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# Figural memory performance and functional magnetic resonance imaging activity across the adult lifespan

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## Abstract

We examined performance and functional magnetic resonance imaging activity in participants ($n = 235$) aged 17–81 years on a nonverbal recognition memory task, figural memory. Reaction time, error rate, and response bias measures indicated that the youngest and oldest participants were faster, made fewer errors, and showed a more conservative response bias than participants in the median age ranges. Encoding and Recognition phases activated a distributed bilateral network encompassing prefrontal, subcortical, lateral, and medial temporal and occipital regions. Activation during Encoding phase did not correlate with age. During Recognition, task-related activation for correctly identified targets (Hit-Targets) correlated linearly positively with age; nontask related activity correlated negative quadratically with age. During correctly identified distractors (Hit-Distractors) activity in task-related regions correlated positive linearly with age, nontask activity showed positive and negative quadratic relationships with age. Missed-Targets activity did not correlate with age. We concluded that figural memory performance and functional magnetic resonance imaging activity during Recognition but not Encoding was affected both by continued maturation of the brain in the early 20s and compensatory recruitment of additional brain regions during recognition memory in old age.

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*Keywords:* Healthy aging; fMRI; Nonverbal memory; Figural memory

## 1. Introduction

Normal aging is accompanied by changes in the structure and function of the brain, and these changes underlie the alterations in cognition and memory seen in old age. As the life expectancy of the population increases, so too does the burden of impairments associated with both normal and abnormal cognitive aging. One of the most commonly investigated effects in the cognitive aging literature is the reduction in memory function in older adults. Memory decline may occur as early as the 50s in otherwise healthy individuals, and it is thought to be due to problems with encoding and retrieval of new information (Beason-Held et al., 2005; Cabeza et al., 1997; Daselaar et al., 2003).

Typically, older adults perform worse than younger ones on tests of recognition memory (Grady, 2008; Rajah and D'Esposito, 2005; Salthouse, 2003, 2011). This decreased performance is often associated with changes in functional magnetic resonance imaging (fMRI) activity, both in regions activated by young participants, and in additional regions not activated by them (e.g., Cabeza et al., 2002; Daselaar et al., 2006; Grady, 2008). Overrecruitment of the latter regions has been attributed to either compensatory processes or dedifferentiation of function (Rajah and D'Esposito, 2005). According to the compensation view, age-related increases or decreases in activation in task-related regions represent functional deficits and concomitant activation increases in nontask-related regions represent an attempt to compensate for this deficiency. The strongest

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evidence for this hypothesis is when increased activity in nontask-related regions is accompanied by nonsignificant performance differences between young and old adults. Note however activation increases in nontask regions without concomitant performance improvement have also been interpreted as unsuccessful (or partially successful) compensatory attempts. Conversely, according to the dedifferentiation view, age-related activity changes reflect reductions in regional localization specificity. Activity spreads and neural regions become less functionally specialized due to changes in the specificity of neurotransmission. The dedifferentiation model posits that this spreading of activation may be beneficial or detrimental to performance—in other words, the model does not deny that some of this activation spread may benefit performance and therefore can be considered compensatory under certain circumstances. In their literature review, Rajah and D'Esposito (2005) concluded that different regions within the prefrontal cortex may show compensation or dedifferentiation under different task conditions.

