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Selective Attention to Emotion in the Aging Brain

Gregory R. Samanez-Larkin and
Elaine R. Robertson
Stanford University

Joseph A. Mikels
Cornell University

Laura L. Carstensen and Ian H. Gotlib
Stanford University

A growing body of research suggests that the ability to regulate emotion remains stable or improves across the adult life span. Socioemotional selectivity theory maintains that this pattern of findings reflects the prioritization of emotional goals. Given that goal-directed behavior requires attentional control, the present study was designed to investigate age differences in selective attention to emotional lexical stimuli under conditions of emotional interference. Both neural and behavioral measures were obtained during an experiment in which participants completed a flanker task that required them to make categorical judgments about emotional and nonemotional stimuli. Older adults showed interference in both the behavioral and neural measures on control trials but not on emotion trials. Although older adults typically show relatively high levels of interference and reduced cognitive control during nonemotional tasks, they appear to be able to successfully reduce interference during emotional tasks.

Keywords: aging, emotion, attention, prefrontal cortex, fMRI

A growing body of research suggests that the ability to regulate emotion effectively remains stable or even improves across the adult life span (Charles & Carstensen, 2007). Compared with their younger counterparts, older adults recover more quickly from negative emotional states, maintain positive emotional states better (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000), report superior emotional control (Gross et al., 1997; Lawton, Kleban, Rajagopal, & Dean, 1992; Tsai, Levenson, & Carstensen, 2000), and display less physiological arousal when experiencing negative emotions (Levenson, Carstensen, Friesen, & Ekman, 1991; Tsai et al., 2000). These somewhat surprising findings are often referred to as the paradox of aging: Despite age-related losses, well-being remains relatively high in old age. Socioemotional selectivity theory (Carstensen, 1992, 2006) contends that people prioritize well-being as time horizons grow shorter. Thus, aging is associated with increased motivation to maintain emotional balance, and consequently more cognitive and social resources are allocated to the regulation of emotion (Carstensen, 2006; Carstensen, Fung, & Charles, 2003).

Recent studies on cognitive aging have generated findings that are consistent with a theoretical formulation grounded in motivation. A number of studies using a variety of experimental methods have found that older adults selectively attend to positive stimuli and are more likely to retrieve positive memories than negative ones (Charles, Mather, & Carstensen, 2003; Fernandes, Ross, Wiegand, & Schryer, 2008; Isaacowitz, Toner, Goren, & Wilson, 2008; Isaacowitz, Wadlinger, Goren, & Wilson, 2006a, 2006b; Kennedy, Mather, & Carstensen, 2004; Mather & Carstensen, 2003). Our research team coined the term *positivity effect* to describe a motivated shift from a preference for negative information in young adults to a preference for positive information at older ages. Selective attention appears to play an essential role in positivity. When older participants are instructed to view stimuli "as if they are watching a movie" or to "let their attention wander," the positivity effect appears reliably (Charles et al., 2003; Isaacowitz et al., 2006a, 2006b; Mather & Carstensen, 2003). Consistent with a motivational formulation, however, when researchers assign older people different experimental goals—for example, to process (or otherwise operate on) both negative and positive experimental materials—the positivity effect is eliminated (Hahn, Carlson, Singer, & Gronlund, 2006; Leclerc & Kensinger, 2008; Mather & Knight, 2006). Mather and Knight (2005), providing particularly compelling support for a motivational formulation. First, they found that people with the highest levels of executive functioning displayed the most positivity; second, they showed that the preference was eliminated when cognitive control resources were occupied by a secondary attentional task (Knight et al., 2007; Mather & Knight, 2005). It appears that, "by default," older people selectively deploy resources to positive material, but when cognitive load increases or when the task requires the pro-

Gregory R. Samanez-Larkin, Elaine R. Robertson, Laura L. Carstensen, and Ian H. Gotlib, Department of Psychology, Stanford University; Joseph A. Mikels, Department of Human Development, Cornell University.

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Correspondence concerning this article should be addressed to Gregory R. Samanez-Larkin, Department of Psychology, Stanford University, Jordan Hall, Building 420, Stanford, CA 94305-2130. E-mail: glarkin@stanford.edu

cessing of both positive and negative stimuli, the effect disappears (for reviews, see Kryla-Lighthall & Mather, 2009; Mather & Carstensen, 2005). Importantly, however, no research to date has explored the neural mechanisms underlying these age differences in emotional attention. Specifically, no studies have used functional neuroimaging to examine selective attention to emotional stimuli in older adults.

Over the past 2 decades, more than 50 neuroimaging studies in younger adults have been conducted in an effort to characterize the brain regions involved in selective attention. A meta-analysis identified a network of regions implicated in the detection or resolution of interference across a range of tasks: the lateral prefrontal cortex, insula, anterior cingulate, inferior parietal lobule, and precuneus (Nee, Wager, & Jonides, 2007). Of the selective attention tasks included in this meta-analysis, one that requires both controlled, directed attention and simultaneous suppression of interference is the Eriksen flanker task (Eriksen & Eriksen, 1974). In a typical Eriksen flanker task, participants are asked to selectively attend by directing attention to and making a judgment about a target word (or letter) while ignoring (i.e., suppressing interference from) distracting words (or letters) presented above and below the target. The meta-analysis revealed that the primary brain areas that show interference effects in this task are the lateral prefrontal cortex (middle and inferior frontal gyri) and the insula (Nee et al., 2007; Wager et al., 2005). Activation in these regions has been found to correlate positively with behavioral interference effects (most typically reaction time [RT]), suggesting that these regions play a role in the detection or resolution of interference. Throughout this article we refer to this positive association as an interference effect in neural activity.

