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Age-related differences in the involvement of the prefrontal cortex in attentional control

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ABSTRACT

We investigated the relative involvement of cortical regions supporting attentional control in older and younger adults during performance on a modified version of the Stroop task. Participants were exposed to two different types of incongruent trials. One of these, an incongruent-ineligible condition, produces conflict at the non-response level, while the second, an incongruent-eligible condition, produces conflict at both non-response and response levels of information processing. Greater attentional control is needed to perform the incongruent-eligible condition compared to other conditions. We examined the cortical recruitment associated with this task in an event-related functional magnetic resonance imaging paradigm in 25 older and 25 younger adults. Our results indicated that while younger adults demonstrated an increase in the activation of cortical regions responsible for maintaining attentional control in response to increased levels of conflict, such sensitivity and flexibility of the cortical regions to increased attentional control demands was absent in older adults. These results suggest a limitation in older adults' capabilities for flexibly recruiting the attentional network in response to increasing attentional demands.
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1. Introduction

Representations arising from distracting stimuli interfere with our ability to selectively attend to task-relevant information. The effect of such representations is heightened when the tendency to respond to distracting information is habitual or reflexive, resulting in the need for greater attentional control to perform important tasks. The classic color-word Stroop task has been extensively used in both the behavioral and neuroimaging literatures to study the mechanisms of attentional control (Banich et al., 2000, 2001; Bench et al., 1993; Desimone & Duncan, 1995). In the Stroop task, participants are asked to inhibit information from the pre-potent word representations and attend to the color in which the words are printed. Heightened attentional control is needed to resolve the interference on trials in which the color and word information are incongruent (e.g. the word 'BLUE' printed in red ink) compared to conditions in which the color and word information are not conflicting. Young adults during performance of the incongruent trials activate a network of regions including the bilateral middle frontal gyrus, bilateral inferior frontal gyrus, anterior cingulate cortex (ACC) and the parietal cortex (Banich et al., 2001; Bench et al., 1993) due to increased attentional control required to overcome the task-irrelevant dimensions of the incongruent condition.

Older adults, in comparison to young adults, are thought to have deficits in their ability to selectively attend to and ignore irrelevant information (see Hasher & Zacks, 1988; Kramer, Humphrey, Larish, Logan, & Strayer, 1994). For example, older adults often show performance deficits on the Stroop task, which is considered to be indicative of an age-related inability to effectively filter the task-irrelevant (word) information. Neuroimaging research has demonstrated increased recruitment of brain regions by older adults to perform cognitive tasks in which younger adults more selectively recruit neural resources (Cabeza et al., 2004; Colcombe et al., 2005; Langenecker, Nielson, & Rao, 2004). This increased recruitment of brain regions has been interpreted in a number of different ways with some researchers suggesting a compensatory role performed by the additional activation to counter the declines associated with advancing age. For example,

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Langenecker et al. (2004), using the Stroop task found that older adults showed more activation than younger adults in the premotor, dorsolateral, ventrolateral and medial frontal areas. Particularly, the study reported greater activation in the left inferior frontal regions by the older participants, thus arguing for the task-specific and supportive role of this region to overcome the greater interference experienced by older adults. Though this study did not report correlations between additional activation and behavioral performance, other studies (Cabeza et al., 2004; Reuter-Lorenz et al., 2000) using a variety of cognitive tasks have reported positive correlations between increased activation and behavioral performance in older adults. The additional recruitment of cortical resources by the better performing subgroup has been interpreted as compensatory processing, serving to deal with, at least in part, age-related inefficiencies in processing associated with different tasks.

Though a compensatory interpretation of additional activation in the presence of declining neural efficiency has some support, the recruitment of more cortical resources on relatively easy tasks might have hidden costs (Reuter-Lorenz & Lustig, 2005; Reuter-Lorenz & Mikels, 2006). Reuter-Lorenz and Mikels (2006) proposed that as a result of the need to allocate substantial cortical resources to tasks that younger adults find relatively easy, older adults have few resources available for more challenging tasks. This pattern of results has been termed the CRUNCH model or the compensation-related utilization of neural circuits hypothesis. According to this hypothesis, older adults show less of a difference compared with younger adults in the activation between two tasks or conditions that differ in difficulty. It is possible that such a finding would represent an age-related failure to flexibly allocate cortical resources with increasing task demands (see DiGirolamo et al. (2001) for a similar hypothesis).

