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Interaction between episodic and semantic memory networks in the acquisition and consolidation of novel spoken words

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ABSTRACT

When a novel word is learned, its memory representation is thought to undergo a process of consolidation and integration. In this study, we tested whether the neural representations of novel words change as a function of consolidation by observing brain activation patterns just after learning and again after a delay of one week. Words learned with meanings were remembered better than those learned without meanings. Both episodic (hippocampus-dependent) and semantic (dependent on distributed neocortical areas) memory systems were utilised during recognition of the novel words. The extent to which the two systems were involved changed as a function of time and the amount of associated information, with more involvement of both systems for the meaningful words than for the form-only words after the one-week delay. These results suggest that the reason the meaningful words were remembered better is that their retrieval can benefit more from these two complementary memory systems.

1. Introduction

In everyday life, we regularly encounter novel words and new concepts, even as adults. How do we encode and consolidate novel words? The Complementary Learning Systems (CLS) account posits two memory networks that interact when we acquire new information (McClelland, McNaughton, & O'Reilly, 1995). The episodic memory network, with the hippocampus as the critical component, is important at the initial stage of learning when discrete episodes of experiences are encoded (e.g., an experience of hearing a novel word). After a subsequent period of consolidation, a shift towards more systematic, lexicalised coding of the memory representation in a distributed neocortical network occurs. The current study explores this consolidation process for words learned with and without meanings.

Through consolidation, novel words become integrated into the existing mental lexicon. It is after this integration process that interaction between novel words and existing words is observed (Davis & Gaskell, 2009). Multiple studies have shown that this lexical integration effect can be measured behaviourally as a slowing down of processing of those existing words with which the novel words overlap in word-form (Bakker, Takashima, van Hell, Janzen, & McQueen, 2014; Davis, Di Betta, Macdonald, & Gaskell, 2009; Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; Henderson, Weighall, Brown, & Gaskell, 2013). In these studies, participants were taught novel words such as *cathedruke* (a word derived from the existing word *cathedral*) and then tested on the detection of a pause in the base words from which the novel words were derived (e.g., *cathe--dral*). It was hypothesised that once the novel words are integrated into the mental lexicon, they should interfere with the processing of phonologically neighbouring words. As a consequence, slowing down of responses in the pause detection task should be observed for the base words (*cathedral*) of the trained novel words (*cathedruke*). This phenomenon was indeed observed, but was found in several studies only after a delay of 24 h or a week (Bakker et al., 2014; Gaskell & Dumay, 2003). Sleep is thought to be one of the driving factors of this integration process (Dumay & Gaskell, 2007; Tamminen, Payne, Stickgold, Wamsley, & Gaskell, 2010), although some studies

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suggest that sleep may not be necessary and that consolidation can be found directly after training (Kapnoula, Packard, Gupta, & McMurray, 2015; Lindsay & Gaskell, 2013; Szmalec, Page, & Duyck, 2012). Sleep seems to be, in any case, beneficial for the new words to be more fully integrated into the lexico-semantic network (Dumay & Gaskell, 2007).

This lexical integration effect was originally tested for novel word forms learned without meanings. Recently, integration of novel words with meanings has also been observed, both at the word-form level (Takashima, Bakker, van Hell, Janzen, & McQueen, 2014) and at the word-meaning level (Clay, Bowers, Davis, & Hanley, 2007; Tamminen & Gaskell, 2013; van der Ven, Takashima, Segers, & Verhoeven, 2015). In previous functional Magnetic Resonance Imaging (fMRI) work, we demonstrated that novel words elicited more activation in the neocortex after a 24-h consolidation period, suggesting a neocortical retrieval route for words that had undergone a period of consolidation (Takashima et al., 2014). This was more pronounced for spoken novel words associated with novel visual pictorial information (unfamiliar objects) compared to words learned only as meaningless phonological forms. In contrast, the behavioural lexical integration effect that emerged after 24 h was significant only for the form-only words. Why did the picture-associated novel words show less integration? We argued that the non-verbalisable nature of the pictures could have caused a delay in integration. In natural language learning, however, new words are normally accompanied by their corresponding conceptual meanings. In the present study, we aimed to find signatures of integration for phonological word forms associated with visual information by (1) testing at a delay of one week instead of 24 h, and (2) by making the visual referents easier to conceptualise (see Fig. 1).