In the general population, memory for pictures tends to be better than that for words—the "picture superiority effect" (e.g., Nelson et al., 1976; Paivio, 1971; Sternberg, 2006), a process that continues into very old age (> 90 years; Cherry et al., 2008; Ally et al., 2008). The mechanism of the picture superiority effect remains a matter of debate, but most major hypotheses posit that it relies on the ability to encode the picture both verbally and visually, whereas words are primarily encoded verbally. Recent research from Resnick and colleagues (Beason-Held et al., 2005, 2008a, 2008b; Golski et al., 1998; Maki et al., 2011) has focused on the development of the figural memory task, a visual recognition memory task that employs picture stimuli that are resistant to verbal encoding (Fig. 1). In a sample of elderly (63–82 years) participants, Beason-Held et al. (2005) demonstrated increases in regional cerebral blood flow using positron emission tomography (PET) in prefrontal cortex, anterior cingulate, lateral, and medial temporal and occipital regions during encoding of verbal and figural stimuli relative to baseline. PET provides a more direct measure of brain metabolism than blood oxygen level-dependent (BOLD) fMRI, however it also has some limitations. In addition to the issues with radiation exposure, PET also has a relatively limited spatial resolution and substantially poorer temporal resolution relative to BOLD fMRI (Huettel et al., 2004). Medial temporal regions exhibited greater regional cerebral blood flow during encoding of figural than verbal stimuli, suggesting that older adults use more resources to perform the figural compared with the verbal memory task. Because this study included only older adults with no younger comparison group, it is difficult to determine how these results fit with the dedifferentiation versus compensation hypotheses. The figural memory task has been specifically developed to measure changes in visual recognition with age, however to date there has been no systematic study of changes in performance or brain activation on the task associated with healthy aging.

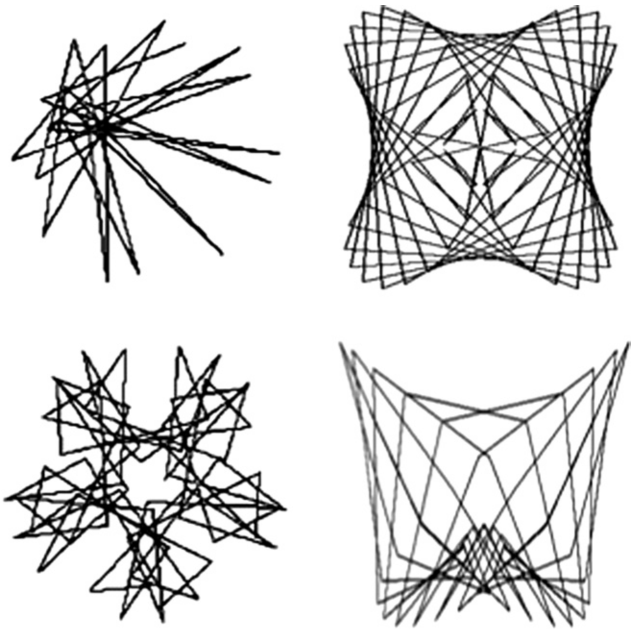

Fig. 1. Two examples of task-stimuli for the Figural Memory task. Top: examples of targets; bottom: examples of distractors.

In general, the vast majority of studies of cognitive aging compare young (approximately 20–30 years) and old (approximately 60–70 years) participant groups, or "young-old" (approximately 60–70 years) and "old-old" (approximately > 75 years) groups to examine the effects of age on memory. This artificial categorizing of age differs substantially between studies and vitiates the continuous nature of age as a variable. Implicitly, these studies assume that the performance of the young group represents an optimal baseline, and therefore changes relative to the young group represent age-related decline (Whitson et al., 2012) also that there is some discrete step from "intact" or "optimized" memory function to "impaired" or "deficient" memory function occurring somewhere in middle age. In a recent review of longitudinal and cross-sectional studies of memory and cognition across the adult lifespan, Salthouse (2011) showed that memory and cognition show both linear and quadratic relationships with age and concluded there is no evidence of a discrete step between a period of stability and a period of negative change. While the use of extreme age groups in the study of aging effects on memory and cognition can be more efficient for detecting age differences than can a continuous sample, it also inflates estimates of age relations, because variance associated with middle-aged adults is ignored and can potentially miss nonlinear relationships between age and memory.

In this study, we investigate changes in figural memory performance and associated neural activity across the adult age span. In a large ($n = 235$) sample with a wide age range

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