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Current Opinion in Behavioral Sciences

Memory and the developing brain: are insights from cognitive neuroscience applicable to education?

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In this paper we present a succinct overview of the current knowledge about the neural correlates of memory development. Behavioral evidence strongly supports the view that developmental effects are specific to memory that is complex, and rich in contextual details. Neuroimaging evidence supports an emerging view that stability and change in memory functioning across age reflects the structural and functional maturation of the brain regions that support memory, particularly regions in the prefrontal cortex and the medial temporal lobe. Recent research efforts using functional neuroimaging have been directed to test hypotheses about the neural basis of age-related difference in memory capacities, prior knowledge, and effective use of strategies and metacognitive abilities. Additionally, we review recent evidence about how the development of the brain may set specific limits on, and present certain opportunities for, memory functioning. Finally, we discuss the challenges in applying insights from investigations into the neural basis of memory development to educational practices. We conclude that even though we have learned a great deal about the neural correlates of memory development, there are still several critical limitations in applying this knowledge to educational practices.

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Current Opinion in Behavioral Sciences 2016, **10**:81–88

This review comes from a themed issue on **Neuroscience of education**

Edited by **Dénes Szűcs**, **Fumiko Hoeft** and **John DE Gabrieli**

For a complete overview see the Issue and the Editorial

Available online 24th May 2016

http://dx.doi.org/10.1016/j.cobeha.2016.05.010

Introduction

Designing effective pedagogical methods depends upon teachers' scientific understanding of students' cognitive capacities in acquiring, maintaining and retrieving information at different ages. These capacities are contingent upon the students' young brains, as the development of the brain may set the limits and provide opportunities for their manifestation. Advances in neuroimaging methods and their growing application in cognitive neuroscience research have generated excitement that knowledge gained through these methods will be meaningful for education and perhaps be able to inform and improve classroom practices. Indeed, identifying the neural correlates supporting memory development is an area of significant current research efforts, propelled by the desire to seek a mechanistic understanding of memory development and the hope to empower education by such understanding. Below we review recent studies that contribute to the identification of the neural correlates of memory development. We show how these efforts align with decades-long investigations into the elements that govern memory development, and we further discuss how brain development may impose endogenous constraints on the development of human memory. We end with consideration of the current challenges, and future potential, of applying the knowledge gained from investigations into the neural basis of memory development to inform educational practices.

The cognitive neuroscience of memory development

A growing body of research in cognitive neuroscience is devoted to characterizing the trends of memory development. In this section, we highlight some important trends first from a cognitive perspective and then from a brain-based perspective.

