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Expectation affects learning and modulates memory experience at retrieval

Alex Kafkas*, Daniela Montaldi

Memory Research Unit, Division of Neuroscience and Experimental Psychology, School of Biological Sciences, University of Manchester, UK

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ABSTRACT

Our ability to make predictions and monitor regularities has a profound impact on the way we perceive the environment, but the effect this mechanism has on memory is not well understood. In four experiments, we explored the effects on memory of the expectation status of information at encoding or at retrieval. In a rule-learning task participants learned a contingency relationship between 6 different symbols and the type of stimulus that followed each one. Either at encoding (Experiments 1a and 1b) or at retrieval (Experiments 2a and 2b), the established relationship was violated for a subset of stimuli resulting in the presentation of both expected and unexpected stimuli. The expectation status of the stimuli was found to have opposite effects on familiarity and recollection performance, the two kinds of memory that support recognition memory. At encoding (Experiments 1a and 1b), the presentation of expected stimuli selectively enhanced subsequent familiarity performance, while unexpected stimuli selectively enhanced subsequent recollection. Similarly, at retrieval (Experiments 2a and 2b), expected stimuli were more likely to be deemed familiar than unexpected stimuli, whereas unexpected stimuli were more likely to be recollected than were expected stimuli. These findings suggest that two separate memory enhancement mechanisms exist; one sensitive and modulating the accuracy of memory for the contextually distinctive or unexpected, and the other sensitive to and modulating the accuracy of memory for the expected. Therefore, the degree to which information fits with expectation has critical implications for the type of computational mechanism that will be engaged to support memory.

1. Introduction

A fundamental function of the human mind is the ability to infer predictions and form expectations (Bar, 2009; Hunt & Aslin, 2001; Schacter, Addis, & Buckner, 2007). Apart from monitoring regularities in the environment, our brains also need to be able to learn from, and thereby adapt to, both expected and unexpected stimulus encounters. An important outstanding question, therefore, relates to the effect the level of expectation can have on the mechanisms brought into play at encoding and retrieval, and how these may selectively enhance different kinds of memory.

Indeed, adaptive behaviour dictates that the memorability of important, motivational or salient events is achieved by triggering a repertoire of orienting behavioural outcomes and by engaging a specialised network of brain regions (Kafkas & Montaldi, 2015a; Lisman & Grace, 2005; Shohamy & Adcock, 2010). On the other hand, evidence also supports the idea that expected information (e.g., as with schemas) can have an advantage in memory (e.g., Bein et al., 2015; Craik & Tulving, 1975). Expectation embedded in a sequence of events has been shown to affect perceptual discrimination and object categorisation (e.g., Bollinger, Rubens, Zanto, & Gazzaley, 2010; Posner, Snyder, & Davidson, 1980; Puri & Wojciulik, 2008). Nevertheless, the way expectation affects memory formation and retrieval has not been explored systematically. Understanding the interaction between expectation and new learning, or the retrieval of already learned information, can critically inform key areas of application, such as organised learning settings (e.g. educational institutions). In the current paper, a set of experiments is reported which systematically explored the effect of expectation on different kinds of memory using a paradigm especially designed to investigate memory formation and retrieval under different levels of expectation.

1.1. Context, expectation, familiarity and recollection

Here we define expectation as the "frame of reference" that describes the sequence of events within a context of temporally related events. Therefore, after establishing that an event A is always followed by event B; an event C is unexpected when following A, while B, is the expected event within the ABC context. In the following experiments, we manipulated expectations for newly learned sequences of events (contexts) and we investigated their effect on memory. The term *context* is used in different ways in the memory literature and in relation to

* Corresponding author at: Division of Neuroscience and Experimental Psychology, Zochonis Building, University of Manchester, Manchester M13 9PL, UK.
E-mail address: Alexandros.kafkas@manchester.ac.uk (A. Kafkas).

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episodic memory often denotes associative retrieval, but in the current experiments and subsequent discussion, *context* is used to describe structured sequences of temporally associated events, such as the ABC context explained above.

Our investigation focuses on recognition memory; the ability to judge whether a stimulus has been encountered before or not. According to the dual-process model (Mandler, 1980; Montaldi & Mayes, 2010; Yonelinas, 2002), this ability can be supported by two contributing kinds of memory. Familiarity memory describes the feeling of memory that a stimulus (e.g., a face) has been encountered before, without recovering additional associative details from a previous encounter. In contrast, recollection describes the feeling of memory that is driven by the retrieval of additional non-stimulus, associative details regarding a previous encounter with a stimulus; therefore, perhaps the name of the person or the place where we met them. Despite previous assertions that the difference between familiarity and recollection reflects differences in confidence (e.g., Donaldson, 1996; Wixted & Stretch, 2004; for an extension of this view in fMRI see Squire, Wixted, & Clark, 2007), we have repeatedly shown (e.g., Kafkas et al., 2017; Kafkas & Montaldi, 2012; Montaldi & Mayes, 2010) that these two types of memory can be matched for confidence (in terms of accuracy and subjective confidence). Therefore, the critical difference between familiarity and recollection is qualitative and determined by whether recognition is accompanied by cued recall of associative information (in recollection) or not (in familiarity) irrespective of the degree of memory confidence/strength (see also Methods for instructions given to participants).

