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Memory-guided attention: Control from multiple memory systems

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Abstract

Attention is strongly influenced by both external stimuli and internal goals. However, this useful dichotomy does not readily capture the ubiquitous and often automatic contribution of past experience stored in memory. We review recent evidence about how multiple memory systems control attention, consider how such interactions are manifested in the brain, and highlight how this framework for 'memory-guided attention' might help systematize previous findings and guide future research.

Introduction

Visual attention is known to be controlled by two factors: stimulus salience (exogenous or stimulus-driven attention) and task goals (endogenous or goal-directed attention). While this dichotomy has proven highly impactful [1], it has overshadowed the contribution of a core aspect of cognition — *memory*. Indeed, memory may be fundamentally important in guiding attention: We repeatedly encounter similar objects and scenes, and prior experience might usefully guide us to information that has been helpful in the past or to new aspects of the environment.

Strict stimulus-driven and goal-directed accounts of attention cannot readily incorporate memory-guided attention. As in stimulus-driven attention, external stimuli are the catalyst for orienting, but differently, this orienting occurs because of their match to stored memories and not their inherent salience. As in goal-directed attention, orienting from memory depends on internal representations, but differently, such representations can guide attention reflexively without volitional control. The fact that memory-guided attention shares properties of both stimulus-driven and goal-directed attention has led to ambiguity in the field, and ultimately, to the view that the top-down/bottom-up dichotomy fails to adequately explain how attention is controlled [2]. We suggest that the impact of memory on attention may be most productively investigated outside the bounds of this dichotomy by considering the role of different memory systems.

Multiple Memory Systems

Memory refers to a diverse set of phenomena and thus may influence attention in many different ways. To catalog these forms of memory-guided attention, we rely on the *multiple memory systems* (MMS) theory. According to MMS, memory is broadly divided into explicit versus implicit (declarative versus non-declarative) types, each comprised of several neurocognitive processes [3]. Explicit memory refers to memory that is consciously accessible, and includes semantic memory (factual information) and episodic memory

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(specific events), as well as short-term or working memory (recently encountered information temporarily held in mind). These forms of memory can be contrasted with implicit memory, where past experiences influence present behavior without requiring conscious awareness or intentional effort. Implicit memory includes skill and habit learning, perceptual learning, associative learning, and priming. These distinctions are still actively debated, especially with respect to their implementation in the brain, but the general architecture of MMS may nevertheless provide a useful organizational scheme. Below, we spotlight recent empirical findings on how different memory systems can guide attention.

Priming

Extensive research has shown that repeated information is processed more rapidly than novel information. This facilitation typically occurs outside of awareness and is specific to the perceptual and cognitive processes shared across the repetition. Priming might influence attention in several ways. For example, repetition of a target's features across visual search trials improves the detection or discrimination of that target, a phenomenon known as *priming of pop-out* [4]. Moreover, priming may operate at longer timescales, such as when initially searching for the features of a target among heterogeneous distractors reduces subsequent attentional capture by task-irrelevant singletons among homogenous distractors [5].

Associative learning

Incidental learning about stable relationships in the environment is studied in several paradigms, including statistical learning, artificial grammar learning, and motor sequence learning. After the extraction of these relationships, exposure to one stimulus may usefully guide attention to the expected location or features of other stimuli. For example, targets are detected faster during visual search when they are embedded in repeated configurations of objects than when embedded in novel configurations, a phenomenon known as *contextual cueing* [6]. Attention may be drawn to stable relationships more generally, with temporal regularities receiving attentional priority over noisier sources of information even when they are task-irrelevant [7] (Fig. 1a).

Working memory

Compared to other forms of memory, working memory is perhaps the most interconnected with attention. Indeed, it is sometimes considered synonymous with goal-directed attention, reflecting sustained attention to internal representations over time [1]. Such internal attention can also have consequences for external attention: Stimuli in the environment that match the contents of working memory are more likely to be attended [8] (Fig. 1b). While working memory is clearly important for maintaining goals and task rules, the fact that this form of memory-guided attention can be automatic distinguishes it from accounts of goal-directed attention that emphasize its flexible and volitional nature.

Episodic memory

After one or more experiences with a specific event, episodic memory can be leveraged to find particular contents of that event. For example, when searching for a target object, the presentation of a familiar scene without the target (but which previously contained the target) facilitates subsequent target detection much like a spatial cue would [9] (Fig. 1c). Beyond orienting attention to aspects of the external world, the successful retrieval of episodic memories *per se* has been argued to capture internal attention in a manner analogous to perceptually salient stimuli (for debate, see [10]).

