



Perceptual difficulty in source memory encoding and retrieval: Prefrontal versus parietal electrical brain activity

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ABSTRACT

It is well established that source memory retrieval – remembering relationships between a core item and some additional attribute of an event – engages prefrontal cortex (PFC) more than simple item memory. In event-related potentials (ERPs), this is manifest in a late-onset difference over PFC between studied items which mandate retrieval of a second attribute, and unstudied items which can be immediately rejected. Although some sorts of attribute conjunctions are easier to remember than others, the role of source retrieval difficulty on prefrontal activity has received little attention. We examined memory for conjunctions of object shape and color when color was an integral part of the depicted object, and when monochrome objects were surrounded by colored frames. Source accuracy was reliably worse when shape and color were spatially separated, but prefrontal activity did not vary across the object–color and frame–color conditions. The insensitivity of prefrontal ERPs to this perceptual manipulation of difficulty stands in contrast to their sensitivity to encoding task: deliberate voluntary effort to integrate objects and colors during encoding reduced prefrontal activity during retrieval, but perceptual organization of stimuli did not. The amplitudes of ERPs over parietal cortex were larger for frame–color than object–color stimuli during both study and test phases of the memory task. Individual variability in parietal ERPs was strongly correlated with memory accuracy, which we suggest reflects a contribution of visual working memory to long-term memory. We discuss multiple bottlenecks for source memory performance.

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Episodic memory is defined as inherently relational, or as Schacter and Tulving (1994, p. 28) put it, consisting of “multifaceted representations in which numerous different kinds of information – spatial, temporal, contextual, and so forth – are bound together”. However, different memory tests require retrieval of more or less information for successful performance. At one extreme are old/new recognition tests that require only an assessment of whether a stimulus was presented sometime in the laboratory experiment. In contrast, source memory tests are those that probe relational information more closely: what voice spoke a word, where was an object viewed, what color was a picture, was an action executed or only imagined, etc. (Johnson, Hashtroudi, & Lindsay, 1993). In these tests, memory for the core event – the word, object, or picture – is considered *item memory*, and *source accuracy* is defined by accurate retrieval of the additional information associated with that item. Introspection suggests that the strength of the binding between different bits of information varies both within

and across memories for individual events: we might remember the location of an event, but not the time, or the exact date of a conversation, but not the clothing of the participants, etc. Empirical results confirm that retrieval of multidimensional memories does not happen in an all-or-none fashion, but that some aspects of a single event can be remembered while others are not (Dodson, Holland, & Shimamura, 1998; Light & Berger, 1976; Meiser & Bröder, 2002; Starns & Hicks, 2005; Vogt & Bröder, 2007).¹

Demonstrations of the relative independence of different source attributes lead to a different question, namely, what determines which particular aspects of context will be bound to the core event during encoding and meet with retrieval success later? One clear

¹ Some of the papers cited here (Meiser & Bröder, 2002; Starns & Hicks, 2005; Vogt & Bröder, 2007) are concerned with the degree of independence of multiple source attributes in memory, and whether any stochastic dependence arises from self-cuing effects during retrieval (remembering one attribute triggers retrieval of others) or from the binding of attributes during encoding. The different studies reached different conclusions as to whether attributes show complete independence versus some degree of dependence, and regarding the mechanism of that dependence. However, all three reject the “all-or-none” account that memory for one source attribute necessarily entails memory for all source attributes.

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answer to this question is provided by the principle of transfer-appropriate processing (Morris, Bransford, & Franks, 1977), that source accuracy will improve to the extent that the relevant relationships are processed during the study phase. Light and Berger (1976) found that when subjects were instructed that they would be tested for their memory of words and their fonts, word/font conjunctions were better remembered than word/color conjunctions, and vice versa when subjects were instructed that the word/color relationships were critical. In a previous experiment closely related to the current design, we have shown that the nature of the encoding task is important even under intentional encoding instructions (Kuo & Van Petten, 2006). In that experiment, participants were always aware that the memory test would require judgments about drawings and their colors. In one session, however, they performed an item-oriented study task of judging the real-life size of the objects depicted in the drawings, while in another session they performed an integrative encoding task of judging object/color relationships as good (red stop sign) or bad (blue apple). The integrative encoding task produced no benefit for recognition of the objects as studied or unstudied, but boosted source accuracy for object–color relationships by some 14%.

