nearby objects, and the other two (*ul* and *ne*) were used to indicate distant objects, as shown in Figure 1. However, unbeknownst to participants, the novel articles also predicted noun animacy, with two of the articles preceding living things (e.g., *gi* giraffe, *ul* lion) and the other two preceding nonliving objects (*ro* kettle, *ne* blanket). A small proportion of violation trials, in which this hidden animacy rule was reversed, were interspersed throughout the learning period (e.g., *ro* giraffe). Participants responded to each phrase as quickly as possible by indicating whether it contained an animate or inanimate object. Learning was assessed using both speeded behavioral responses and event-related brain potentials (ERPs), which are recordings of electrical brain activity measured from the scalp that provide a millisecond-by-millisecond measure of sensory and cognitive processing.

Our results provided convincing evidence that awareness of learning was not required to acquire the hidden rule. Participants who remained unaware of the hidden rule nonetheless showed slower and less accurate responses, and a divergent ERP response to violation phrases. These effects indicate that participants processed the violation phrases differently from the phrases that conformed to the pattern, reflecting implicit knowledge of the hidden rule. Interestingly, ERP results also corroborated participants' subjective verbal reports about their awareness of the rule. Only participants who reported becoming aware of the rule during learning showed a P600 effect to the violation phrases, a positive ERP deflection that has been previously linked to the conscious detection of syntactic violations (Batterink & Neville, 2013b). Taken together, our findings indicate that sensitivity to the animacy rule often occurred implicitly; conscious awareness of the rule was optional. Our conclusion is thus that adults can implicitly acquire complex regularities linking form and meaning.

Sound co-occurrence patterns

In language learning, the co-occurrences of certain sounds can be pivotal. For example, the consonant cluster /*spr*/ is common in English (e.g., spring, sprain, spray), whereas the cluster /*sfr*/ is not permissible (though is found in other languages such as Greek). Acquiring these patterns is thought to drive multiple aspects of language acquisition, including speech segmentation, a critical step in early language acquisition that allows learners to discover word boundaries within spoken language (e.g., Saffran, Aslin & Newport, 1996; Saffran, Newport & Aslin, 1996; Thiessen, Kronstein & Hufnagle, 2013). Sensitivity to these patterns also allows learners to more accurately predict incoming input, facilitating the perceptual processing and comprehension of language (Kuperberg & Jaeger, 2016).

