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Neural correlates of conceptual object priming in young and older adults: an event-related functional magnetic resonance imaging study

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ABSTRACT

In this event-related functional magnetic resonance imaging study, we investigated age-related differences in brain activity associated with conceptual repetition priming in young and older adults. Participants performed a speeded "living/nonliving" classification task with 3 repetitions of familiar objects. Both young and older adults showed a similar magnitude of behavioral priming to repeated objects and evidenced repetition-related activation reductions in fusiform gyrus, superior occipital, middle, and inferior temporal cortex, and inferior frontal and insula regions. The neural priming effect in young adults was extensive and continued through both the second and third stimulus repetitions, and neural priming in older adults was markedly attenuated and reached floor at the second repetition. In young adults, greater neural priming in multiple brain regions correlated with greater behavioral facilitation and in older adults, only activation reduction in the left inferior frontal correlated with faster behavioral responses. These findings provide evidence for altered neural priming in older adults despite preserved behavioral priming, and suggest the possibility that age-invariant behavioral priming is observed as a result of more sustained neural processing of stimuli in older adults which might be a form of compensatory neural activity.

1. Introduction

Normal aging is associated with declines in many cognitive functions including episodic memory, working memory, processing speed, and executive functions (Baltes and Lindenberger, 1997; Nilsson, 2003; Park, et al., 2001; Salthouse, 1996), but there is preservation in select cognitive domains such as verbal abilities and world knowledge (Goh et al., 2012; Park and Reuter-Lorenz, 2009; Park et al., 2002; for reviews, see Hedden and Gabrieli, 2004). A key cognitive function that is purported to remain relatively unaffected by age is implicit memory, which involves changes in behavioral performance—usually facilitation—because of prior stimulus exposure and priming that does not require conscious awareness. The facilitation typically takes the form of faster responses to a previously-presented stimulus or "prime," or recognition or production of the prime to a probe without awareness that the item had been processed earlier. Several studies have reported that priming is preserved in normal older adults (Ballesteros et al., 2008, 2009; Caggiano et al., 2006; Mitchell and Bruss, 2003; Wiggs et al., 2006), and even in Alzheimer's disease patients (Ballesteros and Reales, 2004; Ballesteros et al., 2007; for reviews, Fleischman, 2007; Fleischman and Gabrieli, 1998). Despite such age-invariant behavioral priming effects, it is still not clear whether the neural mechanisms supporting such implicit memory processes also show age-invariance between young and older adults. In at least 1 behavioral study, young adults showed stable priming effects for 1 week after initial testing, but older adults showed significant reduction in priming after only a day (Wiggs et al., 2006). Moreover, there is a great deal of evidence that both episodic memory and working memory are accompanied by increased neural activity with age that is typically viewed as compensatory (see Park and Reuter-Lorenz, 2009 for a review). In the present study, we investigated whether equivalent behavioral priming in young and older adults was associated with differences in neural activity, using a repetition (Rep) priming paradigm involving conceptual judgment of visual objects.

Neuroimaging studies of Rep priming in young adults have shown that activity is reduced in several brain regions when

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processing previously-encountered stimuli. This Rep-related suppression of neural activity or neural priming effect has been attributed to improved efficiency and decreased cognitive demands associated with repeated stimulus presentation (e.g., Buckner et al., 1998; Grill-Spector et al., 2006; Wig et al., 2009; for reviews see Henson, 2003; Schacter and Buckner, 1998; Schacter et al., 2007). In particular, neuroimaging studies of conceptual object processing in young adults have shown that repeated meaning-based classifications of visual objects reduced processing time and neural activity for repeated compared with new stimuli in several occipital/temporal regions, including the fusiform and middle occipital gyri, and left frontal cortices such as the lateral inferior prefrontal cortex (e.g., Buckner et al., 1998; Grill-Spector et al., 1999; Henson, 2003; Koutstaal et al., 2001; Schacter and Buckner, 1998; van Turennout et al., 2000; Vuilleumier et al., 2002; Wig et al., 2005; Zago et al., 2005). The frontal brain regions involved in these studies have been shown to mediate retrieval of semantic knowledge necessary to perform the conceptual tasks, whereas the occipital/posterior brain regions are involved in coding the perceptual representation of the stimuli (Bunzeck et al., 2006; Daselaar et al., 2005; Maccotta and Buckner 2004; for a review see Schacter et al., 2007).

