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Semantic categorisation of a word supports its phonological integrity in verbal short-term memory

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ABSTRACT

In three immediate serial recall (ISR) experiments we tested the hypothesis that interactive processing between semantics and phonology supports phonological coherence in verbal short-term memory (STM). Participants categorised spoken words in six-item lists as they were presented, according to their semantic or phonological properties, then repeated the items in presentation order (Experiment 1). Despite matched categorisation performance between conditions, semantically-categorised words were correctly recalled more often than phonologically-categorised words. This accuracy advantage in the semantic condition was accompanied by fewer phoneme recombination errors. Comparisons with a no-categorisation ISR baseline (Experiment 2) indicated that, although categorisations were disruptive overall, recombination errors were specifically rarer following semantic categorisation. Experiment 3 replicated the key findings from Experiment 1 and also revealed fewer phonologically-related errors following semantic categorisation compared to a perceptual categorisation of high or low pitch. Therefore, augmented activation of semantic representations stabilises the phonological traces of words within verbal short-term memory, in line with the "semantic binding" hypothesis.

Introduction

A wealth of evidence demonstrates that knowledge of the sounds and meanings of words supports their maintenance within verbal short-term memory (STM). Measures of immediate serial recall (ISR) – where a sequence of verbal material is immediately repeated back in order – consistently show higher accuracy for familiar words compared to unfamiliar nonwords (e.g., Hoffman, Jefferies, Ehsan, Jones, & Lambon Ralph, 2009; Hulme, Maughan, & Brown, 1991; Hulme, Roodenrys, & Brown, 1995; Jefferies, Frankish, & Lambon Ralph, 2006a, 2006b; Saint-Aubin & Poirier, 1999, 2000; Thorn, Gathercole, & Frankish, 2005). The independent contribution of phonological knowledge to this effect is demonstrated by recall/repetition advantages for phonologically-familiarised nonwords (or otherwise unfamiliar) stimuli compared to untrained items (Majerus, Linden, Mulder, Meulemans, & Peters, 2004; Melby-Lervåg & Hulme, 2010; Savill et al., 2015) and effects of phonotactic frequency on ISR accuracy (Thorn & Frankish, 2005). Meanwhile, independent influences of semantic knowledge are revealed by the impact of semantic manipulations such as word imageability/concreteness (Bourassa & Besner, 1994; Caza & Belleville, 1999; Jefferies et al., 2006a; Majerus & van der Linden, 2003; Romani, McAlpine, & Martin, 2008; Walker & Hulme, 1999) and by neuropsychological studies of word recall deficits in patients whose semantic knowledge is impaired (Jefferies, Jones, Bateman, & Lambon Ralph, 2004, 2005; Majerus, Van der Linden, Poncelet, & Metz-Lutz, 2004; Martin & Saffran, 1997; Patterson, Graham, & Hodges, 1994).

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The explanations offered for these phenomena tend to attribute them to processes either (a) at the point of recall, where the accessibility of the lexical forms of words in long-term memory (LTM) influences the likelihood of correctly restoring the degraded phonological trace ('redintegration'; Schweickert, 1993; see also Hulme et al., 1991, 1995, 1997; Saint-Aubin & Poirier, 2000), or (b) prior to recall, with temporary activation of long-term linguistic representations directly supporting STM (hereon referred to as 'language-based' accounts'; Acheson & MacDonald, 2009; Majerus, 2013; Martin & Saffran, 1997; Patterson et al., 1994). In redintegration accounts, long-term linguistic knowledge facilitates item reconstruction, with little provision for improved order memory (beyond recall of existing inter-item associations; Stuart & Hulme, 2000), while in language-based accounts it influences phonological encoding and maintenance of the sequence: phonological–lexical and semantic knowledge is thought to contribute to phoneme order memory (Hoffman et al., 2009; Jefferies, Frankish, & Noble, 2009; Jefferies et al., 2004, 2006a; Patterson et al., 1994) while syntactic knowledge supports word order (Acheson & MacDonald, 2009). These broad perspectives offer different predictions regarding how and when semantic representations influence recall. According to the redintegration account, LTM representations accessed at recall would most likely influence the rate of items recalled in *any* position (i.e., an increase in targets reconstructed successfully both in and out of position. In contrast, language-based accounts make specific predictions about the effect of semantic knowledge on phoneme ordering in STM (cf. "semantic binding hypothesis").