Several studies have suggested that older adults perform relatively poorly on tasks that rely heavily on the lateral prefrontal cortex (Hedden & Gabrieli, 2004). Older adults exhibit consistently poorer performance than younger adults on tasks that require the inhibition of interference (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993). The task used most commonly to examine age differences in selective attention and interference suppression is the Stroop task. In a traditional Stroop, the participants' task is to name the color of a word while ignoring the semantic meaning of the word (i.e., the name of a different color that creates interference). Although there is some debate about whether the age-related behavioral increase in interference on the Stroop task is due to declining cognitive control or to general slowing (Verhaegen & De Meersman, 1998; West, 1996), investigators have documented an age-related increase in interference in neural activity (i.e., greater activation in older adults) in the same regions that have been implicated in cognitive control and attentional interference: the inferior and middle frontal gyri (Langenecker, Nielsen, & Rao, 2004; Zysset, Schroeter, Neumann, & Yves von Cramon, 2007).

Few neuroimaging studies, however, have used emotional stimuli to assess attentional interference. One study used a go/no-go task to examine emotionally guided response inhibition and found that with increasing inhibitory demand, young adults activated the inferior frontal gyrus (IFG; Shafritz, Collins, & Blumberg, 2006). Although the authors identified a distinct set of lateral and medial prefrontal regions that were activated only in the emotional, and not in the nonemotional, go/no-go task, several previous studies using nonemotional stimuli (reviewed above) have found strong activation in this frontal region during tasks with high inhibitory demands. A second study using a matching task also found activation in the lateral prefrontal cortex during emotional interference in healthy young adults (Fales et al., 2008). Thus, although additional regions, such as the medial prefrontal cortex, may be involved in suppressing emotional interference (Shafritz et al., 2006), both nonemotional and emotional attentional control should recruit a similar network of brain regions. Indeed, two studies with young adults have demonstrated that general emotional suppression recruits the same lateral prefrontal regions—the middle and inferior frontal gyri—that are recruited in nonemotional cognitive control tasks (Depue, Curran, & Banich, 2007; Goldin, McRae, Ramel, & Gross, 2008). It is important to note, however, that no prior studies have examined selective attention through the suppression of interference from emotional stimuli in older adults using functional neuroimaging.

The goal of the present study was to use both behavioral and neural measures of interference to examine age differences in selective attention to emotional lexical stimuli. Participants completed a modified flanker task in which their primary task was to make an emotional categorical judgment. A control flanker task was also included in which participants' primary task was to make a nonemotional categorical judgment. Given the same underlying cognitive mechanisms necessary to complete both the emotional categorization task and the control categorization task (selective attention), overcoming interference from both emotional and nonemotional stimuli was expected to activate the same neural network of cognitive control regions. Thus, as suggested in the cognitive aging literature, compared with younger adults, older adults may show lower levels of selective attention and be more susceptible to interference in both the emotional and the nonemotional tasks.

It is also possible, however, that older adults will instead be able to ignore incongruent flanking stimuli, thereby reducing interference in the emotional task, but will not be able to successfully suppress interference in the nonemotional control task. Previous research has found that the cognitive impairments of older adults can be reduced or eliminated when the task requires controlled processing of emotional stimuli. For example, in a working memory task with emotional stimuli and emotional judgments, older adults were found to perform as well as younger adults (Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005). Thus, although older adults have been found to exhibit interference effects of emotional distractor stimuli while making nonemotional judgments (Wurm, Labouvie-Vief, Aycock, Rebucal, & Koch, 2004), they may be less sensitive to interference in the present task, which requires them to make an emotional judgment. Similarly, compared with their younger counterparts, older adults have been found to show higher levels of interference and reduced cognitive control in nonemotional tasks; nevertheless, they may be able to use the same neural mechanisms to reduce interference in emotional tasks (Mather & Carstensen, 2005). Thus, we predicted that although older adults will show interference effects in the nonemotional control task, they will not be susceptible to interference in either behavioral response time or neural activation in the emotional task. More specifically, we predicted that, compared with younger adults, older adults would show greater levels of interference in the nonemotional control task but similar or even reduced levels of interference in the emotional task. Moreover, on the basis of the behavioral evidence that the prioritization of emotional goals requires cognitive control (Knight et al., 2007; Mather & Knight, 2005), to the extent that lateral prefrontal regions of the brain play a role in the representation or suppression of interference, we expected this same pattern of age differences between tasks to be reflected in neural activation of the prefrontal cortex (Kryla-Lighthall & Mather, 2009; Samanez-Larkin & Carstensen, forthcoming).

Method

Participants

Twelve younger female adults (19–25 years of age) and 12 older female adults (66–81 years of age) participated in the study. Participants were recruited from the San Francisco Bay Area; they completed a telephone screening interview to determine eligibility. This telephone interview included questions relevant to their safety in the scanner and their history of physical or mental disorders (specifically stroke and neurological damage, history of heart failure, or prescription medicine, shown in previous studies to interfere with the blood oxygen level dependent signal). If eligible, participants completed two sessions. In the first session, participants completed a questionnaire packet and two cognitive tests, were given a thorough explanation of the scanning procedures, and completed a practice version of the task. In the second session, participants engaged in the attentional interference task while undergoing functional magnetic resonance imaging (fMRI). All participants gave written informed consent, and the experiment was approved by the Institutional Review Board of Stanford University.

Prior to the scanning session, participants received a verbal description of the task and completed a 5-min practice version of each condition of the task. Once in the scanner, participants completed six alternating runs of the attention task.

