



A familiar pattern? Semantic memory contributes to the enhancement of visuo-spatial memories

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ABSTRACT

In this study we quantify for the first time electrophysiological components associated with incorporating long-term semantic knowledge with visuo-spatial information using two variants of a traditional matrix patterns task. Results indicated that the matrix task with greater semantic content was associated with enhanced accuracy and RTs in a change-detection paradigm; this was also associated with increased P300 and N400 components as well as a sustained negative slow wave (NSW). In contrast, processing of the low semantic stimuli was associated with an increased N200 and a reduction in the P300. These findings suggest that semantic content can aid in reducing early visual processing of information and subsequent memory load by unitizing complex patterns into familiar forms. The N400/NSW may be associated with the requirements for maintaining visuo-spatial information about semantic forms such as orientation and relative location. Evidence for individual differences in semantic elaboration strategies used by participants is also discussed.

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1. Introduction

Our experience of the world consists of a series of complex objects and events which we perceive as a unified whole. Each component of an event or scene can be made up of multiple individual features such as colour, location and even function, each of which are proposed to be represented by separable subsystems within our memory. For example, multi-component models of working memory (e.g. [Baddeley, 2000](#); [Logie & van Der Meulen, 2007](#); [Pearson, 2006](#)) propose distinct systems responsible for the temporary storage and manipulation of verbal and visuo-spatial information within our environment, along with a central executive responsible for the co-ordination of these subsystems. Particularly relevant here, the processing and integration of information across such cognitive subsystems and the construction of coherent representations of the world around us, benefits greatly from prior experience and higher-level long-term knowledge. This link between long-term knowledge and working memory systems is so strong that some models of memory propose that working memory is made up of activated long-term memory representations and attentional control processes (e.g. [Cowan, 1999](#)).

In an experimental setting, behavioural research has demonstrated the critical role semantic long-term memory (SLTM) plays

in unitizing information and subsequently improving short-term memory for linguistic and visual information. In the verbal domain, working memory span for semantically linked words (e.g. from everyday sentences) is enhanced compared to span for random unrelated words ([Baddeley, Hitch, & Allen, 2009](#)). In the visual domain, [Avons and Phillips \(1987\)](#) demonstrate that memory for novel visual patterns is modulated by the degree to which SLTM can be recruited to unitize individual components of a novel pattern into a familiar form (e.g. recognising shapes and letters; see [Brown, Forbes, & McConnell, 2006](#)). Similarly, [Sun, Zimmer, and Fu \(2011\)](#) found expert participants (Chinese compared to German participants) were able to benefit from semantic knowledge on a memory task for Chinese and novel characters by extracting meaning from the stimuli even when the complexity of the task was manipulated (3–14 strokes). This level of semantic integration observed in laboratory tasks is employed seamlessly in everyday life; for example, when we perceive a mobile phone, we do not see a collection of plastic parts and buttons, we perceive a unified whole and remember the object as a single item. While previous literature supports the idea that SLTM can ‘scaffold’ visuo-spatial working memories, the neuro-cognitive mechanisms engaged during task performance remain unclear. In addition, relative to long-term verbal episodic memory discussed below, the concept of unitization and its role in supporting encoding during visuo-spatial working memory processing has been neglected.

The conceptualisation of unitization has benefited considerably from the wealth of research that already exists, related to successful episodic long-term memory. Research suggests that during

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encoding, binding individual features of an event into a single coherent representation can subsequently aid in the successful retrieval of episodic memories. This work has been framed within a dual process model of episodic memory which suggests both familiarity and recollection can contribute to successful retrieval of events in the world around us (see Yonelinas, 2002 influential 30 year review of recollection vs. familiarity). Recollection of an event is characterised by retrieval of an event with accompanying contextual and associative information and is involved during both item and associative recognition tasks. Familiarity processing does not necessitate the retrieval of such episodic richness and is largely recruited when item based memory judgements are made (Aggleton & Brown, 2006; Riby, Smallwood, & Gunn 2008; Smith et al., 2009; Tulving, 1985). Particularly relevant to the current investigation, under certain conditions familiarity can contribute to associative memory when individual features are bound together into a single representation. For example, during the encoding of word pairs such as “tree-house” the recruitment of pre-existing conceptual relationships can aid the unitization of the elements into a single unified whole (see for example Rhodes & Donaldson, 2008). Elsewhere, Greve, van Rossum, and Donaldson (2007) draw on early evidence from the ‘levels of processing’ literature and argue that the semantic content of the ‘to be remembered’ information enhances both behavioural and electrophysiological indices of successful associative memory. In that study, semantically coherent material in the form of related word pairs were proposed to be unitized into a single representation which enabled a subsequent shift in the use of familiarity based retrieval (indexed by an enhanced FN400 ERP and behaviour identified through the process dissociation procedure). Although the work proposing a critical role of semantic memory in the unitization process has been neglected in the visual domain other factors have been demonstrated to contribute to this unitization process. For example, Curby, Glazek, and Gauthier (2009) investigated the impact of expertise on Visual Short Term Memory (VSTM), and demonstrated that where a participant is an expert in a particular domain (e.g. cars) they are able to use this information to assist with unitization of the stimulus. In addition, further studies have investigated the impact of training participants through repetitive presentations of novel stimuli such as polygons and demonstrated an improvement in capacity for both trained and untrained polygons, suggesting a development of LTM expertise for the stimuli can enhance visuo-spatial capacity (Chen, Eng and Jaing, 2006).

