Published in final edited form as:

Psychol Aging. 2009 September ; 24(3): 519–529. doi:10.1037/a0016952.

Selective Attention to Emotion in the Aging Brain

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Abstract

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 non-emotional 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 non-emotional tasks, they appear to be able successfully to reduce interference during emotional tasks.

Keywords

aging; emotion; attention; interference; suppression; inferior frontal gyrus; middle frontal gyrus; 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 to 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

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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 (SST; 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 youth 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, e.g., 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) provided particularly compelling support for a motivational formulation. First, they found that people with the highest levels of executive functioning displayed the most positivity and, 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 processing 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 two 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) suggesting that these regions play a role in the detection or resolution of interference. Throughout this paper we will refer to this positive association as an interference effect in neural activity.

A number of studies suggest 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 which 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 (Shafritz, Collins, & Blumberg, 2006). Although the authors identify a distinct set of lateral and medial prefrontal regions that were activated only in the emotional, and not in the non-emotional, go/no-go task, several previous studies using non-emotional 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 like the medial prefrontal cortex may be involved in suppressing emotional interference (Shafritz et al., 2006), both non-emotional 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 non-emotional 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 non-emotional categorical judgment. Given the same underlying cognitive mechanisms necessary to complete both the emotional categorization task and control categorization task (selective attention), overcoming interference from both emotional and non-emotional 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 non-emotional 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 non-emotional 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 non-emotional judgments (Wurm, Labouvie-Vief, Aycocock, Rebucal, & Koch, 2004), they may be less sensitive to interference in the present task, which requires them to make an emotional judgment. Similarly, compared to their younger counterparts, older adults have been found to show higher levels of interference and reduced cognitive control in non-emotional 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 non-emotional 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 to younger adults, older adults would show greater levels of interference in the non-emotional control task but similar or even reduced levels of interference in the emotional task. Moreover, based on 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 (age 19–25) and twelve older female adults (age 66–81) 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 five-minute 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 (WPSI; Wahler, 1973), on which they indicated how often they are bothered by each of 42 physical symptoms. The Future Time Perspective scale (FTP; 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 (PANAS; Watson, Clark, & Tellegen, 1988) was administered to assess the extent to which participants were currently experiencing each of 22 emotional states. The 5-item Subjective Well-being and Satisfaction with Life Scale (SWLS; Diener, Emmons, Larsen, & Griffin, 1985) assessed general overall satisfaction with life. Two subtests from the Wechsler Adult Intelligence Scale Third Edition (WAIS-III; Wechsler, 1997), Digit Span and Digit Symbol, were administered to each participant.

Modified Eriksen Flanker Task

Participants completed two versions (substance, valence) of a modified Eriksen flanker task (Eriksen & Eriksen, 1974) developed by Ochsner and colleagues (Ochsner, Hughes, Robertson, Cooper, & Gabrieli, in press). 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; non-word) 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; non-word) 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 the Bradley and Lang (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 counter-balanced across participants. During each trial, the target and flanking words were presented on the screen for 2 seconds followed by a 2-second fixation cross, for a total trial length of 4 seconds. Using a four-button response box, participants used their dominant right 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 2000 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 non-significant main effects for age and task, and a non-significant interaction of age and task, all $p > .05$.

fMRI acquisition

Imaging was performed using 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, high-resolution structural scans were acquired using a T1-weighted spoiled grass sequence (TR, 100 ms; TE, 7 ms; flip, 90°).

fMRI preprocessing and analyses

All imaging analyses were conducted using Analysis of Functional Neural Images software (AFNI; Cox, 1996). For preprocessing, voxel time series were interpolated to correct for non-simultaneous slice acquisition within each volume and corrected for three-dimensional motion. Visual inspection of motion correction confirmed that no subject's head moved more than 2.0 mm in any dimension from one volume acquisition to the next. Data were preprocessed via hi-

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 based on her own response latencies (i.e., raw reaction times 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 which 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 using a global family-wise error rate ($Z > 3.88$, $p < 0.0001$, 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-group 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. Due to the relatively small size of the spheres, the whole brain data were resampled at 2 mm³ for VOI analyses.

Results

Participant Characteristics

Compared with the older adults, the younger adults reported having a more expansive future time perspective, $t(22) = 2.89$, $p < .01$, $d = 1.23$, 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 $p > .05$.