Questionnaires

A demographics questionnaire assessed the participants' age, marital status, occupational status, level of income, and number of years of education. Participants completed a measure of physical health, the Wahler Physical Symptom Inventory (Wahler, 1973), on which they indicated how often they are bothered by each of 42 physical symptoms. The Future Time Perspective scale (Carstensen & Lang, 1995) is a 10-item, self-report measure that assesses how much time people feel they have left in their lives. The state version of the Positive and Negative Affect Schedule (Watson, Clark, & Tellegen, 1988) was administered to assess the extent to which participants were currently experiencing each of 22 emotional states. The five-item Subjective Well-Being and Satisfaction With Life Scale (Diener, Emmons, Larsen, & Griffin, 1985) assessed general overall satisfaction with life. Two subtests from the Wechsler Adult Intelligence Scale–Third Edition (Wechsler, 1997)—digit span and digit symbol—were administered to each participant.

Modified Eriksen Flanker Task

Participants completed two versions (substance and valence) of a modified Eriksen flanker task (Eriksen & Eriksen, 1974) developed by Ochsner, Hughes, Robertson, Cooper, and Gabrieli (2009). For the valence categorization task, participants indicated whether a central target word was positive or negative while ignoring flanking stimuli of the same (congruent), opposite (incongruent), or no (XXXX; nonword) valence category. Flanking stimuli appeared above and below the target word for the duration of the presentation (see Appendix A). For the substance categorization task, participants indicated whether a central target word was a metal or fruit while ignoring flanking stimuli from the same (congruent), different (incongruent), or no (XXXX; nonword) substance category. Eight metal words and eight fruit words were selected for the substance categorization task, and 16 positive (mean valence = 7.70, SD = 0.23; mean arousal = 5.45, SD = 1.85) and 16 negative words (mean valence = 2.69, SD = 0.75; mean arousal = 5.45, SD = 1.90) were selected for the valence categorization task (see Appendix B). According to normative ratings provided by Bradley and Lang's (1999) affective word database (ANEW), the positive and negative words differed significantly in valence, $t(30) = 20.55$, $p < .0005$, but not in arousal, $t(30) = -0.01$, $p > .05$. Previous studies using similar words from this database have demonstrated that younger and older adults do not differ in their subjective ratings of valence or arousal and that these individual ratings in both age groups correlate highly with the normative ratings (Wurm et al., 2004).

Participants completed four runs of the valence task for a total of 384 trials, and two runs of the substance task for a total of 192 trials. The order of runs was counterbalanced across participants. During each trial, the target and flanking words were presented on the screen for 2 s followed by a 2-s fixation cross, for a total trial length of 4 s. Using a four-button response box, participants used their dominant hand to indicate the valence or substance category of the central target word by pushing the response button assigned to each category. Participants were instructed to respond as quickly and as accurately as possible, and both responses and response latencies were recorded for each trial. Before being analyzed, all reaction-time data were trimmed to exclude error trials and latencies less than 200 ms or greater than 2,000 ms. All participants were highly accurate on both tasks (see Appendix C). Indeed, an analysis of variance (ANOVA) conducted on error rates, with age (younger, older) as a between-subjects factor and task (valence, substance) as a within-subject factor, yielded nonsignificant main effects for age and task, and a nonsignificant Age × Task interaction (all ps > .05).

fMRI Acquisition

Imaging was performed with a 3.0 Tesla General Electric (Milwaukee, WI) MRI scanner with a standard fMRI head coil. Twenty-eight 4-mm-thick axial oblique slices (AC-PC aligned; in-plane resolution, 3.5 × 3.5 mm; no gap) provided adequate whole brain coverage. Functional scans of the entire brain were acquired every 2 s (repetition time [TR], 2 s) with a $T2^*$-sensitive in/out spiral pulse sequence (echo time [TE], 40 ms; flip, 90°) specifically designed to minimize signal dropout in artifact prone regions (Glover & Law, 2001). After the functional scans, we acquired high-resolution structural scans using a T1-weighted spoiled grass sequence (TR, 100 ms; TE, 7 ms; flip, 90°).

fMRI Preprocessing and Analyses

We conducted all imaging analyses using Analysis of Functional Neural Images software (Cox, 1996). For preprocessing, voxel time series were interpolated to correct for nonsimultaneous slice acquisition within each volume and corrected for three-dimensional motion. Visual inspection of motion correction confirmed that no participant's head moved more than 2.0 mm in any dimension from one volume acquisition to the next. Data were preprocessed via high-pass filtering (admitting frequencies above 90 s), and computation of percentage signal change was calculated with respect to the mean activation over the entire experiment in each voxel.

Preprocessed time series data for each individual were analyzed with a whole brain regression model to identify regions of the brain that correlated with behavioral interference across both categorization tasks and across all participants. Unique regressors were created for each participant on the basis of her own response latencies (i.e., raw RTs for each individual trial). Additional covariates in the model included six regressors describing residual motion and six regressors modeling baseline, linear, and quadratic trends for each experimental run. The regressor of interest was convolved with a gamma-variate function that modeled a prototypical hemodynamic response (Cohen, 1997) prior to inclusion in the model. Coefficient maps were slightly spatially smoothed (kernel FWHM = 4 mm) and spatially normalized by warping to Talairach space to account for anatomical variability. Thresholds for statistical significance were set with a global family-wise error rate ($Z > 3.88$, $p < .0001$, uncorrected) and required a minimum cluster of 20 face-to-face contiguous voxels.

Volume of interest (VOI) analyses examined interaction effects with age in the regions modulated by behavioral interference (i.e., that were correlated significantly with response time) identified in the whole brain regression model described above. Main effects of age on the raw fMRI signal were not explored and are not reported. Group or age main effects are highly sensitive to between-groups differences in hemodynamics and cannot be meaningfully interpreted (Samanez-Larkin & D'Esposito, 2008). Instead, the main effects of age reported in the VOI analyses explored differences between conditions and more closely approximate an interaction effect. VOIs were specified by imposing 6-mm-diameter spheres at foci identified in the whole brain analysis. Activation time courses were extracted and averaged from these VOIs by trial type. Because of the relatively small size of the spheres, the whole brain data were resampled at 2 mm^3 for VOI analyses.