Most studies of verbal STM have examined item and order recall at a whole-item level (i.e., whether items are recalled in the correct serial position, or out of position, or not recalled at all) but have not examined recall at the phoneme level. The current study analyses phoneme-level errors to examine the predictions of the semantic binding hypothesis, which holds that both phonological–lexical and semantic-level representations support the coherence of phonological representations in STM. This hypothesis (Patterson et al., 1994), inspired by parallel-distributed-processing (PDP) models of language, holds that prior exposure to the sequence of speech sounds that comprises a known word influences the likelihood of those speech sounds emerging together at recall, while the semantic activation that co-occurs with a word's phonological form over time provides a second source of constraint. A loosening of lexical/semantic constraints – when lexical/semantic activation for target items is relatively weak – should therefore particularly increase the likelihood of phonemes breaking away from list items and migrating between them. This pattern is evident in recall errors made by semantic dementia patients to words with degraded semantic representations whose phonological task performance is otherwise normal ('mint, rug' → 'rint, mug') (Jefferies et al., 2005; Majerus, Norris, & Patterson, 2007; Patterson et al., 1994) and in errors to words and nonwords when they are mixed together in a list (Jefferies et al., 2006a). Yet there is difficulty in establishing whether such effects are semantic or largely lexical (since the contribution of phonological–lexical and semantic information from known words is often confounded) (Jefferies et al., 2006a; Papagno, Vernice, & Cecchetto, 2013).

One way to test for purely semantic effects is to examine the phonological coherence of lists while manipulating the degree of semantic activation during encoding. Acheson, MacDonald, and Postle (2011) disrupted semantic processing for list items using irrelevant category judgments to pictures presented concurrently. They found increased item order errors in ISR for concrete words but not for nonwords, relative to non-semantic orientation judgments. While that study supports the view that semantic activation influences serial ordering in STM, compatible with language-based accounts, the mechanism underpinning the effect remains unclear for two reasons: (i) dual-task testing continued during recall itself, which could disrupt semantically-driven redintegrative processes; and (ii) the increase in item order errors during semantic categorisation may have reflected an increase in phoneme movement at the sub-item level (in line with the semantic binding account). Given the nature of the stimuli and strategic editing of responses to produce real words, such phoneme movement could have produced whole-item order errors.

The present study

The following experiments took a similar approach to Acheson et al. (2011) but addressed the question of whether influencing semantic activation of items *at encoding* would impact upon their phonological coherence in subsequent serial recall (i.e., ordering at the sub-item level), as predicted by the semantic binding hypothesis. Rather than manipulate ISR stimuli or disrupt semantic activation with an unrelated task, we biased the activation of language representations with encoding tasks that directed attention to different aspects of the stimuli. Word lists were carefully constructed to enable tracking of phoneme migrations between words without their potential categorisation as whole word movement and to match for linguistic properties between list sets. Since, in each experiment, the word properties and recall task were matched between categorisation conditions, any difference in ISR between conditions would be attributable to the encoding state (differences which would not be expected in the case of a redintegration mechanism operating in isolation). In two experiments (Experiments 1 and 3), participants categorised spoken words according to a semantic or phonological property ('natural or man-made' or 'long or short vowel' respectively) – or, in Experiment 3, also a perceptual property ('high or low pitch') – and, after categorisation of the sixth word, verbally recalled the stimuli in sequence. In each case, participants were told which categorisation decision to make prior to the first list item to minimise interference with the phonological trace to be recalled. Following the semantic binding hypothesis, we predicted more phonologically coherent item recall – measurable in terms of *fewer phonologically-related errors* (i.e., where phonemes have broken away from the target item, and may have recombined with phonemes from another item) alongside more accurate recall overall – for