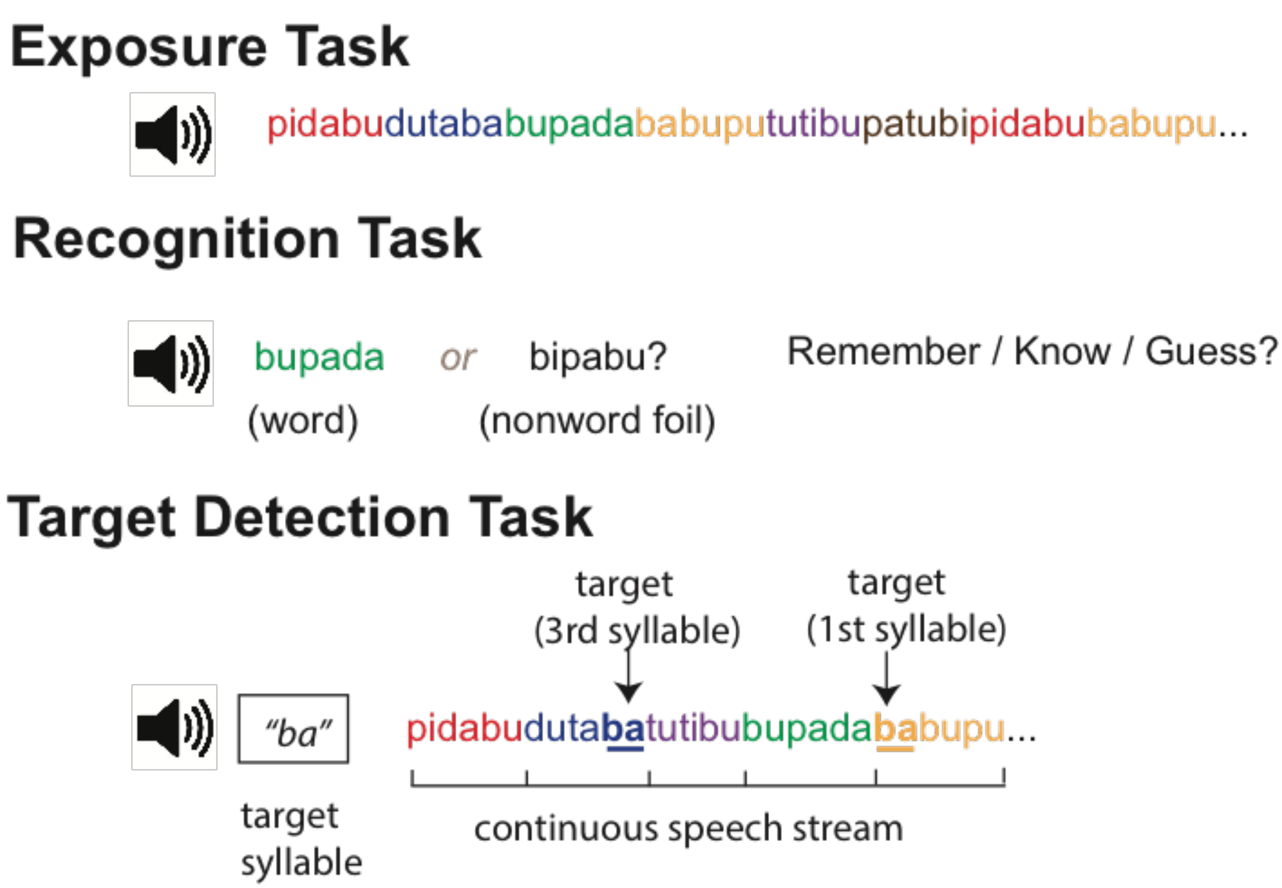

Figure 2: Paradigm used to study learning of sound co-occurrence patterns.

Are adult learners of a second language aware of these sound co-occurrence patterns? If so, is awareness of these patterns necessary for learning, or does it simply accompany learning in an optional manner? We addressed these questions by exposing participants to an artificial language made up of a continuous stream of repeating trisyllabic nonsense words (e.g., *babupupatubipidabu*...; Batterink, Reber, Neville & Paller, 2015). The co-occurrence of individual sounds within words was the only cue to word boundaries, as shown in Figure 2. We then assessed what participants had learned about the sound patterns of the artificial language. In an explicit test, participants attempted to discriminate between words from the language and foils. In an implicit test, we measured reaction times to target syllables within the speech stream; faster responses to predictable compared to unpredictable targets provided evidence of learning. Behavioral responses and ERPs revealed learning on both tasks. On the explicit test, participants discriminated between words and foils at above-chance levels, and also showed an ERP response to words that had been previously associated with successful recognition memory. On the implicit task, participants responded more quickly to predictable syllables (i.e., those that appeared in the second and third positions of the trisyllabic words), with ERPs providing corresponding evidence of faster and more efficient processing for predictable compared to unpredictable syllables (i.e., those that appeared in the first position of a word). Interestingly, a subgroup of participants who failed to demonstrate explicit knowledge of the sound patterns still demonstrated implicit learning. Similarly, at the item level, words not recognized better than chance on the explicit task still elicited prediction effects on the implicit task. Even though learners can become aware of sound co-occurrence patterns during exposure to a new language, this explicit knowledge is not critical for learning.

We then asked a related question: does increasing learners' explicit awareness of underlying sound patterns improve their ability to predict incoming language input? We randomly assigned participants to an explicit or implicit training group (Batterink, Reber & Paller, 2015). Learners in both groups were exposed to a continuous stream of repeating trisyllabic nonsense words, as in prior studies. Prior to this exposure period, however, participants in the explicit group received supplementary training on the individual words. This training produced a high level of explicit knowledge of the sound patterns. The critical finding was that on the prediction task, responses in the explicit group were faster to predictable targets but slower to unpredictable targets relative to responses in the implicit group. Explicit learners also showed a larger P300 ERP response, a positive ERP deflection occurring approximately 300 ms poststimulus, which indexes attentional allocation and controlled, effortful processing. We inferred that learners with explicit knowledge of sound co-occurrence patterns consciously retrieve this knowledge during online processing, a strategy that confers both benefits (for predictable syllables) and costs (for unpredictable syllables, as reflected by the increase in response time to these syllables). Overall, explicit knowledge of sound patterns may lead to a more effortful, less automatic mode of processing, which could mean that a limited role of awareness in learning sound patterns can be functionally advantageous.

