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Contextual priming of word meanings is stabilized over sleep

M. Gareth Gaskell[a,*], Scott A. Cairney[a], Jennifer M. Rodd[b]

[a] University of York, UK
[b] University College London, UK

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ABSTRACT

Evidence is growing for the involvement of consolidation processes in the learning and retention of language, largely based on instances of new linguistic components (e.g., new words). Here, we assessed whether consolidation effects extend to the semantic processing of highly familiar words. The experiments were based on the word-meaning priming paradigm in which a homophone is encountered in a context that biases interpretation towards the subordinate meaning. The homophone is subsequently used in a word-association test to determine whether the priming encounter facilitates the retrieval of the primed meaning. In Experiment 1 (N = 74), we tested the resilience of priming over periods of 2 and 12 h that were spent awake or asleep, and found that sleep periods were associated with stronger subsequent priming effects. In Experiment 2 (N = 55) we tested whether the sleep benefit could be explained in terms of a lack of retroactive interference by testing participants 24 h after priming. Participants who had the priming encounter in the evening showed stronger priming effects after 24 h than participants primed in the morning, suggesting that sleep makes priming resistant to interference during the following day awake. The results suggest that consolidation effects can be found even for highly familiar linguistic materials. We interpret these findings in terms of a contextual binding account in which all language perception provides a learning opportunity, with sleep and consolidation contributing to the updating of our expectations, ready for the next day.

1. Introduction

Over the last 20 years, a substantial body of psycholinguistic research has uncovered remarkable plasticity in the adult system. Whereas previously language development might have been characterised as a steady progression towards a fairly stable state, it is now clear that such a stable state is never achieved. Instead, we retain substantial plasticity as adults, allowing us to adapt our perception of phonemes when exposed to unfamiliar accents (Norris, McQueen, & Cutler, 2003), tailor our production system to reflect the statistical structure of our environment (Dell, Reed, Adams, & Meyer, 2000) and acquire and retain new forms (Gaskell & Dumay, 2003), meanings (Fang & Perfetti, 2017; Rodd et al., 2012) and syntactic constructions (Kaschak & Glenberg, 2004; Ryskin, Qi, Duff, & Brown-Schmidt, 2017). Along with these observations of plasticity, there has also been an enhanced recognition of the applicability of detailed theories of memory function to the domain of psycholinguistics (Davis & Gaskell, 2009; Gagnepain, Henson, & Davis, 2012; Szmalec, Page, & Duyck, 2012).

One key example of this increased synergy between memory and language has involved our understanding of the importance of consolidation processes in language learning. Studies of infants (Friedrich, Wilhelm, Mölle, Born, & Friederici, 2017; Gomez, Bootzin, & Nadel, 2006; Horváth, Myers, Foster, & Plunkett, 2015), children (Friedrich et al., 2017; Henderson, Weighall, Brown, & Gaskell, 2012; James, Gaskell, Weighall, & Henderson, 2017; Sandoval, Leclerc, & Gómez, 2017; Williams & Horst, 2014) and adults (Bakker-Marshall et al., 2018; Bakker, Takashima, van Hell, Janzen, & McQueen, 2014; Dumay & Gaskell, 2007; Kurdziel, Mantua, & Spencer, 2017) have shown that retention and integration of new linguistic knowledge can benefit from a consolidation period, and sometimes specifically from a sleep period (Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010). For example, interference from learning a new word (e.g., "cathedruke") on the recognition of its existing neighbour (e.g., *cathedral*) tends not to be observed immediately (although cf. McMurray, Kapnoula, & Gaskell, 2016), but instead emerges after a period of sleep (Dumay & Gaskell, 2007) and is associated with the prevalence of spindle activity (brief ~12–15 Hz bursts of activity in non-REM sleep) during the intervening night (Tamminen et al., 2010). These observations can be explained by systems consolidation models (e.g., Rasch & Born, 2013) applied to language learning (Davis & Gaskell, 2009) in which sleep provides an opportunity for new hippocampally mediated memories to be replayed (Ji & Wilson, 2007; Nadel, Hupbach, Gomez, & Newman-Smith, 2012)

* Corresponding author at: Department of Psychology, University of York, YO10 5DD, UK.
E-mail address: gareth.gaskell@york.ac.uk (M.G. Gaskell).

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and strengthened in cortical networks.

Although it is fairly clear that consolidation is a component process in the retention of language knowledge, there is substantial variability in the extent to which consolidation effects are found (McMurray et al., 2016), which likely reflects the nature of the material to be learned. The studies that have revealed consolidation effects in language learning have tended to focus on examples of new material (e.g., novel words or grammars), and it is possible that stimulus novelty is the main factor that determines the level of reliance on consolidation. This would fit with a complementary systems account of language learning (McClelland, 2013) in which the hippocampus steps in to facilitate learning in cases where adjustment of cortical weights would interfere with existing knowledge (Mirković & Gaskell, 2016).

An exception to this rule is the study of Gaskell et al. (2014), who examined the role of sleep in the acquisition of phonotactic constraints in speech production. The research exploited the work of Dell and colleagues (Dell et al., 2000; Warker & Dell, 2006; Warker, Dell, Whalen, & Gereg, 2008; Warker, Xu, Dell, & Fisher, 2009) who had shown that speakers can acquire new phonotactic constraints (e.g., absence of a /g/ at syllable offset) over brief periods of time, as evidenced by the structure of their speech errors. Gaskell et al. (2014) extended the work of Warker (2013) and showed that when the constraint is a more complex "second-order constraint" (e.g., absence of a /g/ after /ae/) the integration of this constraint into speech errors is facilitated by a period of sleep (specifically, slow-wave sleep). A recent study demonstrated that consolidation also benefits the acquisition of second-order constraints when the material to be learned is non-linguistic (Anderson & Dell, 2018). The phonotactic consolidation effect can in some ways be thought of as learning of new material (i.e. the "gaps" in the repertoire of allowable sequences are new), but in other ways the change can be thought of as a revision of existing knowledge about the co-occurrence probabilities of various phonemes. Therefore, it remains to be seen whether sleep and consolidation are important for the retention of new evidence that acts to revise a well-established body of existing linguistic knowledge.