One way to think of stabilisation of novel words from a systems-consolidation point of view is that with consolidation, the word becomes less dependent on episodic memory (a specific memory of the event in which a new word was acquired). Instead it becomes more conceptual in nature, that is, the word is no longer associated with the context in which it was experienced, but more with its concept or meaning. This semantic representation may be different from a memory representation of a word that comprises an experience. For example, one might associate the novel word *kathedrook* with a Japanese harp-like instrument upon seeing the object and hearing the word. Remembering the experience of seeing an actual *kathedrook* and hearing its name involves retrieving an episodic memory, whereas being able to describe what a *kathedrook* is would depend on processing in the semantic memory system. These two representations, even though they both refer to the object *kathedrook*, may be stored in different structures of the brain or may be accessed via different memory networks. The hippocampal episodic network is likely to be utilised when we remember the experience of seeing an object and hearing its name (Moscovitch, Nadel, Winocur, Gilboa, & Rosenbaum, 2006; Squire & Knowlton, 1994), whereas the semantic memory system, in a distributed neocortical network, is likely to be utilised when we retrieve the semantic information associated with the word (Binder & Desai, 2011; Martin & Chao, 2001; Patterson, Nestor, & Rogers, 2007; Price, 2010). After some time, we might not remember exactly where or when we encountered new words, but we nevertheless remember many of them and know what they mean. This is because the nature of the two memory systems differs: the episodic hippocampal memory is prone to decay over time, whereas the semantic memory is more stable over time.

The second aim of this study was to investigate the stability of novel semantic memory representations. We measured response latency on a task in which participants retrieved the matching referent when cued with a trained novel word, just after training (association memory test, Day1) and again after a week's delay (Day8). If the referent is presented in a form that is not exactly the same as the one shown during the training, but still refers to the same concept, one cannot rely on episodic memory to perform this task. In order to choose the correct referent, one would instead have to rely on generalised semantic memory. We tested the accuracy and latency of retrieval by presenting referents in the same way as during training (Meaning-same condition) and in a different form (Meaning-similar condition). For example, if they were trained on the word *kathedrook* in association with a photo depicting the word, they will have the same photo that was shown during the training as the correct response option for the Meaning-same condition at test, whereas for the Meaning-similar condition, another photo of a *kathedrook* would be presented (see Fig. 1). We hypothesised that participants would be more accurate and faster in choosing the associated meaning information if associative memory strength was stronger. Referents that were the same as those presented during training could be chosen by accessing both the episodic memory representation and the lexical-semantic memory representation, whereas for physically different referents, access to a generalised semantic concept is necessary. Thus we assumed that reaction times (RTs) on the two association memory tests would be slower in the Meaning-similar condition than in the Meaning-same condition. After a delay, however, the Meaning-same condition may slow down due to decay of episodic memory traces, but this should not be the case in the Meaning-similar condition if semantic representations are stable over time.

In recent years, studies on the neural correlates of novel word representations have increased in numbers (e.g., Cornelissen et al., 2004; Davis et al., 2009; Mestres-Missé, Càmara, Rodriguez-Fornells, Rotte, & Münte, 2008; Paulesu et al., 2009; Takashima et al., 2014). Semantic representation is thought to be distributed across a wide range of cortical areas (reviewed in: Binder & Desai, 2011; Martin, 2007; Patterson et al., 2007; Price, 2010), and many of these regions have been reported to be involved in the processing of novel words as well. Semantic information can be related to modality-specific (e.g. visual, auditory, tactile) and more abstract verbal information, where sensory specific information is thought to recruit sensory-specific cortical areas (reviewed in Martin, 2007; Patterson et al., 2007). With respect to the processing of multi-modal information, Damasio introduced Convergence zone theory, which states that sensory-specific information converges into the multi-modal units in association areas of the brain (Damasio, 1989). Building on this theory, Simmons and Barsalou (2003) proposed a hierarchical distribution model in which posterior regions are more modality specific, and anterior structures more modality general (further reviewed in Meyer & Damasio, 2009). Recent studies on the semantic system also suggest a role for posterior higher-order associative areas in the temporo-parietal junction including the angular gyrus, which acts as a convergence zone in a distributed semantic network (Binder, Desai, Graves, & Conant, 2009; Graves, Binder, Desai, Conant, & Seidenberg, 2010; Vandenberghe et al., 2013), and the posterior middle temporal gyrus, which acts as a lexical hub (Gow, 2012; Hickok & Poeppel, 2004, 2007). Concepts of novel words can be sensory-specific if the novel word is associated with input in a specific modality, such as visual or auditory information. It can also be more abstract in nature if the concept is conveyed verbally (e.g. reading the definition in a dictionary). Does the representation of a novel word differ according to the type of conceptual information that accompanies it? To our knowledge, no imaging study has systematically compared the impact of different types of conceptual information on novel word learning and consolidation. The third aim of the present study was therefore to investigate whether there are differences in the consolidation trajectory when novel word-forms were associated with verbal versus pictorial referents.

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