1. Categorizing source attributes: the *intra-item* versus *extra-item* distinction

Leaving aside the benefits of an appropriate encoding orientation, it has long been suspected that some sorts of source information might be easier to remember than others, and/or rely on different retrieval strategies, and/or rely on different brain circuits. Multiple schemes for categorizing varieties of source attributes have been proposed. For instance, Johnson and co-workers suggested that internally versus externally generated information might be a natural division, one that makes it more difficult to discriminate two classes of perceptual information (as might arise in a test of deciding which of two experimenters spoke a word) than to discriminate a perceptual source from a self-generated source (as might arise in test of deciding whether a word was spoken by an experimenter or one's self; Hashtroudi, Johnson, & Chrosniak, 1989; Johnson et al., 1993). Moscovitch (1992) proposed a different fundamental division between “associative context” – aspects of an event that occur simultaneously and in the same location (e.g., perceptual source attributes) – and “organizational context” derived from considering an event in relation to other events (e.g., temporal sequence). A variety of data (briefly reviewed below) indicate that PFC plays a larger role in source memory tests than in episodic memory tests that do not focus on relational information (item memory tests). Moscovitch initially suggested that memory encoded by the hippocampal system can offer the multidimensional details of an individual event, but that prefrontal cortex must be engaged when a task necessitates organizing multiple events retrieved from the hippocampal system. In later work, the associative/organizational dichotomy evolved to differentiate perceptual attributes from the spatial and temporal context of even a single stimulus. The multiple perceptual attributes that make up a stimulus (e.g., shape and color) were hypothesized to be more tightly bound to each other than to (for instance) the location in which the stimulus was presented (Troyer, Winocur, Craik, & Moscovitch, 1999). This latter division echoed earlier suggestions that different encoding mechanisms promote memory for “intra-item” versus “extra-item” attributes (Geiselman & Bjork, 1980; Smith, Glenberg, & Bjork, 1978). Bjork and co-workers found that rote rehearsal selectively enhanced recognition of intra-item relationships (such as a word and a voice) but not extra-item attributes (such as a word and the room where it was heard).

The present experiment was designed to compare brain activity during the encoding and retrieval of intra-item versus extra-item source attributes. A handful of studies have compared these two varieties of context, but their links to brain activity have been indirect. Troyer and co-workers compared memory for the temporal order of words (extra-item) to memory for ink color (intra-item), and in a second experiment compared voice to spatial location. In both studies, assigning a secondary task during the encoding and retrieval phases led to a greater accuracy impairment for the extra-item (spatiotemporal) source tests than for the intra-item source tests (Troyer & Craik, 2000). Given the premise that attentional control critically involves prefrontal cortex (PFC), these results were taken as support for Moscovitch's (1992) suggestion that extra-item source memory is more demanding of PFC than intra-item source memory.

A second sort of indirect link comes from comparisons between young and old adults. Even healthy older adults show a disproportionate deficit in source memory tests as compared to item tests, and it has been argued that this deficit reflects a special vulnerability of PFC to aging (West, 1996, 2000). In a meta-analysis of 46 studies, Spencer and Raz (1995) indeed observed a greater age-related deficit in spatiotemporal source memory compared to perceptual source memory. This result might then argue that spatiotemporal source tests are more taxing of PFC than perceptual source tests.

Experiments that include measures of brain activity have, to date, not addressed the intra-item versus extra-item distinction in source memory. Instead, results from a variety of methods have consistently indicated that PFC is both strongly engaged by, and necessary for good performance in source memory tests under most circumstances. The role of PFC in the temporal organization of memory was initially discovered through studies on patients with frontal lobe damage (Milner, Petrides, & Smith, 1985; Janowsky, Shimamura, & Squire, 1989; see also Swick, Senkfor, & Van Petten, 2006 for a non-temporal source test in frontal patients). The relationship between PFC and spatiotemporal source memory was corroborated in healthy young adults via event-related potentials (ERPs) in list-discrimination and spatial source tests (Trott, Friedman, & Ritter, 1997; Van Petten, Senkfor, & Newberg, 2000). On the other hand, a number of ERP studies have also demonstrated engagement of PFC during source tests that tap conjunctions of perceptual attributes that might be considered “intra-item”, such as word-voice and object–color pairings (Friedman, Cycowicz, & Bersick, 2005; Senkfor & Van Petten, 1998; Kuo & Van Petten, 2006; Wilding, Doyle, & Rugg, 1995). Finally, ERPs have also shown greater prefrontal engagement when judging what encoding task accompanied a studied object than during old/new discriminations (Senkfor, Van Petten, & Kutas, *in press*; see also Johansson, Stenberg, Lindgren, & Rosen, 2002; Wilding, 1999 for related findings). This last variety of source memory test blurs the distinction between “intra-item” and “extra-item” attributes given that properties of an object determine the specifics of how an encoding task is carried out. Functional magnetic resonance imaging (fMRI) results have similarly shown greater prefrontal activity in source tests than old/new recognition tests, when the source tests require spatial or temporal judgments (Rugg, Fletcher, Chua, & Dolan, 1999; Slotnick, Moo, Segal, & Hart, 2003; Suzuki et al., 2002), perceptual judgments (Fan, Snodgrass, & Bilder, 2003; Ranganath, Heller, & Wilding, 2007; Ranganath, Johnson, & D'Esposito, 2000; Raye, Johnson, Mitchell, & Nolde, 2000), and judgments about the encoding task that accompanied a stimulus (Dobbins, Foley, Schacter, & Wagner, 2002; Dobbins & Han, 2006; Dobbins, Rice, Wagner, & Schacter, 2003). However, these observations of prefrontal activity across intra-item and extra-item source tests have little to say about the possibility that some varieties of

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