Semantic memory

By generalizing across numerous distinct episodes, semantic memory can influence attention in environments that are novel but nevertheless share features with the past. For example, global image statistics that predict the semantic category of a scene bias attention to the typical location of target objects in scenes from that category [11]. Moreover, attention can be rapidly drawn towards distractors that are semantically related to a target object, much as perceptual similarity with a target influences attention [12] (Fig. 1d). These examples reflect relatively automatic influences of semantic knowledge on attention (i.e., semantic priming), although presumably the same knowledge could be retrieved and used in a volitional manner.

Memory-Guided Attention

Much like memory, attention refers to a motley collection of phenomena in search of unifying principles [1]. Here we emphasize that sensitivity to prior experience might be one such principle, and that ignoring the contribution of memory may hinder a complete theory of attention. Complicating matters is the fact that all memory systems described above operate constantly and in parallel, and may meaningfully impact several components of attention. Thus, although memory is not often experimentally manipulated in studies of attention, it likely contributes to performance nonetheless. Here we propose that these mnemonic components of attention tasks can and should be identified. To this end, MMS provides a useful perspective with which to catalog and categorize the component processes involved.

If successful, investigating the contributions of memory to attention will benefit our understanding of attention in several ways. First, it will help explain variance in behavior: While almost all attention experiments treat each trial as a discrete event divorced from other trials, accounting for priming from previous trials and the distribution of cues and targets in the trial history may improve our ability to explain and predict behavioral performance. Second, this endeavor will help generate new hypotheses: Because memory impacts attention in neither a strictly goal-directed nor stimulus-driven manner, some rethinking of the mechanisms involved in controlling attention might be required when past experience is taken into account. For instance, working memory is used to maintain task rules and goals but can also guide attention automatically, raising important questions about the role of volition in goal-directed attention. Third, this endeavor will help organize attention findings: Identifying the mnemonic components of attention tasks will provide a common language for understanding attentional phenomena by grouping them based on, for example, the memory system involved, the reliance upon goal-directed attention, and the timescale of prior experience providing guidance.

More broadly, although there has been extensive research on how attention constrains learning and memory, the reverse interaction of how memory guides attention has received less study. We believe that a more comprehensive understanding of memory-guided attention will impact disciplines beyond the field of attention. In the memory literature, for example, there is active debate about the role of attentional processes in episodic memory retrieval [10]. Likewise in developmental psychology, memory-guided attention is already integral to looking-time and other habituation methods used to measure the perceptual and cognitive abilities of infants [13].

Future Directions

The systematic study of memory-guided attention is nascent, and there are several key aspects that require experimental evaluation. First, forms of memory-guided attention vary in the extent to which the influence of past experience on attention is *automatic*. This is also a distinction between stimulus-driven attention (more automatic) and goal-directed attention (less automatic), but the automaticity of guidance from memory may be unrelated to stimulus salience or goal relevance *per se*. Second, experimental context profoundly impacts how memory guides attention. The distribution of events over time can influence expectations, and ultimately the allocation of attention [14]. Moreover, attention can be drawn to either novel or familiar information based on the demands of the task context [13]. Third, different forms of memory are supported by distinct neural systems. How these systems interact with attention networks in the brain to guide attention remains largely unknown (Box 1).

Conclusions

Memory and attention are typically studied as separate parts of cognition. We have highlighted some of the important ways in which these parts interact, although much work clearly remains. The concept of memory-guided attention may eventually help us to better understand memory and attention in isolation, as well as to formulate a more integrated understanding of the mind and brain.

Acknowledgments

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Box 1

Neural mechanisms for implementing memory-guided attention

Attention is generally thought to operate on the cortical and subcortical pathways involved in perception. These pathways are hierarchical in nature, with increasingly complex representations formed as information travels from sensory receptors to association cortex. Goal-directed attention is controlled by higher-level regions of cortex (e.g., dorsal frontal and parietal cortex), which bias processing of competing neural activity in lower-level regions (e.g., occipital cortex). Bottom-up attention broadly refers to how salient stimuli registered by sensory receptors can reflexively bias processing in lower-level regions and certain higher-level regions (e.g., ventral parietal cortex).