Table 1
Demographics, Questionnaire Data, and Cognitive Test Score Means

Variable	Younger adults (n = 12)	Older adults (n = 12)
Age (years)	22.2 (2.6)[a]	73.3 (5.2)[a]
Education (years)	15.4 (1.3)	14.8 (2.2)
Scaled income	3.3 (0.9)	2.8 (1.1)
Health (WPSI)	36.2 (19.4)	38.3 (18.7)
Future time perspective (FTP)	53.1 (7.1)[a]	41.8 (11.4)[a]
Positive affect (PANAS)	32.1 (7.2)[b]	38.9 (7.6)[b]
Negative affect (PANAS)	13.3 (2.3)	12.3 (1.4)
Satisfaction with life (SWLS)	17.2 (2.9)	21.8 (4.6)
Digit span (WAIS-III)	17.2 (2.9)	15.3 (4.1)
Digit symbol (WAIS-III)	100.6 (13.3)[a]	60.4 (14.1)[a]

Note. Standard deviations are listed in parentheses. WPSI = Wahler Physical Symptom Inventory; FTP = Future Time Perspective scale; PANAS = Positive and Negative Affect Schedule; SWLS = Subjective Well-Being and Satisfaction With Life Scale; WAIS-III = Wechsler Adult Intelligence Scale–Third Edition.
[a] Significant difference at $p < .01$ (two-tailed). [b] Significant difference at $p < .05$ (two-tailed).

Results

Participant Characteristics

Compared with the older adults, the younger adults reported having a more expansive future time perspective, $t(22) = 2.89$, $p < .01$, $d = 1.23$; reported lower levels of positive affect, $t(22) = -2.25$, $p < .05$, $d = -0.96$; and completed more items on the digit symbol test, $t(22) = 7.2$, $p < .01$, $d = 3.07$ (see Table 1). The younger and older adults did not differ in level of education, income, health, negative affect, satisfaction with life, or digit span (all ps $> .05$).

Task Behavior

We first conducted behavioral analyses examining effects of task conditions on RTs and then conducted further analyses examining age differences in measures of behavioral interference calculated from these RTs (see Table 2 for mean RTs by condition and age group). We conducted a repeated measures ANOVA on RTs, with age (younger, older) as a between-subjects factor and task (valence, substance) and trial type (incongruent, nonword, congruent) as within-subject factors. The ANOVA yielded a main effect of task, $F(1, 22) = 66.18$, $p < .001$, $\eta^2 = .75$: Participants were slower across all trial types on the valence categorization task than on the substance categorization task, $t(23) = 8.19$, $p < .001$. A main effect of trial type, $F(2, 21) = 37.00$, $p < .001$, $\eta^2 = .78$, indicated that incongruent flanking words slowed RT more than did congruent flanking words. In fact, follow-up tests indicated that across both tasks, compared with nonword stimuli, incongruent flanking words slowed RTs—substance, $t(23) = 5.88$, $p < .001$; valence, $t(23) = 2.49$, $p < .05$—whereas congruent flanking words did not—substance, $t(23) = 0.25$, $p = .80$; valence, $t(23) = 0.08$, $p = .94$. Thus, no further analyses were conducted on congruent trials. The main effect of age, $F(1, 22) = 1.41$, $p = .25$, $\eta^2 = .06$; the Task $\times$ Age interaction, $F(1, 22) = 0.72$, $p = .41$, $\eta^2 = .03$; the Trial Type $\times$ Age interaction, $F(2, 21) = 1.41$, $p = .90$, $\eta^2 = .01$; and the three-way Task $\times$ Trial Type $\times$ Age interaction, $F(2, 21) = 2.31$, $p = .12$, $\eta^2 = .18$, all were not significant.[1]

Measures of behavioral interference were computed by subtracting average RT (in milliseconds) on nonword trials from average RT (in milliseconds) on incongruent trials for each task (valence, substance). A repeated measures ANOVA conducted on these measures with age (younger, older) as the between-subjects factor

[1] Because of age-group differences in self-reported positive affect, this variable was included as a covariate, but no main effects or interactions involving positive affect were obtained (all ps $> .05$).

Table 2
Raw Reaction Times in Milliseconds by Task and Age

Task	Younger adults	Older adults
Substance categorization		
Congruent	732 (90)	797 (115)
XXXX	739 (106)	794 (112)
Incongruent	767 (83)	845 (107)
Valence categorization		
Congruent	832 (118)	919 (149)
XXXX	828 (110)	924 (136)
Incongruent	849 (113)	929 (129)

Note. Standard deviations are listed in parentheses. XXXX = nonword.

and task (valence incongruent, substance incongruent) as the within-subject factor yielded a significant main effect of task, $F(1, 22) = 9.23$, $p < .05$, $\eta^2 = .30$; a nonsignificant main effect of age, $F(1, 22) = 0.17$, $p = .68$, $\eta^2 = .01$; and a significant Age × Task interaction, $F(1, 22) = 4.84$, $p < .05$, $\eta^2 = .18$ (see Figure 1). Follow-up *t* tests examining interference effects within groups using difference scores (incongruent − nonword) for each task indicated that the presence of incongruent flanking words produced interference effects in younger adults in both the substance categorization task, $t(11) = 3.21$, $p < .01$, and the valence categorization task, $t(11) = 2.80$, $p < .05$. In contrast, for older adults, the presence of incongruent flanking words produced interference effects for the substance task, $t(11) = 5.41$, $p < .0005$, but not for the valence task, $t(11) = 0.72$, $p = .49$. Direct comparisons between groups revealed significantly greater interference effects in the older adults than in the younger adults for the substance categorization task, $t(22) = 1.74$, $p < .05$, $d = 0.74$, but not for the valence categorization task, $t(22) = -1.62$, $p = .06$, $d = -0.69$.

