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Attentional Control in the Aging Brain: Insights from an fMRI Study of the Stroop Task

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Several recent studies of aging and cognition have attributed decreases in the efficiency of working memory processes to possible declines in attentional control, the mechanism(s) by which the brain attempts to limit its processing to that of task-relevant information. Here we used fMRI measures of neural activity during performance of the color–word Stroop task to compare the neural substrates of attentional control in younger (ages: 21–27 years old) and older participants (ages: 60–75 years old) during conditions of both increased competition (incongruent and congruent neutral) and increased conflict (incongruent and congruent neutral). We found evidence of age-related decreases in the responsiveness of structures thought to support attentional control (e.g., dorsolateral prefrontal and parietal cortices), suggesting possible impairments in the implementation of attentional control in older participants. Consistent with this notion, older participants exhibited more extensive activation of ventral visual processing regions (i.e., temporal cortex) and anterior inferior prefrontal cortices, reflecting a decreased ability to inhibit the processing of task-irrelevant information. Also, the anterior cingulate cortex, a region involved in evaluatory processes at the level of response (e.g., detecting potential for error), showed age-related increases in its sensitivity to the presence of competing color information. These findings are discussed in terms of newly emerging models of attentional control in the human brain.

Key Words: aging; fMRI; attentional control; stroop; competition; conflict; anterior cingulate; prefrontal cortex; parietal cortex.

INTRODUCTION

While researchers have a tendency to discuss attention and working memory in isolation of one another, advances in our understanding of cognitive neuroscience have made it clear that they are mutually dependent functions, sharing many of the same neural substrates (e.g., dorsolateral prefrontal cortex) (e.g., Baddeley, 1986; Cohen & Servan-Schreiber, 1992; Posner & Dehaene, 1994; Taylor et al., 1997; Wagner, 1999; Banich et al., 2000a, 2000b; MacDonald et al., 2000). For instance,

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working memory maintains representations of current task demands. Such representations are crucial to attentional processes responsible for selecting task-relevant representations and actions. Likewise, selective attention acts to limit the contents of working memory to task-relevant representations and actions. Furthermore, it can aid in prioritizing the contents of working memory. The interdependence of these and other cognitive functions (e.g., long-term memory) presents a major challenge to understanding the etiology of cognitive deficits associated with age (i.e., >60 years) (Salthouse, 1996). For example, researchers interested in understanding age-related declines in working memory performance must determine whether they are due to impairment of processes specific to working memory function (e.g., storage and maintenance of representations active within working memory) as opposed to impairment of related processes, such as aspects of attentional function (e.g., selection of the representations that gain access to, or are operated upon within, working memory).

In fact, recent studies suggest that age-related declines in working memory function are related to decreases in the effectiveness of selection processes. More specifically, with age (i.e., 60–75 years), working memory processes become increasingly susceptible to disruption by task-irrelevant information (West, 1999a, May et al., 1999). For example, West (1999a) found that when older adults attempted to retain the location of a target stimulus in working memory, the presence of a visual distractor impaired performance more than in younger adults. He concluded that age-related decreases in the ability to inhibit irrelevant information reduce the speed with which older adults can encode information in working memory. In another study of the impact of aging on working memory, May et al. (1999) found that age-related increases in susceptibility to proactive interference appear to be more influenced by changes in attentional mechanisms rather than decreases in the storage capacity of working memory. May et al. (1995) had a similar interpretation for age-related decreases in negative priming, arguing that increases in inhibition failures appeared to be more related to decreases in the efficiency of attentional than episodic retrieval mechanisms (but see Kieley & Hartley, 1997; Kramer et al., 1994). Decreases in the ability to discriminate between relevant and irrelevant information have also been noted in aging studies of off-target verbosity in natural speech (Gold, Andres, Arbuckle, & Schwartz, 1988).

Several researchers have suggested that the increased ability of irrelevant information to disrupt working memory processes can be attributed to an age-related decline in inhibitory function. For example, Hasher and Zacks (1988) have argued that there is a decline in the aging brain's ability to prevent the entrance of irrelevant information into working memory, to suppress irrelevant and nongoal oriented representations active within working memory, and to inhibit inappropriate responses (for alternative findings and views related to Hasher and Zack's theory, see Burke, 1997, & McDowd, 1997).

Current models of attention (e.g., Posner & Dehaene, 1994; Carter et al., 1995; Banich et al., 2000a, 2000b; MacDonald et al., 2000) posit that attentional control is responsible for inhibitory functions such as those described by Hasher and Zacks (1988). It is generally agreed that a distributed network of structures within the brain, including anterior cingulate cortex, prefrontal cortex, parietal cortex, extrastriate cortex, superior colliculus, thalamus, and the basal ganglia, supports attentional function. Under attentionally demanding conditions, top-down control or coordination of activity within the network of structures responsible for selection is required to enable complex goal-oriented behaviors (referred to as attentional control). For example, neural activity within processing systems containing task-relevant information needs to be amplified, whereas that of processing systems containing irrelevant and potentially interfering information must be decreased. With regard to working memory,