Task Behavior

We first conducted behavioral analyses examining effects of task conditions on reaction times (RTs) and then conducted further analyses examining age differences in measures of behavioral interference calculated from these RTs. 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, non-word, 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 to non-word 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 by age interaction, $F(1, 22) = 0.72$, $p = .41$,

$\eta^2 = .03$, the trial type by age interaction, $F(2, 21) = 1.41, p = .90, \eta^2 = .01$, and the three-way interaction of task, trial type, and age, $F(2, 21) = 2.31, p = .12, \eta^2 = .18$, all were not significant.ⁱ

Measures of behavioral interference were computed by subtracting average RT (ms) on non-word trials from average RT (ms) 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 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 non-significant main effect of age, $F(1, 22) = 0.17, p = .68, \eta^2 = .01$, and a significant interaction of age and task, $F(1, 22) = 4.84, p < .05, \eta^2 = .18$ (see Figure 1). Follow-up t-tests examining interference effects within groups using difference scores (incongruent non-word) 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, $t(11) = .72, p = .49$. Direct comparisons between groups revealed significantly greater interference effects in the older 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 non-significant age by 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 (1) were significantly related to behavioral performance in the first level of analysis, and (2) 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 inferior frontal gyrus (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, volume-of-interest (VOI) analyses examined interaction effects with age in the regions that were modulated by behavioral

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

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, non-word, congruent) as the within-subject factors. Repeated-measures ANOVAs yielded non-significant main effects of task and trial type and non-significant interactions of task and trial type for the left cingulate gyrus, left lingual gyrus, left insula and left substantia nigra, all $p > .05$. 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 $p > .05$, 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 interactions of age, task, and trial type. 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 non-word or congruent trials in both the IFG, $F(2, 21) = 6.92$, $p < .005$, $\eta^2 = .40$, and MFG, $F(2, 21) = 8.83$, $p < .005$, $\eta^2 = .46$. This main effect was qualified, however, by a significant interaction of age, task, and trial type in both the IFG, $F(2, 21) = 5.59$, $p < .05$, $\eta^2 = .35$ ⁱⁱ, and MFG, $F(2, 21) = 5.49$, $p < .05$, $\eta^2 = .34$ ⁱⁱⁱ, 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-second lag) on non-word 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-subjects factor yielded a non-significant main effect of age, $F(1, 22) = 0.08$, $p = .78$, $\eta^2 = .00$, a non-significant main effect of task, $F(1, 22) = 0.03$, $p = .86$, $\eta^2 = .00$, and a non-significant interaction of task and age, $F(1, 22) = 2.06$, $p = .17$, $\eta^2 = .09$. Although the task by 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: non-significant 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^{iv} yielded non-significant age differences for both the substance, $U = 66$, $Z = -0.35$, $p = .36$, and the valence categorization tasks, $U = 50$, $Z = -1.27$, $p = .10$.

More consistent age differences were obtained for the left middle frontal gyrus (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 non-significant main effect of age, $F(1, 22) = 0.11$, $p = .74$, $\eta^2 = .01$, a non-significant main effect of task, $F(1, 22) = 0.02$, $p = .88$, $\eta^2 = .00$, but a significant interaction of age and task, $F(1, 22) = 5.35$, $p < .05$, $\eta^2 = .20$. Follow-up tests within groups indicated that younger adults showed significant interference in neural

ⁱⁱThe task by trial type by age interaction remains significant when PA is included as a covariate in the model, $F(2, 20) = 3.68$, $p < .05$, $\eta^2 = .27$.

ⁱⁱⁱThe task by trial type by age interaction remains significant when PA is included as a covariate in the model, $F(2, 20) = 4.07$, $p < .05$, $\eta^2 = .29$.

