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Competition from unseen or unheard novel words: Lexical consolidation across modalities

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ABSTRACT

In four experiments we investigated the formation of novel word memories across modalities, using competition between novel words and their existing phonological/orthographic neighbours as a test of lexical integration. Auditorily acquired novel words entered into competition both in the spoken modality (Experiment 1) and in the written modality (Experiment 4) after a consolidation period of 24 h. Words acquired from print, on the other hand, showed competition effects after 24 h in a visual word recognition task (Experiment 3) but required additional training and a consolidation period of a week before entering into spoken-word competition (Experiment 2). These cross-modal effects support the hypothesis that lexicalised rather than episodic representations underlie post-consolidation competition effects. We suggest that sublexical phoneme–grapheme conversion during novel word encoding and/or offline consolidation enables the formation of modality-specific lexemes in the untrained modality, which subsequently undergo the same cortical integration process as explicitly perceived word forms in the trained modality. Although conversion takes place in both directions, speech input showed an advantage over print both in terms of lexicalisation and explicit memory performance. In conclusion, the brain is able to integrate and consolidate internally generated lexical information as well as external perceptual input.

Introduction

As anyone who has ever attempted to learn a foreign language knows, successful storage of novel words is one of the keys to achieve competence. Furthermore, although the basis of our native language vocabulary is built during childhood, even word learning in our first language continues throughout life. We constantly enrich our mental lexicons as our environment presents us with neologisms, loanwords, or specialist terminology. While some of these novel words will first be encountered in speech, others are acquired in print, and some may never even be perceived in the other modality. It seems reasonable to assume, however, that the modality in which a word was initially acquired at some point in time ceases to influence lexical processing. For example, an individual may have learned the word *hippopotamus*[1] in its spoken form as a child, and first encountered the printed word *hippocampus* in a neuroscience textbook. This presumably does not stop these

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[1] Example from Henderson, Weighall, and Gaskell (2013).

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form-overlapping words from entering into lexical competition with each other, perhaps not even if this individual has never yet heard the spoken form of *hippocampus*. The present study explores if and how such cross-modal effects arise by investigating the role of modality in novel word learning.

One of the most astonishing features of first language vocabulary acquisition is the speed with which novel items are encoded: children excel at 'fast mapping' sounds to meanings (Carey & Bartlett, 1978). Adults appear to be capable of similarly rapid vocabulary acquisition, at least under certain circumstances. Indeed, Saffran, Newport, Aslin, Tunick, and Barrueco (1997) found young adults and first-grade children to be equally skilled at segmenting and storing novel words from a string of nonsense syllables in an incidental learning task. More recently, Shtyrov, Nikulin, and Pulvermüller (2010) reported a neurophysiological counterpart of these behavioural findings on the early stages of word learning. After as little as 14 min of passive listening, neural response patterns to novel words became qualitatively identical to those elicited by existing words, suggesting that memories of the novel words had been established.

While both children and adults are thus clearly able to form representations of novel words after minimal exposure, these findings do raise the question whether such rapidly created memories are of the same nature as the rich, stable, highly interconnected representations that constitute the mental lexicon. A recent line of research suggests that this is not the case, but that rapidly stored novel word memories and existing lexical representations initially rely on different memory systems with distinct neural substrates. Only after a post-learning consolidation period, during which they are integrated with the existing lexicon, are novel words thought to have acquired truly word-like properties and hence to be fully 'lexicalised' (Davis & Gaskell, 2009; Gaskell & Dumay, 2003).

According to the Complementary Learning Systems (CLS) framework (McClelland, McNaughton, & O'Reilly, 1995), this consolidation mechanism has its neural basis in the interaction between the medial temporal lobe, most importantly the hippocampus, and the neocortical memory system. The hippocampus serves as a fast-learning, temporary storage area, encoding novel information in a sparse and episodic fashion. Following encoding, a slower neocortical learning process takes place during which novel memories are integrated into the existing, widely distributed memory network. The latter process is thought to rely heavily on memory reactivation during sleep (e.g., Rasch, Büchel, Gais, & Born, 2007; Wilson & McNaughton, 1994). Thus, by gradually interleaving new and old information post-learning, the CLS account solves the problem of catastrophic interference (McCloskey & Cohen, 1989).

Successful memory integration is especially relevant in the context of word learning. Whereas tasks that simply measure recall or recognition of novel words may be performed based on the retrieval of purely episodic, non-lexical memory traces, the ability of those novel words to interact with the existing lexicon would be evidence that cortical, lexical representations have been formed. For example, a phenomenon central to most theories of spoken word recognition is lexical competition: a set of multiple candidates that match the incoming acoustic signal compete for selection, thus slowing down recognition of the target (McQueen, Norris, & Cutler, 1994). As argued by Gaskell and Dumay (2003), the ability of a novel word to enter into lexical competition with its existing neighbours can therefore be considered a strong test of lexical integration.

To test the hypothesis that lexical integration requires offline consolidation, Gaskell and Dumay (2003) familiarised subjects with spoken novel words (e.g., *cathedruke*) which overlapped phonologically with existing base words (e.g., *cathedral*). Immediately after training and on several subsequent days, subjects made speeded responses to the existing base words and control words in a lexical decision task. Reaction times to the existing base words increased, but only after a consolidation period of several days, suggesting that offline consolidation indeed plays a role in word learning. Certain paradigms, including Hebbian learning (Szmalec, Page, & Duyck, 2012) and interleaved training of novel and existing neighbour words (Lindsay & Gaskell, 2013), have been shown to evoke lexical competition effects within a single day in the absence of sleep. Nonetheless it is evident that, like non-linguistic memory consolidation, novel word integration is facilitated by offline consolidation and particularly sleep (Dumay & Gaskell, 2007; Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010).

Although most work on novel word integration has used auditory paradigms, consolidation effects have also been observed in visual word recognition. Bowers, Davis, and Hanley (2005) taught participants novel word forms in a typing task, and subsequently measured reaction times to existing orthographic neighbours in a semantic decision task. As in the spoken-word literature, robust competition effects emerged only after a delay (in this case of 24 h). In a picture naming paradigm, Clay, Bowers, Davis, and Hanley (2007) furthermore observed a consolidation-dependent interference effect when meaningful, visually acquired novel words were superimposed on semantically related pictures. Thus, at least when training and test modalities are consistent, consolidation effects occur both in spoken and printed word recognition. However, little is known about how these different modalities interact during encoding and consolidation of novel words.

Most current models of the bimodal lexicon assume a modality-specific word-form level that contains autonomous orthographic and phonological representations. These nodes have independent connections to the semantic level, that is, they are activated in parallel rather than serially (e.g., Caramazza, 1997; Grainger & Ferrand, 1994). This autonomy of representation does not imply isolation in processing, however: cross-modal connections are thought to link phonology and orthography at one or more processing levels. For example, in the Bimodal Interactive Activation model (Ferrand & Grainger, 2003; Grainger & Ferrand, 1994) phonological and orthographic representations of the same word are linked both through direct lexical facilitatory connections and by means of a sublexical bidirectional grapheme–phoneme conversion mechanism. Activation can spread cross-modally through these connections, and word recognition in both modalities should thus be affected by orthographic and phonological information.