Finally, we conducted a repeated measures ANOVA to examine the presence of a positivity effect within the valence categorization task, with age (younger, older) as the between-subjects factor and central word valence (positive, negative) as the within-subject factor. This analysis yielded a significant main effect of valence, $F(1, 22) = 11.70$, $p < .05$, $\eta^2 = .35$, but a nonsignificant Age × Valence interaction, $F(1, 22) = 0.001$, $p = .98$, $\eta^2 = .00$, providing no evidence of an age-related positivity effect within the valence categorization task. Across all participants, negative incongruent flanking words produced more interference on positive central word trials than positive incongruent flanking words produced on negative central word trials, $t(23) = 3.50$, $p < .05$.

Interference Effects in Neural Activity

The goal of the neuroimaging analyses was to identify regions that might help explain the age differences in behavioral RTs. The first step was to identify regions of interest where activation was positively related to behavioral interference (i.e., increased RT in high interference conditions). The second step was to extract data from these identified volumes of interest and conduct additional analyses to characterize age differences in activation in these regions. Consequently, only regions that (a) were significantly related to behavioral performance in the first level of analysis and (b) showed interaction effects with age in the second level of analysis were analyzed in detail.

For the first level of neuroimaging analyses, a whole-brain model identified neural regions that correlated with behavioral interference (i.e., with RT) across both categorization tasks and across all participants. This whole-brain analysis yielded significant associations between behavioral performance and neural activation in bilateral insula, bilateral IFG, left middle frontal gyrus (MFG), left cingulate gyrus, left lingual gyrus, and left substantia nigra across all participants, such that activity in all of these regions increased with behavioral interference (see Table 3). In the second level of analysis, VOI analyses examined interaction effects with age in the regions that were modulated by behavioral interference. Average peak percent signal extracted from each of these VOIs was examined with repeated measures ANOVAs with age (younger, older) as the between-subjects factor and task (valence, substance) and trial type (incongruent, nonword, congruent) as the within-subject factors. Repeated measures ANOVAs yielded nonsignificant main effects of task and trial type and nonsignificant Task × Trial Type interactions for the left cingulate gyrus, left lingual gyrus, left insula, and left substantia nigra (all *p*s > .05). Analyses for three of the regions that were associated with behavioral performance, however, yielded a main effect of trial type (interference): the right insula, left IFG, and left MFG (see below). Because there were no significant interaction effects with age in the right insula (all *p*s > .05), we did not conduct further analyses in this region.

As predicted, the main effects of trial type for the lateral prefrontal regions (i.e., IFG, MFG) were qualified by significant three-way Age × Task × Trial Type interactions. A repeated measures ANOVA yielded a significant main effect of trial type, such that across both the valence and substance tasks, incongruent trials produced greater neural activity than did nonword or congruent trials in both the IFG, $F(2, 21) = 6.92$, $p < .005$, $\eta^2 = .40$, and the MFG, $F(2, 21) = 8.83$, $p < .005$, $\eta^2 = .46$. This main effect was qualified, however, by a significant Age × Task × Trial Type interaction in both the IFG, $F(2, 21) = 5.59$, $p < .05$, $\eta^2 =$

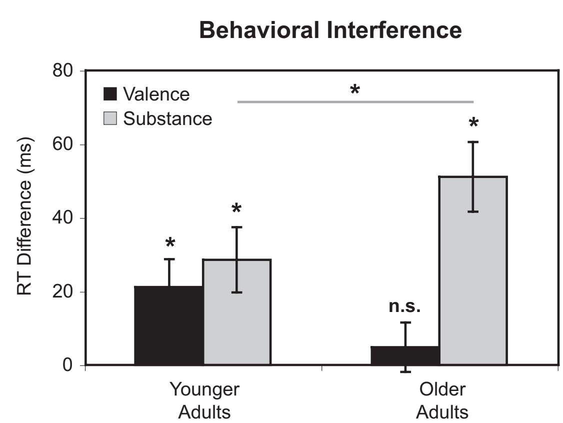

Figure 1. Behavioral interference effects by task and age. Younger adults show significant interference effects of incongruent flanking stimuli on reaction time (RT) in both the valence and substance categorization tasks. Older adults, however, show a significant interference effect of incongruent flanking stimuli in the substance categorization task but not in the valence categorization task. An asterisk indicates a significant difference at $p < .05$. Error bars represent *SEM*.

Table 3
Whole Brain Main Effect of Behavioral Interference Across All Participants

Region	Talairach coordinates R	A	S	Peak Z	Voxels
Left cingulate gyrus (BA 32)	−4	22	32	4.915	733
Left middle frontal gyrus (BA 46)	−44	20	26	5.431	182
Left insula (BA 13)	−30	16	10	5.795	215
Right insula/inferior frontal gyrus (BA 13/47)	48	12	2	4.842	452
Left inferior frontal gyrus (BA 13)	−46	6	16	4.754	351
Left substantia nigra	−12	−18	−6	5.700	238
Left cerebellum	−34	−42	−34	5.835	839
Right cerebellum	36	−54	−34	5.703	543
Left lingual gyrus (BA 18)	−2	−80	−2	4.738	543
Left declive	−36	−82	−18	4.791	192

Note. Global threshold: $p < .0001$. Cluster sizes are reported as the number of 2-mm^3 voxels. R = Right; A = Anterior; S = Superior; BA = Brodmann's Area.