One interesting characteristic of this type of learning is that it appears to occur remarkably quickly. In a recent study (Batterink, under review), we exposed learners to a large number of different speech streams, each one made up of novel and unique repeating nonsense words. Remarkably, on the implicit prediction task, participants showed faster responses to more predictable targets (i.e., those that occurred in the second and third syllable positions of the words) after just a single prior exposure to an embedded nonsense word. This learning was dissociable from learners' ability to explicitly identify the underlying pattern in the speech streams. These results demonstrate that learning of sound patterns occurs continuously, rapidly and largely unintentionally. In addition, taken together with our previous findings, these data provide converging evidence that explicit awareness of sound co-occurrence patterns may optionally accompany learning, but is not necessary to produce facilitation effects.

How does sleep influence pattern learning in language?

Growing evidence indicates that pattern learning at a general level is critically influenced by offline memory consolidation during sleep (e.g., Stickgold & Walker, 2013; Wagner, Gais, Haider, Verleger & Born, 2004; Ellenbogen, Hu, Payne, Titone & Walker, 2007; Durrant, Taylor, Cairney & Lewis, 2011; Durrant, Cairney & Lewis, 2013; Djonlagic et al., 2009). Memories that share common elements may be reactivated during sleep in a way that promotes connections among them (Lewis and Durrant, 2011). If idiosyncratic aspects of each memory are lost over time, a general schema may result. In the context of language acquisition, this schema could represent overarching linguistic rules abstracted over multiple exemplars and learning episodes.

We have investigated this idea using two approaches: (1) by examining correlations between sleep physiology and pre-to-post sleep changes in learning, and (2) by using a technique called targeted memory reactivation (TMR), which involves presenting memory cues associated with a prior learning episode during sleep (Oudiette & Paller, 2013). In a study using the first approach, we exposed participants to a hidden linguistic rule in which novel articles (*ul*, *ro*, *gi* and *ne*) predicted the animacy of associated nouns, as described above (Batterink et al., 2014). An afternoon nap was interposed between two 20-min learning sessions. We found that sleep organization predicted an increase in post-nap sensitivity to the rule, as measured through reaction times: participants who obtained greater amounts of both slow-wave (SWS) and rapid-eye-movement sleep (REM) showed increased sensitivity to the hidden linguistic rule in the post-nap learning session. Consistent with previous findings showing interactions between SWS and REM (e.g., Stickgold, Whidbee, Schirmer, Patel & Hobson, 2000; Mednick, Nakayama & Stickgold, 2003; Gais, Plihal, Wagner & Born, 2000), this result suggests that the combination of SWS and REM facilitates the abstraction of complex patterns in language. Perhaps SWS strengthens and consolidates individual memories, and subsequent REM facilitates integration of new memories with older memories (e.g., Walker & Stickgold, 2010).

In a study using the TMR approach, we found converging evidence for the idea that sleep facilitates pattern extraction in language (Batterink & Paller, in press). Participants gradually acquired the grammatical rules of an artificial language through an interactive, trial-and-error-based learning procedure. They also completed a second learning task involving passive exposure to a tone sequence following a probabilistic pattern. Each participant was randomly assigned to one of two conditions involving covert presentations of either the artificial language (grammar-cued condition) or the tone sequence (tone-cued condition) during an afternoon nap. Upon awakening, participants' ability to generalize the rules of the grammar system was assessed via their performance on new phrases. Participants re-exposed to the language during sleep showed larger gains in grammatical generalization compared to tone-cued participants. This gain in performance was driven by enhanced rule abstraction, rather than chunk-based knowledge (i.e., knowledge of pairs or triplets in the phrases). Thus, grammatical generalization was biased by auditory cueing during sleep, supporting the idea that the extraction of patterns in language can be facilitated during sleep.

Conclusions

Regularities or patterns characterize language at every level. Our findings suggest that the acquisition and processing of many of these highly complex and subtle patterns occurs beneath the surface. This learning naturally lies outside of our conscious awareness. Characterizing the contributions of implicit and explicit mechanisms — two fundamentally different learning mechanisms — to various aspects of language is an important part of gaining a comprehensive, mechanistic understanding of language acquisition throughout the lifespan.

Understanding which aspects of language are usually acquired implicitly, but which may require conscious processes in adult second-language learners, has important practical implications for second-language training. The underlying mechanisms of learning are critical; some types of patterns in language may be acquired optimally through passive, incidental exposure, whereas others may be acquired most efficiently through explicit instruction (e.g., second-language syntactic rules; Batterink & Neville, 2011). Continuing this line of research may lead to novel, more targeted and more effective forms of second-language training.

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