In this study, we manipulated the level of conflict in the incongruent conditions of the Stroop task (Milhalm et al., 2001; Liu, Banich, Jacobson, & Tanabe, 2006) to examine differential recruitment of brain regions in both young and old participants. We presented a modified version of the Stroop task to our participants: older adults between 58 and 75 years of age, and younger adults between 18 and 35 years of age. In addition to the neutral (the word LAMP printed in red ink) and the congruent (the word RED printed in red ink) conditions we had two types of incongruent conditions (incongruent-eligible and incongruent-ineligible) enabling us to further study the effect of increases in conflict on behavioral performance and brain processes in younger and older adults. The paradigm was a three-choice manual response task, in which participants were asked to respond to the three ink colors (red, green or purple) using their right hand. An incongruent-eligible stimulus was one of the words from the set of colors that the participant could respond with (red, green or purple) printed in an incongruent ink-color (e.g. the word RED printed in green ink). An incongruent-ineligible stimulus, in contrast, was any color-word other than red, green or purple printed in an incongruent color (e.g. the word BLUE printed in green ink). For both these trials, the participants were asked to make responses (see Fig. 1 for a pictorial representation of the task). The main difference between the two incongruent conditions was that in the eligible condition the actual color-word was a part of the response set with which the participant could respond and hence greater response conflict. In the ineligible trials, the color-word was not a part of the response set.

Milhalm et al. (2001) employed this paradigm to investigate attentional control in young adults. They reported that young adults activated primarily the left prefrontal cortex during the incongruent-ineligible condition relative to the neutral condition. Performance on the incongruent-eligible trials relative to neutral

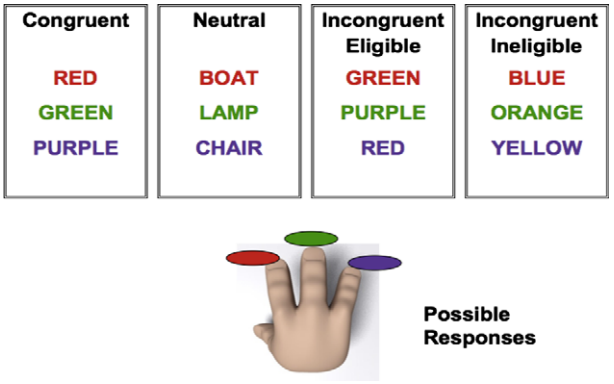

Fig. 1. Pictorial representation of the modified version of the Stroop task used in the study. Participants could only respond to three ink colors: red, green or purple. For the incongruent-eligible condition (third box) the word was one of the ink colors that the participant could respond with (red, green or purple) but printed in an incongruent ink-color (such as GREEN printed in red ink). For the incongruent-ineligible condition (fourth box), the word could be any color-word other than red, green or purple printed in an incongruent ink-color (such as the word BLUE printed in red ink).

trials resulted in greater activation in the left PFC along with additional activation in the right PFC and anterior cingulate cortex. The authors conceptualized the additional activation during the incongruent-eligible condition as being reflective of the differences in the amount of conflict experienced in the two tasks. That is, the incongruent-ineligible condition was thought to involve non-response conflict given that the word was not a part of the response set, while the incongruent-eligible condition was hypothesized to involve both response and non-response conflict.

Through this manipulation, we were interested in examining whether older adults have a reduced capability to flexibly allocate attentional resources. We used an event-related functional magnetic resonance imaging (fMRI) paradigm to investigate the recruitment of the prefrontal and parietal cortices in older adults in response to increased attentional demands on this version of the Stroop task. Previous studies using the traditional Stroop task have examined age-related differences in attentional control (see Langenecker et al., 2004; Milhalm et al., 2002) and in this study, in addition to examining cortical recruitment during the incongruent condition relative to the neutral condition, we examined the neural circuitry recruited by the older adults compared with the younger adults during the two incongruent conditions. This enables a unique comparison of the neural resources utilized by the two groups in response to increasing cognitive demands. We predicted that the older adults would demonstrate increased activation of the cortical resources in response to all conditions of the Stroop task, such that cortical resources recruited by the younger adults during the more challenging incongruent conditions would be recruited by older adults in response to the congruent and the neutral condition. In addition, we also predicted that older adults would recruit bilateral areas of the dorsolateral prefrontal cortex in response to the easier task condition (incongruent-ineligible), thereby leaving no additional resources for the more challenging condition (i.e. incongruent-eligible). In other words, as opposed to younger participants who would demonstrate an increase in activation in response to increases in conflict between the incompatible conditions, older adults would recruit similar brain regions in response to easier task conditions, supporting the claim that older adults have more difficulty flexibly and adaptively recruiting neural resources to assist task performance.