.35,[2] and the MFG, $F(2, 21) = 5.49$, $p < .05$, $\eta^2 = .34$,[3] indicating that the pattern of neural activity across task conditions in these two regions differed in the younger and older participants.

Degree of interference in neural activity was computed by subtracting average peak signal change (with a 4-s lag) on nonword trials from average peak signal change on incongruent trials for each task (valence, substance) for both the IFG and MFG. A repeated measures ANOVA conducted on these interference measures in the IFG with age (younger, older) as the between-subjects factor and task (valence incongruent, substance incongruent) as the within-subject factor yielded a nonsignificant main effect of age, $F(1, 22) = 0.08$, $p = .78$, $\eta^2 = .00$; a nonsignificant main effect of task, $F(1, 22) = 0.03$, $p = .86$, $\eta^2 = .00$; and a nonsignificant Task $\times$ Age interaction, $F(1, 22) = 2.06$, $p = .17$, $\eta^2 = .09$. Although the Task $\times$ Age interaction was not significant, given the identified age differences in behavioral performance, we conducted follow-up tests to explore within-condition effects within groups. These subsequent tests revealed that whereas younger adults showed significant interference in the left IFG on incongruent valence trials, $t(11) = 2.47$, $p < .05$, but not on incongruent substance trials, $t(11) = 0.92$, $p > .05$, older adults showed the reverse pattern: nonsignificant interference in the left IFG on incongruent valence trials, $t(11) = 1.164$, $p > .05$, and significant interference on incongruent substance trials, $t(11) = 2.30$, $p < .05$ (see Figure 2). Although the effects within groups were relatively consistent with the behavioral results, direct comparisons between groups[4] yielded nonsignificant age differences for both the substance ($U = 66$, $Z = -0.35$, $p = .36$) and the valence ($U = 50$, $Z = -1.27$, $p = .10$) categorization tasks.

More consistent age differences were obtained for the left MFG. A repeated measures ANOVA conducted on the interference measures in the MFG with age (younger, older) as the between-subjects factor and task (valence incongruent, substance incongruent) as the within-subject factor yielded a nonsignificant main effect of age, $F(1, 22) = 0.11$, $p = .74$, $\eta^2 = .01$; a nonsignificant main effect of task, $F(1, 22) = 0.02$, $p = .88$, $\eta^2 = .00$; but a significant Age $\times$ Task interaction, $F(1, 22) = 5.35$, $p < .05$, $\eta^2 = .20$. Follow-up tests within groups indicated that younger adults showed significant interference in neural activity in the left MFG on incongruent valence trials, $t(11) = 3.60$, $p < .005$, but nonsignificant interference on incongruent substance trials, $t(11) = 1.36$, $p > .05$. In contrast, older adults again showed the reverse pattern: nonsignificant interference in the left MFG on incongruent valence trials, $t(11) = 1.97$, $p > .05$, but significant interference on incongruent substance trials, $t(11) = 4.58$, $p < .05$ (see Figure 3). Direct comparisons between groups revealed significantly greater interference effects in the older adults for the substance categorization task ($U = 43$, $Z = -1.67$, $p < .05$) but significantly reduced interference effects in the valence categorization task ($U = 41$, $Z = -1.79$, $p < .05$).

Discussion

Using both behavioral and neural measures of interference, in the present study we provide additional evidence that selective attention to emotion remains stable with age. We hypothesized that older adults would show interference in behavioral response time and neural activation in the nonemotional control task but not in the emotional task. As predicted, the behavioral results suggest that older adults are more susceptible than are younger adults to interference from incongruent flanking stimuli in a nonemotional categorization task, but unlike younger adults, older adults are not susceptible to interference from incongruent flanking stimuli in an emotional categorization task. On the surface, these behavioral findings are consistent with results of previous studies demonstrating relatively high levels of emotional control and low levels of nonemotional cognitive control in older adults (MacPherson, Phillips, & Della Sala, 2002; Mikels et al., 2005). An important contribution of the present functional neuroimaging data, however, is the additional evidence that a common network of lateral pre-

[2] The Task $\times$ Trial Type $\times$ Age interaction remains significant when positive affect is included as a covariate in the model, $F(2, 20) = 3.68$, $p < .05$, $\eta^2 = .27$.

[3] The Task $\times$ Trial Type $\times$ Age interaction remains significant when positive affect is included as a covariate in the model, $F(2, 20) = 4.07$, $p < .05$, $\eta^2 = .29$.

[4] In the VOI analyses in the IFG and MFG, nonparametric tests were used as more robust comparisons between groups. Thus, the group differences in these relatively small samples are not due to subject outliers.