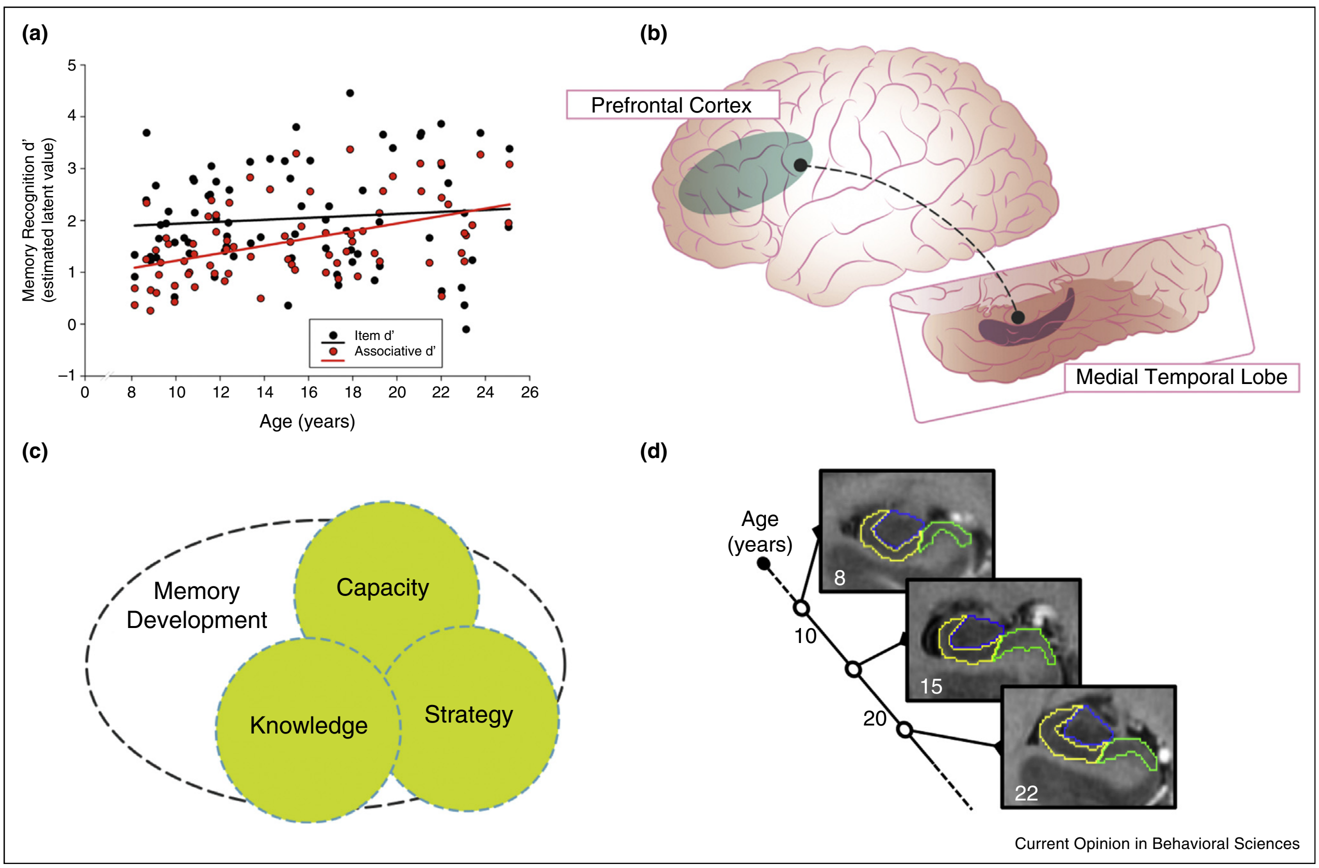
Cognitive perspective

Converging evidence suggests there exists little difference between children and adults when recognition is dependent primarily on the familiarity with studied materials; in contrast, there are large differences between children and adults for memories that depend on recollection of rich contextual details [1]. This notion has been further corroborated by recent studies using a wide range of experimental paradigms [2–6]. For example, Yim *et al.* [3] demonstrated that the ability to form memory with an increasingly complex relational context starts between the ages of 4 and 7 and continuously develops well into adulthood. The specific type of relational context may also determine the magnitude of developmental effects in the measured memory [4,6]. Finally, in a recent study Koenig *et al.* [5] used the process dissociation paradigm, to test developmental difference in familiarity and recollection processes. Participants studied a series of pictures with either one or two objects presented (e.g., two alligators, one glass) and tested for their recognition of the objects and for whether it was one or two objects that were presented during study. The combination of these testing conditions and an additional manipulation of the speed of response was used to show that although both familiarity and recollection processes are evident in children as young as 5 years, recollection is less robust in 5-year-olds compared to older children and adults. Overall, the recent behavioral evidence is consistent with the notion that age effects are found when the demanding aspects of memory are tested, and that children may rely more on a memory representations that retain less detailed information about the configuration and context in which the information was studied (see Figure 1a for an example).

Brain perspective

Developmental researchers in cognitive neuroscience aim to map the cognitive processes that constitute the developmental change in behavior to the brain. Among the multiple brain regions that support memory functioning, two key regions have been the focus of developmental studies: the prefrontal cortex (PFC) and the medial temporal lobe (MTL). A protracted structural development in the PFC is a consistent finding and is thought to underlie the well-documented increase in the recruitment of the PFC by children during memory encoding and retrieval [1,7–9]. In contrast, there are more modest changes in the MTL [10], and age effects in MTL

Figure 1



Toward a mechanistic understanding of memory development. **(a)** Behavioral evidence suggests that certain aspects of memory functioning are stable from middle childhood to adulthood, whereas others, which require detailed and flexible memory such as the ability to correctly recall specific associations, show protracted maturation. Memory sensitivity for item recognition (black) does not differ by age, whereas memory sensitivity for associative recognition (red) increases by age (adapted from [2]). **(b)** Memory development is linked to age difference in activation in key regions known to support memory, including the prefrontal cortex schematically shown on rendition of the lateral view of the brain and the medial temporal lobe shown on a partial rendition of a medial view of the brain. Additional evidence links memory development to age-related increase in the functional connectivity between these regions, represented by the line connecting the two regions. Original art by Julian Wong. **(c)** Decades-long answers to the question 'what is memory development the development of?' highlight the net effects of age differences in basic memory capacities, growth in the individual's knowledge base, and increase in the effective use of mnemonic strategies. **(d)** The development of the brain can be measured by comparing indices of regional volume. Because of the crucial role of the hippocampus in memory, recent advances in high-resolution structural imaging of the hippocampus and reliable methods of estimating regional hippocampal volumes constitute promising directions toward constructing a mechanistic understanding of how brain development supports the development of memory. Shown are example tracings of the hippocampal subfields on high resolution *in vivo* brain images obtained from a child, an adolescent, and a young adult.
Adapted from [38•].