The above mentioned research gives a flavour of the work that already exists regarding unitization and memory processing. Here, the aim was to capitalise on the temporal precision of event-related potentials (ERPs) and examine the electrophysiological components elicited during the integration of visual information and long-term knowledge. Two variants of a visual matrix task (Orme, 2009) that manipulates semantic relevance (easily labelled highly semantic patterns vs. difficult to label low semantic patterns) were employed to facilitate the differential engagement of SLTM operations. The task is an adaptation of the Visual Patterns Task (VPT; Della Sala, Gray, Baddeley, & Wilson, 1997); in this version of the task participants are presented with a matrix (ranging from 10 cells to 26 cells) with half the cells filled in black, following a delay they are then shown a second grid and asked to make a same/different judgement. The matrices presented have been classified in terms of participants ratings of pattern meaningfulness. Orme (2009) employed these patterns across a series of studies and demonstrated enhanced recognition memory for visual patterns which were rated as being greater in meaningfulness (high semantic patterns), when compared to those rated as less meaningful (low semantic patterns). In addition, with an encoding time of 1500 ms, the high semantic patterns were shown to be maintained without a significant drop in performance across maintenance

intervals increasing up to 11.5 s. In contrast, memory for the low semantic patterns decays over a period of 4.5 s. Neither the stability nor the overall superiority in memory for the high semantic patterns was removed by concurrent Dynamic Visual Noise (DVN). The stability for the high semantic patterns was shown to be removed by a reduction in encoding time (reduced to 500 ms) and by irrelevant speech. However, the overall superiority in memory for high semantic patterns remained.

Electrophysiological studies that have revealed a family of ERPs engaged during working and episodic memory encoding constitute the groundwork for the present investigation. Early studies focused on the well-established P300, deflections of which are thought to index memory storage and attention allocation (Polich, 2007 for review). Greater magnitude P300 deflections typically reflect encoding operations that lead to ‘rich’ memory representations and most successful remembering. For instance, in a ‘subsequent memory’ paradigm ERPs are greater for recalled vs. forgotten items, are enhanced for distinct easily memorable vs. frequent stimuli (Karis, Fibiani & Donchin, 1984), and are greater for ‘remember’ vs. ‘know’ responses (Yonelinas, 2002 for review). Increasing the demands of the ‘to be remembered’ information reduces the component amplitude (Morgan, Klein, Boehm, Shapiro, & Linden, 2008) and importantly task manipulations that promote the use of SLTM give rise to increased magnitude ERPs (Paller, Kutas, & Mayes, 1987). Closely related to the P300 and often occurring together, studies exploring visuo-spatial cognition have explored the importance of the earlier peaking N200. This component is modulated by stimulus complexity and resources associated with stimulus classification (e.g. Ritter, Simson, Vaughn, 1983). For example, increased amplitudes are observed for difficult compared to easy visual discriminations (Senkowski & Herrmann, 2002) and greater amplitude components are elicited for the more demanding processing of colour vs. spatial information (Morgan, Jackson, Klein, Mohr, Shapiro, & Linden, 2010). A study by Berti, Geissler, Lachman and Mecklinger (2000) assessed ERP components employed in a visual working memory task. In this task participants were asked to make same/different judgements using arrays of dots. In one condition, they were required to make a ‘same’ response if they array was identical in terms of shape and spatial orientation (Identity Comparison), in the second condition they were required to make a same judgment if the array was the same shape regardless of spatial orientation (Categorical Comparison). They observed enhanced negativity for arrays with eight elements compared to arrays containing only four elements, occurring at 350 ms. The authors argue that this represents a late N200 component indexing enhanced difficulty of stimulus classification. In addition, the categorical comparison condition gave rise to an enhanced P300 component when compared to the identity comparison condition, this is interpreted by the authors as representing an increase in the amount of information extracted from the stimulus. Overall, the N200 is a useful measure of selective attention to stimulus features (Luck, 2005 for discussion).

The N400 ERP has been at the heart of previous research on language processing and has also been elicited in response to visual stimuli and imagery-based processing that helps form coherent representations of the world. For example, Nittono and Hori (2002) investigated the notion that high imagery words are recalled better than the low imagery words, finding a larger magnitude N400 for the presumably deeper processed high imagery stimuli. They concluded that the N400 involved the activation of a semantic network responsible for imagery-based information. The N400 has more generally, been proposed as an index of the automatic activation of semantic networks (Kiefer, 2002). Here, we utilise this electrophysiological component to examine the facilitative role of semantic memory in unitization of visual features. In the visual domain, the N400 has been shown to be mod-

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