In contrast to young adult studies, there have been relatively few neuroimaging studies on Rep priming in older adults, and these studies have reported mixed effects of age on neural priming (Bäckman et al., 1997; Bergerbest et al., 2009; Daselaar et al., 2005; Gold et al., 2009; Lawson et al., 2007; Lustig and Buckner, 2004; Olichney et al., 2010). In an early positron emission tomography study using a word-stem completion task, Bäckman et al. (1997) reported similar Rep-related blood flow reductions in the right extrastriate cortex as well as similar behavioral priming effects in both young and older adults. Using a living/nonliving word classification task, Lustig and Buckner (2004) found that both young and older adults showed equivalently faster response times for repeated compared with novel words along with decreases in activation in the left inferior frontal gyrus. In a perceptual Rep-priming task involving abstract shapes, Soldan et al. (2008) also found that older adults show reduced activation to repeated stimuli to the same extent as young adults in occipital regions. Gold et al. (2009) also reported age-invariant behavioral and neural priming on a verbal lexical-semantic facilitation task. In contrast to these studies, Daselaar et al. (2005) used a word-stem completion task and found less behavioral priming and less Rep-related activation reductions in older compared with younger adults in the left anterior superior temporal and right occipital regions. Similarly, Bergerbest et al. (2009) employed an abstract/concrete word judgment task and found similar behavioral priming in both age groups but smaller Rep-related activation reductions in older compared with younger adults in left prefrontal regions with additional Rep-related reductions in right prefrontal regions. Importantly, activation reduction in the right frontal regions correlated positively with a vocabulary measure in older adults suggesting a compensatory role for the additional right hemisphere recruitment in their study. Finally, given these mixed reports of age effects on neural priming across these studies that involve different types of tasks and stimuli, it is unclear if the neural system supporting priming across the brain is preserved in older adults.

In the present study, we investigated the effects of aging on neural priming in the whole brain, using an event-related functional magnetic resonance imaging (fMRI) experiment that involved an implicit conceptual priming task with repeated pictures of familiar objects. We reasoned that Rep of meaningful objects accompanied with a conceptual judgment task would engage semantic retrieval processes in the frontal regions, as word stimuli do, and additional perceptual processing in posterior regions, which might be less pronounced when processing word stimuli. Thus, we were able to examine age-related effects of neural priming in anterior and posterior parts of the brain and their role in behavioral priming within the same study. In addition, we chose pictures of familiar objects to reduce possible age-related variation related to differences in task difficulty (e.g., Soldan et al., 2008).

Because several studies have shown that younger and older adults exhibit equivalent behavioral priming effects, we expected age-invariant behavioral priming, measured as response time benefits, with object Reps. At the neural level, however, we considered that posterior attentional and perceptual processing of visual stimuli might operate with less specialization and efficiency in older compared with younger adults, a finding that has been reported in several previous studies (Carp et al., 2010; Chee et al., 2006; Goh et al., 2010; Huang et al., 2012; Park et al., 2004, 2012). Because stimulus processing in these posterior regions occurs with less fidelity with age, more neural resources in other brain regions such as in the frontal lobe are required to maintain equivalent behavioral performance (Goh et al., 2010; Gutchess et al., 2005; Park et al., 2004). Therefore, we hypothesized that less efficient stimulus processing in older adults' posterior brain regions and the accompanying greater frontal recruitment would be generally associated with less activation reduction to repeated stimuli compared with younger adults. Of note, to validate our sample's performance with previous studies, we also included a recognition test to behaviorally assess participants' implicit and explicit memory (e.g., Bergerbest, 2009; Lustig and Buckner, 2004; Soldan et al., 2008), expecting that relative to younger adults, older adults would show comparable implicit memory performance but worse explicit memory performance.

2. Methods

2.1. Participants

There were 19 young (mean age, 24.6 years; SD, 3.0, range, 20–32; 9 male and 10 female subjects) and 18 older adults (mean age, 66.3 years; SD, 3.8; range 61–72; 10 male and 8 female subjects) who participated in this study. All participants had an Mini Mental State Examination score >27 with mean 29.2 (SD, 1.1) and 28.3 (SD, 1.0) for the young and older adults, respectively. Participants were screened for counter-indications for magnetic resonance imaging scanning and health status, with the presence or history of clinical dementia, neurological disorders, stroke, depression, and cardiovascular disease as exclusionary criteria (although hypertension controlled with medication was not exclusionary). Additionally, participants underwent a brief neuropsychological test battery. The results can be found in Supplementary Table 1 and are within range of performance associated with normal age-related cognitive differences as reported in numerous previous studies (e.g., Park et al., 2002).

Visual acuity in the scanner was corrected to 20/20 on the Snellen Scale and participants with cataracts and macular degeneration were not included in this experiment. All participants gave informed consent for participation in the study, which was approved by the University of Illinois at Urbana-Champaign Institutional Review Board, and were remunerated for their participation.

2.2. Stimuli

The stimulus set for the fMRI experiment consisted of 48 color photographs of familiar objects selected from different libraries. The pictures were selected so that 24 items depicted living objects (e.g., tree, bear) and 24 items depicted nonliving objects (e.g., whistle, refrigerator). These living and nonliving items were equally