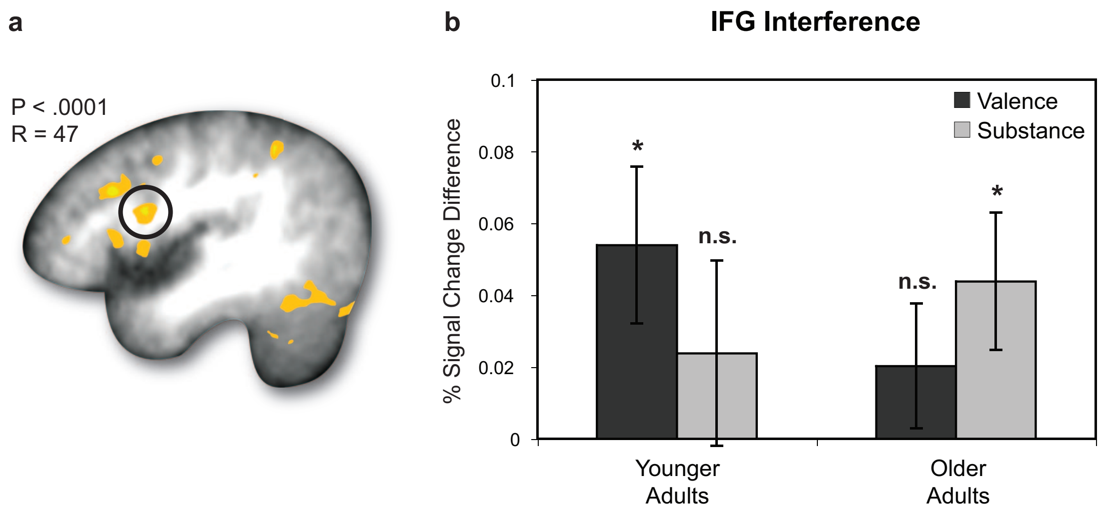

Figure 2. (a) Main effect of behavioral interference in the left inferior frontal gyrus (IFG; circled) across all participants and both tasks. (b) Younger adults show a significant interference effect of incongruent flanking stimuli on neural signal change in the left IFG in the valence categorization task but not in the substance categorization task. Older adults show the opposite pattern with a significant interference effect of incongruent flanking stimuli in the substance categorization task but not in the valence categorization task. An asterisk indicates a significant difference at $p < .05$. Error bars represent *SEM*.

frontal regions in the middle and inferior frontal gyri is recruited during interference in both the emotional and nonemotional tasks. The same regions showed a similar interference effect across both emotional and nonemotional categorization tasks in a recent functional imaging study using the same task with a sample of only younger adults (Ochsner et al., 2009). These lateral prefrontal regions have been previously implicated more generally in cognitive control and more specifically in resolving attentional interference (Nee et al., 2007). Although older adults showed higher levels of interference in the nonemotional task than did their younger counterparts, they were able to successfully reduce interference in the emotional task.

In the present study, all participants were highly accurate in both tasks, making very few errors. Moreover, there were no age group differences in error rates. Although results of previous studies examining age differences in labeling specific emotions in more

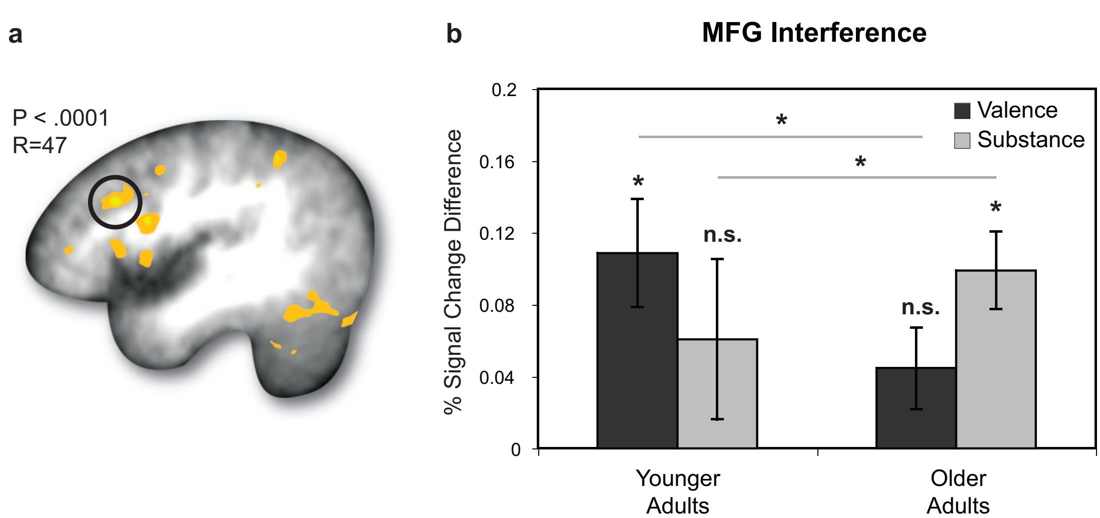

Figure 3. (a) Main effect of behavioral interference in the left middle frontal gyrus (MFG; circled) across all participants and both tasks. (b) Younger adults show a significant interference effect of incongruent flanking stimuli on neural signal change in the left MFG in the valence categorization task but not in the substance categorization task. Older adults show the opposite pattern with a significant interference effect of incongruent flanking stimuli in the substance categorization task but not in the valence categorization task. An asterisk indicates a significant difference at $p < .05$. Error bars represent *SEM*.

complex lexical stimuli are mixed (Grunwald et al., 1999; Isaacowitz et al., 2007; Phillips, MacLean, & Allen, 2002), younger and older adults have been found not to differ in making simple valence categorization judgments in single-word lexical stimuli (Keightley, Winocur, Burianova, Hongwanishkul, & Grady, 2006). Importantly, therefore, the present results cannot be attributed to differential error rates between the two age groups.

We did not find significant age differences in performance as a function of emotional valence. This finding contributes to growing refinement of the concept of a positivity effect. The positivity effect appears to emerge on experimental tasks that allow participants' to freely allocate their attention to emotional or nonemotional stimuli (Charles et al., 2003; Isaacowitz et al., 2006a, 2006b; Mather & Carstensen, 2003). In contrast, when experimental tasks demand attention to positive and negative stimuli, older adults do not selectively attend to positively valenced stimuli (Hahn et al., 2006; Leclerc & Kensinger, 2008; Mather & Knight, 2006). Consistent with this pattern, in the present study, in which all participants were required to attend selectively to both positively and negatively valenced stimuli, younger and older adults responded comparably in the emotion task on trials of both positive and negative emotional words. Thus, the pattern emerging across studies suggests that older adults are at least as able as younger adults to selectively process and successfully inhibit both positive and negative material when the tasks demand it. Theoretically, the positivity effect reflects chronically activated goals to regulate emotion (Carstensen, 2006). It makes sense, then, that it appears as the "default" attentional strategy (i.e., in tasks that do not require attention to specific emotional stimuli) but fails to appear when experimental instructions provide participants with explicit goals, as in the present study. This pattern speaks against explanations that positivity results from neural or cognitive decline.