Numerous studies have revealed that familiarity and recollection can be dissociated at the behavioural level as some variables have been shown to selectively affect only one kind of memory (e.g., Brandt, Gardiner, & Macrae, 2006; Gardiner, Gregg, & Karayianni, 2006; Gardiner, Gregg, Mashru, & Thaman, 2001; Gardiner & Richardson-Klavehn, 2000; Norman, 2002; Rajaram, 1993). It remains unclear, however, the extent to which expectations influence familiarity and/or recollection memory, and whether any effects are common to both kinds of memory. Traditionally, dual-process models of recognition memory (Mandler, 1980; Tulving, 1985) describe recollection as strongly dependent on the context in which encoding occurs as it involves the *reinstatement* of a previous encounter with a stimulus or event, and events always occur in some kind of context. In contrast, familiarity has traditionally been referred to as an automatic (Jacoby, 1991) and context-free form of memory. Thus, it is reasonable to argue that familiarity would not be influenced by the encoding or retrieval context (see e.g., Macken, 2002). However, some evidence for familiarity memory sensitivity to background context does exist (Ecker, Zimmer, Groh-Bordin, & Mecklinger, 2007; Tsivilis, Otten, & Rugg, 2001).

1.2. The effect of expectation on the encoding of information

The processing of information that takes place at encoding is critical for memory formation, as it may determine the extent to which successful memories are formed and the type of memory experienced later, at retrieval (Davachi & Dobbins, 2008; Kafkas & Montaldi, 2011; Paller & Wagner, 2002; Schacter, Norman, & Koutstaal, 1998). For example, the level of processing engaged in at encoding, determined by the nature of the task at hand when information is encoded, has been linked to different degrees of retrieval success in recognition and recall tasks (Craik & Tulving, 1975; Craik, 2002). Memory formation can also be manipulated by contextual factors that may be peripheral to the presented stimulus. For example, recognition and recall memory for word stimuli is enhanced when they are encoded in contexts congruent with pre-experimental knowledge (e.g., "Is a CORKSCREW an opener?") than when they are described in incongruous statements (e.g., "Is SPINACH ecstatic?") (Craik & Tulving, 1975; Schulman, 1974; Staresina, Gray, & Davachi, 2009). This *congruency effect* has been explained as a recollection enhancement effect, selective to the processing of congruent target words (Bein et al., 2015; Fisher & Craik, 1980).

Non-semantic contextual factors influencing processing at encoding that are not driven by pre-experimentally established semantic meaning should also affect memory encoding. For example, stimuli that are distinctive within a list context, perhaps due to a perceptual characteristic (e.g., larger font) or a semantic characteristic (e.g., "cat" among a list of inanimate object words) are recalled and recognised better than less distinctive items (the Von Restorff effect; Fabiani & Donchin, 1995; Rangel-Gomez & Meeter, 2013; von Restorff, 1933; Wallace, 1965). This effect suggests that the expectations that evolve during a series of temporally linked encoding episodes, may influence the on-going encoding operations and thus result in different memory outcomes at retrieval.

Indeed, in a recent study (Kafkas & Montaldi, 2015a) it was shown that encountering unexpected stimuli (as defined by the probability of occurrence of familiar and novel stimuli) at retrieval, triggered increased exploratory behaviour (revealed through eye tracking), leading subsequently to greater recollection. Moreover, this was shown to be supported, at the neural level, by increased connectivity between dopaminergic striatal/midbrain structures and the hippocampus, a structure that has a selective role in supporting recollection (e.g., Eichenbaum, Yonelinas, & Ranganath, 2007; Kafkas & Montaldi, 2012; Sauvage, Fortin, Owens, Yonelinas, & Eichenbaum, 2008). In the same study, encountering expected stimuli resulted in enhanced subsequent familiarity-based recognition.

The differential effect that contextual expectation at encoding may have on subsequent recollection and familiarity is further explored in the current experiments (Experiments 1a and 1b). Unlike in our previous study (Kafkas & Montaldi, 2015a), the expectation status of a stimulus in the current experiments is not defined by the probability of encountering a novel or a familiar item in a recognition list – a characteristic that is also directly related to the type of decision that participants were asked to make (i.e., whether an item is old or new). Rather, in the experiments reported here, the expectation for each stimulus is based on a preceding cue, whereby the relationship between the cue and the target was either consistent (expected) or inconsistent (unexpected) with a previously learned predictive rule. Critically, this expectation manipulation was incidental to the encoding task that participants were asked to complete. Finally, in order to measure the effect of context-based expectation at encoding on later familiarity and recollection, two different encoding tasks were employed; one optimised to predominantly support familiarity (free viewing task) and the other optimised to predominantly support recollection (semantic task).

1.3. The effect of expectation on information retrieval

Another outstanding question is how expectations operating at retrieval may affect memory and whether this effect may be similar or different from the effect of expectations at encoding. Some theories of recognition memory regard recognition decisions as inferential or *attributional* in the sense that feelings of familiarity are mediated by an attribution derived from the perceived ease, or *fluency*, with which a stimulus is processed (Jacoby & Dallas, 1981; Jacoby & Kelley, 1987; Jacoby & Whitehouse, 1989; Westerman, Lloyd, & Miller, 2002; Whittlesea & Williams, 1998, 2000; Whittlesea, 1993; Whittlesea, Jacoby, & Girard, 1990). Along these lines, Whittlesea (2003) proposed that recognition memory constitutes an active reconstruction of memories, based on the attribution of current experience to past events. This attribution may be modulated by characteristics of the presented stimulus, the task at hand, the context in which this process takes place, or a combination of these.

In a seminal study, Jacoby and Whitehouse (1989) explored the role played by attribution in recognition memory decisions by manipulating perceptual fluency of old and new words. They showed that fluent processing can be erroneously attributed to a previous encounter, when