In the current study, we examine the potential for sleep and/or consolidation to influence the process of selection between the various familiar meanings of lexically ambiguous words. This domain exemplifies the building up of a body of knowledge over the course of a lifetime relating to the likelihood of different meanings, and yet has been shown to be susceptible to priming effects in the short term, suggestive of plasticity (Rodd, Cutrin, Kirsch, Millar, & Davis, 2013). For example, the word "pen" has multiple meanings, and in the absence of biasing contextual cues participants tend to retrieve the most frequent meaning of the word (in this case, relating to the writing implement meaning; Twilley, Dixon, Taylor, & Clark, 1994). This frequency bias is likely to reflect some kind of learning mechanism that amasses frequency counts from experience of the usage of the ambiguous word over a long period of time.

Rodd et al. (2013) examined whether a recent experience with a particular meaning of an ambiguous word could alter the likelihood of retrieval of the different meanings. According to a kind of "knowledge crystallization" account, such an effect of recent experience would be unlikely, because frequency biases accumulated over many experiences across decades should not alter by a discernible amount on the basis of a single new encounter. However, an explanation that favours recent experience or maintains strong plasticity would suggest that meaning frequency biases should be more flexible. Rodd et al. tested these different accounts using a *word-meaning priming* paradigm.[1] Participants first encountered a set of ambiguous words embedded in spoken sentences that biased the subordinate (i.e., less favoured) meaning of the word (e.g., "A pen was used by the farmer to enclose the stock before he moved them to the market"). Participants were then tested on their comprehension of the primed ambiguous words—compared with a baseline unprimed condition—by presenting the ambiguous words in isolation as cues and asking participants to generate an associated word. Rodd et al. found that the proportion of associate responses consistent with the primed meaning rose from about 0.17 in the unprimed condition to 0.24 in the primed condition. A second experiment showed that the priming effect could not be explained simply in terms of standard semantic priming, which was more short-lived.

This word-meaning priming effect is relatively abstract, in that it applies regardless of whether the same or a different speaker is used for the priming sentence and the isolated cue word (Rodd et al., 2013), and transfers across spoken and written modalities (Gilbert, Davis, Gaskell, & Rodd, 2018). Although the delay used between exposure and testing was relatively long compared with many semantic- or form-priming studies (about 20 mins on average), this latency does not really provide much information about whether long-term lexical representations are being altered. Rodd et al. (2016) went further in mapping out the time-course of word-meaning priming effects. They compared (in Experiment 2) exposure-test latencies of 1, 20 and 40 min with an unprimed baseline, finding that all three latencies showed some priming of associate responses, but with the 1-min condition stronger than the two longer latency conditions. This was taken as evidence of a relatively fast-fading component of the priming. Three further experiments examined longer latencies in a more naturalistic design, with good evidence that priming effects showed gradual decay across a day, and that beyond a day these effects weakened and were no longer significant (Experiment 1, Experiment 4). Intriguingly, though, participants with specific repeated experience of particular meanings of words (rowers with esoteric meanings of words like "feather") showed an influence of that experience on the likelihood of retrieval of the esoteric meaning several hours after that experience (e.g., rowing early morning and testing in the afternoon).

Rodd et al. (2016) outlined a working model that might explain this complex pattern of priming effects. They argued that distributed connectionist models of ambiguous word representation and processing (Joordens & Besner, 1994; Kawamoto, Farrar, & Kello, 1994; Rodd, Gaskell, & Marslen-Wilson, 2004) provide a natural account of how meaning biases could be updated as a consequence of a recent experience via adjustment of the long-term weights between form and meaning units. This would make the primed meaning a little easier to access and the unprimed meaning(s) a little harder to access. This model, then, can quite easily explain the enhanced likelihood of accessing a primed meaning of an ambiguous word at a later timepoint. But is it also possible to explain the apparent decay in this effect that is seen across the course of the remainder of the day? Rodd et al. suggested that this could be a consequence of further learning and updating of weights in response to intervening unrelated language exposure, given the highly interconnected nature of representations in a distributed model of meaning. However, they also pointed out that the specific decay function observed in their studies, with strong decay initially and weaker decay later on, might be difficult to accommodate in such a model, speculating that multiple mechanisms might reasonably be involved.

Borrowing again from the memory literature, the apparent decay observed by Rodd et al. (2016) might indeed be a product of a second system involved in the priming of ambiguous word meanings. Several models of memory and forgetting have argued that the hippocampus incorporates a prodigious ability to encode new associations through pattern separation of sparse representations (Sadeh, Ozubko, Winocur, & Moscovitch, 2014; Yassa & Stark, 2011). This makes these representations resistant to interference, given that they have little overlap with other representations, but at the same time they are

[1] We use the term word-meaning priming for consistency with the prior literature on this paradigm. The term "priming" is used in its simplest sense, as a description of the facilitation of access to a particular meaning as a consequence of a prior stimulus presentation, rather than as a description of a particular mechanism.