^{iv}In the VOI analyses in the IFG and MFG, non-parametric tests were used as more robust comparisons between groups. Thus, the group differences in these relatively small samples are not due to subject outliers.

activity in the left MFG on incongruent valence trials, $t(11) = 3.60, p < .005$, but non-significant interference on incongruent substance trials, $t(11) = 1.36, p > .05$. In contrast, older adults again showed the reverse pattern: non-significant 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, the present study provides 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 non-emotional 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 non-emotional 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 non-emotional 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 prefrontal regions in the middle and inferior frontal gyri is recruited during interference in both the emotional and non-emotional tasks. The same regions showed a similar interference effect across both emotional and non-emotional categorization tasks in a recent functional imaging study using the same task with a sample of only younger adults (Ochsner et al., in press). 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 non-emotional 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 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 non-emotional 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., in press). The experimental task was purposefully unaltered in order 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 non-word 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 non-emotional 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 non-emotional 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 substance categorization tasks. As was demonstrated in previous studies, activation in these regions was positively correlated with reaction time (Wager et al., 2005). If these regions are involved in cognitive control, one might expect greater activation to lead to a reduction in reaction time. However, Wager and colleagues (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 non-emotional 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 non-emotional 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 non-significant interference on incongruent trials in the non-emotional task. In contrast, older adults showed the reverse pattern: non-significant interference in lateral prefrontal cortex on incongruent trials in the emotional task, but significant interference on incongruent trials in the non-emotional 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 non-emotional 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.

Acknowledgments

Author note

This research was supported by National Institute on Aging grant AG08816 to Laura L. Carstensen, National Institute of Mental Health grant MH59259 to Ian H. Gotlib, and Stanford Roybal Center on Advancing Decision Making for Aging (CADMA) grant AG024957 to Ian H. Gotlib and Elaine R. Robertson. During the preparation of this manuscript Gregory R. Samanez Larkin was supported by National Institute on Aging pre-doctoral NRSA AG032804. The authors thank Kevin Ochsner for sharing the flanker task prior to publication, and Derek M. Isaacowitz and two anonymous reviewers for their helpful comments on earlier drafts of the manuscript.

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Figure 1.

Behavioral interference effects by task and age. Younger adults show significant interference effects of incongruent flanking stimuli on reaction time 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.

Figure 2.

(a) Main effect of behavioral interference in the left inferior frontal gyrus (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 inferior frontal gyrus in the valence categorization task but not 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.

Figure 3.

(a) Main effect of behavioral interference in the left middle frontal gyrus (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 middle frontal gyrus in the valence categorization task but not 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.

Substance Task

Valence Task

Appendix A.
Task Design

Table 1

Demographics, questionnaire data, and cognitive test score means. Standard deviations listed in parentheses.

	Younger Adults (n = 12)	Older Adults (n = 12)
Age (years)	22.2 (2.6) **	73.3 (5.2) **
Education (# of years)	15.4 (1.3)	14.8 (2.2)
Scaled Income	3.3 (0.9)	2.8 (1.1)
Health (WAHLER)	36.2 (19.4)	38.3 (18.7)
Future Time Perspective (FTP)	53.1 (7.1) **	41.8 (11.4) **
Positive Affect (PANAS)	32.1 (7.2) *	38.9 (7.6) *
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-R)	17.2 (2.9)	15.3 (4.1)
Digit Symbol (WAIS-R)	100.6 (13.3) **	60.4 (14.1) **

* significant difference at $p < .05$ (two-tailed)

** significant difference at $p < .01$ (two-tailed)

Table 2

Raw reaction times in milliseconds by task and age. Standard deviations listed in parentheses.

	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)

Whole brain main effect of behavioral interference across all participants (Global threshold: $P < .0001$). Cluster sizes reported as the number of 2 mm³ voxels.

Table 3

	Talairach coordinates			Peak		Voxels
	R	A	S	Z		
L Cingulate Gyrus (BA 32)	-4	22	32	4.915		733
L Middle Frontal Gyrus (BA 46)	-44	20	26	5.431		182
L Insula (BA 13)	-30	16	10	5.795		215
R Insula / Inferior Frontal Gyrus (BA 13 / 47)	48	12	2	4.842		452
L Inferior Frontal Gyrus (BA 13)	-46	6	16	4.754		351
L Substantia Nigra	-12	-18	-6	5.700		238
L Cerebellum	-34	-42	-34	5.835		839
R Cerebellum	36	-54	-34	5.703		543
L Lingual Gyrus (BA 18)	-2	-80	-2	4.738		543
L Declive	-36	-82	-18	4.791		192

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. Standard deviations listed in parentheses.

	Substance	Valence
Younger Adults	.02 (.02)	.04 (.03)
Older Adults	.03 (.04)	.03 (.02)