It is also important to note that previous studies have found a positivity effect when positive or negative stimuli are paired with neutral stimuli (Isaacowitz et al., 2006a, 2006b; Knight et al., 2007; Mather & Carstensen, 2003) but not when they are paired with other valenced stimuli (Knight et al., 2007). In the present study, the incongruent trials of interest contain positive–negative pairs of emotional words. Future studies should explore more systematically age differences in situations in which positive and negative emotional information compete for attentional resources.

It is also important to note that neutral words were not included in the valence categorization task. For the current study of healthy aging, we chose a task that has been used previously to examine selective attention to emotional stimuli in younger adults (Ochsner et al., 2009). The experimental task was purposefully unaltered to facilitate comparisons with previously published work. In future studies, it will be interesting to examine whether the same patterns emerge with a neutral word comparison condition. Using the nonword condition as a baseline in both tasks may have been a problem in the current study if regions of the brain implicated in semantic, linguistic processing had shown strong interactions with age, but this was not the case.

The brain imaging results of the present study are consistent with findings from previous neuroimaging studies examining selective attention. The increased interference in both behavior and neural activity in lateral prefrontal regions in older adults observed in the substance categorization task is consistent with results of a recent study using a different nonemotional selective attention task (Madden et al., 2007). Further, the same lateral prefrontal regions that have been found to be activated as a function of interference in previous nonemotional flanker tasks (Bunge, Hazeltine, Scanlon, Rosen, & Gabrieli, 2002; Hazeltine, Bunge, Scanlon, & Gabrieli, 2003; Wager et al., 2005) were also identified in the present study as a main effect of interference in both the valence and the substance categorization tasks. As was demonstrated in previous studies, activation in these regions was positively correlated with RT (Wager et al., 2005). If these regions are involved in cognitive control, one might expect greater activation to lead to a reduction in RT. However, Wager et al. (2005) have suggested that these regions are more highly activated on trials in which there is more interference with which to contend (p. 337). In the present study, it is possible that because older adults are able to attend selectively to central emotional stimuli, they are not as influenced by the flanking stimuli, and therefore, these flankers do not generate interference. In the nonemotional task, the older adults may not be as motivated to attend selectively, and as a result, the incongruent stimuli may generate interference.

In summary, in the present study we found that although older adults are susceptible to interference in a nonemotional control task, they do not show significant interference in either behavioral response time or neural activation in an emotional task. Using fMRI, we found that younger adults showed significant interference in neural activity in lateral prefrontal regions on incongruent trials in the emotional task but nonsignificant interference on incongruent trials in the nonemotional task. In contrast, older adults showed the reverse pattern: nonsignificant interference in lateral prefrontal cortex on incongruent trials in the emotional task but significant interference on incongruent trials in the nonemotional task. In a direct comparison of younger and older adults, analyses in one lateral prefrontal region—the MFG—yielded significantly greater interference effects in the older adults for the nonemotional task but significantly reduced interference effects in the older adults for the valence categorization task. Although the age differences were not equally significant across both regions of the lateral prefrontal cortex, the follow-up tests did reveal the same pattern numerically in the IFG. Thus, the present study provides neural evidence supporting a role of at least one prefrontal control region in age-related differences in selective attention to emotional stimuli.

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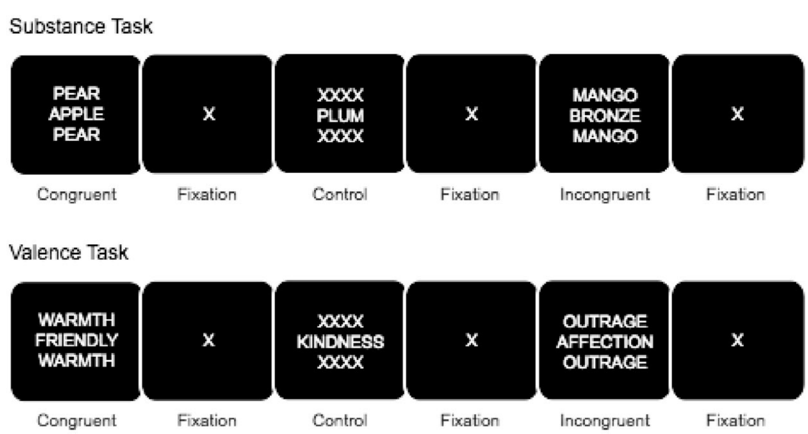
Appendix A

Task Design



Appendix B

Word Stimuli

Substance task	
Metal	Fruit
aluminum	apple
bronze	banana
copper	cherry
iron	mango
platinum	peach
tin	pear
zinc	pineapple
steel	plum
Valence task	
Positive	Negative
affection	anger
desire	assault
ecstasy	brutal
elated	failure
free	fatigued
friendly	fight
fun	hate
intimate	loneliness
kindness	moody
love	outrage
luxury	pity
peace	rage
secure	sad
snuggle	thrill
warmth	unhappy
weary	violent

Appendix C

Categorization Error Rate by Task

Group	Substance	Valence
Younger adults	0.02 (0.02)	0.04 (0.03)
Older adults	0.03 (0.04)	0.03 (0.02)

Note. Standard deviations are listed in parentheses.

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