In the case of memory-guided attention, the source of the attentional bias is unclear. Multiple memory systems are largely supported by distinct neural systems, each with unique topography, connectivity, and computational properties. Thus, there are numerous neural circuits through which memory could influence attention. A potentially fruitful direction for future research might be to isolate different neural signatures of memory and then test how they interact with known neural mechanisms of attention. Below we speculate about two general types of interaction between memory representations and attentional control processes based on whether memory is directly expressed in systems relevant for attention.

Indirect Route

This route refers to instances where mnemonic processing is largely performed in dedicated memory systems, beyond regions that control attention or are directly modulated by attention. To influence attention, these systems must generate a signal that informs the perceptual attention apparatus. For example, this type of memory-guided attention might describe how long-term memory processes supported by the medial temporal lobe engage the dorsal frontal-parietal spatial attention network [6, 9].

Direct Route

This route refers to instances where memory directly alters sensory representations competing for attention. Unlike above, the match of past experience with sensory input is not computed in a dedicated memory system, but rather occurs locally within brain regions responsible for perceptual processing. For example, the attenuated response evoked by repeated versus novel stimuli in selective areas of visual cortex (i.e., repetition attenuation [13]) might bias attention toward any novel stimuli simultaneously available in the environment, given their relatively stronger responses [15]. Moreover, if an association between stimuli is ‘hard-wired’ (i.e., no additional relational processing is needed for it to be expressed), such representations might underlie automatic forms of guidance from memory. This might explain, for example, why attention is drawn towards information in the environment that is semantically related to current task goals [12].

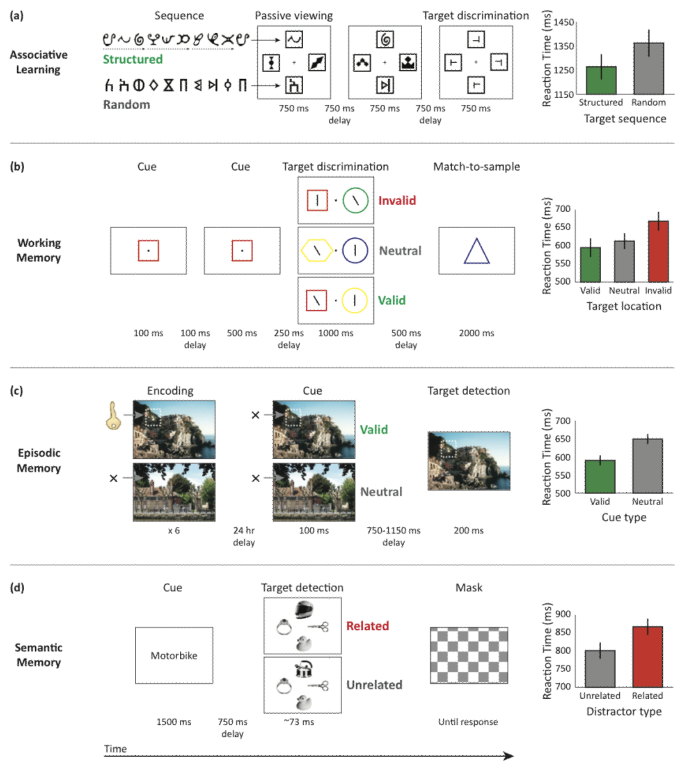

Figure 1. Behavioral examples of memory-guided attention

(a) Associative learning: Visual search arrays occasionally interrupted four parallel streams of shapes that were task-irrelevant. Targets were discriminated more quickly when they appeared at a stream location where the order of shapes was generated from hidden triplets that repeated over time ('structured') versus at a stream location where the order of shapes was shuffled ('random'), showing that attention is biased towards regularities [adapted from 7]. **(b)** Working memory: The orientation of the tilted line target was discriminated during the maintenance period of a delayed match-to-sample task. The target line appeared in a shape that matched the shape held in working memory ('valid'), the distractor line appeared in this matching shape instead ('invalid'), or the matching shape was not presented ('neutral'). Discrimination was slowest in the invalid condition, showing that attention is drawn towards the contents of working memory [adapted from 8]. **(c)** Episodic memory: Scenes that did ('memory') or did not ('neutral') contain a search target were encoded into long-term memory. The next day, these scenes were presented as cues, but now all without a target, followed by visual search for the target. Detection was faster after memory cues than after neutral cues, showing that episodic memory can guide attention to previously useful locations [adapted from 9]. **(d)** Semantic memory: Visual search arrays did ('related') or did not ('unrelated') contain a distractor that was semantically related to a verbally cued target object. Correct rejections were slower when related distractors were present, showing that attention is attracted to items that are semantically related to goal-relevant information [adapted from 12].