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Leveling the playing field: Attention mitigates the effects of intelligence on memory

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ABSTRACT

Effective attention and memory skills are fundamental to typical development and essential for achievement during the formal education years. It is critical to identify the specific mechanisms linking efficiency of attentional selection of an item and the quality of its memory retention. The present study capitalized on the spatial cueing paradigm to examine the role of selection via suppression in modulating children and adolescents' memory encoding. By varying a single parameter, the spatial cueing task can elicit either a simple orienting mechanism (i.e., facilitation) or one that involves both target selection and simultaneous suppression of competing information (i.e., IOR). We modified this paradigm to include images of common items in target locations. Participants were not instructed to learn the items and were not told they would be completing a memory test later. Following the cueing task, we imposed a 7-min delay and then asked participants to complete a recognition memory test. Results indicated that selection via suppression promoted recognition memory among 7–17 year-olds. Moreover, individual differences in the extent of suppression during encoding predicted recognition memory accuracy. When basic cueing facilitated orienting to target items during encoding, IQ was the best predictor of recognition memory performance for the attended items. In contrast, engaging suppression (i.e., IOR) during encoding counteracted individual differences in intelligence, effectively improving recognition memory performance among children with lower IQs. This work demonstrates that engaging selection via suppression during learning and encoding improves memory retention and has broad implications for developing effective educational techniques.

1. Introduction

Paying attention helps us form robust memories. Despite the centrality of these processes during development, identifying the mechanisms linking attention and memory within the context of individual differences in intelligence and developmental change has remained challenging. In the present study we focused on school-age children and adolescents to best expose these interactions during formal education years, when attentional strategies aimed at enhancing learning and memory might have lasting effects on achievement. We provide evidence that the nature of the underlying mechanism driving orienting has crucial implications for the efficacy of memory encoding for subsequent retrieval. Specifically, we show that selection mechanisms involving suppression have the power to boost memory encoding, effectively counteracting individual differences in intelligence.

Memory does not develop or function in isolation. Numerous studies have shown that effective attention

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allocation is necessary for successful memory encoding and retrieval. For example, memory performance suffers when attention is divided between two tasks (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Fernandes & Moscovitch, 2000) or distracted by irrelevant stimuli (Wais, Rubens, Boccanfuso, & Gazzaley, 2010). Cowan et al. (2005; Cowan, Fristoe, Elliott, Brunner, & Saults, 2006; Cowan, Nugent, Elliott, Ponomarev, & Saults, 1999) have shown that attention can influence both what information is selected for working memory as well as how much information can be retained in working memory. Recent work has also shown that cognitive control contributes to improved recognition memory performance by biasing selective attention towards task relevant versus task irrelevant information (Richter & Yeung, 2012).

Previous studies have also shown that cueing attention to relevant stimuli supports enhanced performance learning and visual short term memory tasks, both in adulthood (Hauer & MacLeod, 2005; Schmidt, Vogel, Woodman, & Luck, 2002) and during development (Astle, Nobre, & Scerif, 2012; Reid & Striano, 2005; Reid, Striano, Kaufman, & Johnson, 2004; Ross-Sheehy, Oakes, & Luck, 2011). For example, Astle et al. (2012) presented children with an array of multiple objects and later asked them to recall whether a single item had been present in the array. Children showed a significant improvement in this short-term memory task when the location of the relevant item was cued prior to presentation of the multiple item array, and, conversely, showed a significant deficit in visual short-term memory when an irrelevant location was cued prior to presentation of the object array. Critically, these examples reflect a well-established interaction between spatial attention and spatial working memory (Awh & Jonides, 2001; Chun, 2011; Fuster, 2000; Ikkai & Curtis, 2011). However, it remains unclear whether these effects extend to recognition memory processes that occur beyond the initial short-term representation and are classically relevant for building stable knowledge structures.

The present study extends previous work in several ways. First, we examined the role of selective attention in modulating memory encoding occurring at longer time scales, rather than focusing on short-term or working memory processes. Second, rather than treating attention as a unitary process, we instead compared the impact of different orienting mechanisms on memory encoding, allowing us to begin to tease apart the specific mechanisms of *how* selective attention influences memory encoding. Finally, we considered how these attention and memory interactions might vary depending on individual differences in intelligence and across a wide developmental range.

Selective attention reflects a continual balance between two primary components – enhanced processing of attended stimuli and concurrent suppression of irrelevant or unattended information (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000). Together, this dual excitation and suppression resolves the conflict between the numerous stimuli that are continually competing for our attentional resources. Previous research has shown that these processes are associated with differential activity in visual cortex, with enhanced signal associated with information appearing in attended locations and suppression of the signal associated with information appearing in unattended or competing locations (Brefczynski & DeYoe, 1999; Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Gandhi, Heeger, & Boynton, 1999; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999; Pestilli & Carrasco, 2005; Slotnick, Schwarzbach, & Yantis, 2003; Smith, Singh, & Greenlee, 2000). However, to our knowledge, no one has considered the impact of this modulation of visual cortex activity on memory encoding of the attended items.

Within this framework, attention orienting can be driven by different underlying mechanisms, some of which elicit the suppression component of selective attention while others do not (Posner & Cohen, 1984; Tipper, 1985). As such, the nature of the selection mechanisms underlying visual orienting, and particularly whether suppression is involved, may have important implications for subsequent encoding of the attended information. Our working hypothesis is that relative to selection powered by excitation alone, concurrent suppression at the unattended location should generate a signal for the attended information that is more robust and less susceptible to interference, thus supporting enhanced encoding for subsequent retrieval.

The present study utilized the spatial cueing paradigm (Posner, 1980) to examine the role of selection via suppression in modulating children and adolescents' recognition memory. In this task, attention is engaged at a central location while a cue flashes in the periphery. After a delay of varying length, a target appears in the same cued location or in the opposite, non-cued location. Following a very short cue-to-target delay (<250 ms) individuals typically respond faster to targets appearing in the cued location. This facilitation effect reflects a mechanism in which attention is reflexively drawn to the peripheral cue and remains engaged at the cued location when the target appears (Posner, 1980; Posner & Cohen, 1984). In contrast, following a longer (>250 ms) cue-to-target delay, attention instead becomes suppressed at the cued location and individuals respond faster to targets appearing in the opposite, non-cued location, an effect termed inhibition of return (IOR) (Klein, 2000; Posner, Rafal, Choate, & Vaughan, 1985). Unlike facilitation, IOR reflects a mechanism in which attention is enhanced at the non-cued location and concurrently suppressed at the cued location. Although traditional spatial cueing tasks use a single target, IOR nonetheless elicits a suppression effect that is similar to that observed when competing stimuli are present (McDonald, Ward, & Kiehl, 1999).

Thus, by varying a single timing parameter (the cue-to-target delay, see Fig. 1), the spatial cueing task can elicit either a basic orienting mechanism that involves excitation alone (i.e., facilitation) or one that involves both excitation and suppression (i.e., IOR). In the present study we capitalized on this nuance to directly compare children and adolescents' encoding and subsequent recognition memory in the context of basic excitation versus concurrent excitation and suppression. We modified the classic task by placing common object images for encoding in the attended locations. Following the spatial cueing/encoding phase, participants were tested on a standard recognition memory task.