Research Report

Amygdala Responses to Emotionally Valenced Stimuli in Older and Younger Adults

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ABSTRACT—*As they age, adults experience less negative emotion, come to pay less attention to negative than to positive emotional stimuli, and become less likely to remember negative than positive emotional materials. This profile of findings suggests that, with age, the amygdala may show decreased reactivity to negative information while maintaining or increasing its reactivity to positive information. We used event-related functional magnetic resonance imaging to assess whether amygdala activation in response to positive and negative emotional pictures changes with age. Both older and younger adults showed greater activation in the amygdala for emotional than for neutral pictures; however, for older adults, seeing positive pictures led to greater amygdala activation than seeing negative pictures, whereas this was not the case for younger adults.*

Older adults experience less negative affect than younger adults in both cross-sectional and longitudinal studies (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Charles, Reynolds, & Gatz, 2001; Gross et al., 1997; Mroczek, 2001). The improved affective experience seen in old age stands in sharp contrast to the many physical and cognitive declines associated with aging. This improved emotional experience may be associated with changes in the way emotional information is initially processed and later remembered. For example, when pairs of faces are presented, older adults are less likely to attend to negative than to neutral or positive faces (Mather & Carstensen, 2003). Whether remembering pictures, options related to a recent decision, or their own emotional experiences, older adults remember relatively less emotionally negative information and relatively more emotionally positive information compared with younger adults (Charles, Mather, & Carstensen, 2003; Fung & Carstensen, 2003; Levine & Bluck, 1997; Mather, 2003; Mather & Johnson, 2000).

It is unknown what neural mechanisms might be associated with these age-associated changes in emotion processing. Because of its central role in emotional attention and memory, however, the amygdala is a region of particular interest (Adolphs, 2002; Cahill et al., 1996; Canli, Zhao, Brewer, Gabrieli, & Cahill, 2000; Hamann, Ely, Hoffman, & Kilts, 2002). With age, the amygdala may show decreased reactivity to negative information while maintaining or increasing its reactivity to positive information.

METHOD

Participants

Seventeen younger adults between the ages of 18 and 29 years ($M = 23.41$, $SD = 3.24$; 8 female and 9 male) and 17 older adults between the ages of 70 and 90 years ($M = 78.41$, $SD = 4.86$; 8 female and 9 male) were paid for their participation. Participants were screened to ensure that they were healthy, met the physical requirements for functional magnetic resonance imaging (fMRI), and were not taking psychotropic drugs. Cognitive impairment was measured as the number of incorrect responses to eight questions from the Short Portable Mental Status Questionnaire (Pfeiffer, 1975). No participant made more than one incorrect response on this test, and the average score did not significantly differ for younger ($M = 0.24$, $SD = 0.44$) and older ($M = 0.06$, $SD = 0.24$) adults. Average years of education did not differ significantly between younger ($M = 16.91$, $SD = 2.40$) and older ($M = 16.94$, $SD = 2.51$) adults. However, younger adults did not score as well ($M = 17.64$, $SD = 3.22$) as older adults ($M = 22.06$, $SD = 1.82$) on a vocabulary questionnaire, $t(32) = 4.92$, $p < .001$. Younger adults completed more Digit-Symbol Substitutions from the Wechsler Adult Intelligence Scale (Wechsler, 1981) than did older adults ($M_{younger} = 70.35$, $SD = 10.67$; $M_{older} = 42.65$, $SD = 11.03$), $t(32) = 7.44$, $p < .001$. On average, younger adults also generated more responses ($M = 34.29$, $SD = 9.08$) than older adults ($M = 24.58$, $SD = 6.23$), $t(32) = 3.64$, $p < .01$, on the Animal Naming task (Kertesz, 1982).

Procedure

Participants were scanned using event-related fMRI while they viewed randomly ordered positive, negative, and neutral emotional

pictures (Lang, Bradley, & Cuthbert, 1995).[1] They saw 64 pictures of each valence in addition to 64 fixation trials (a large cross in the center of the screen) for 3 s each. These 256 trials were split into two scans, with each scan containing equal numbers of the four types of trials. During the scan, participants used a four-button device to rate their subjective emotional arousal to each picture on a scale from 1 to 4, with 4 being most arousing. The instructions asked them to "make judgments of how excited or calm you feel when you view each picture. At one extreme of the scale, you are stimulated, excited, frenzied, jittery, wide-awake, aroused. At the other end of the scale, you feel completely relaxed, calm, sluggish, dull, sleepy, unaroused."

fMRI Data Acquisition

Imaging data were acquired on a 3-T MRI Signa LX Horizon Echospeed scanner (G.E. Medical Systems, Waukesha, Wisconsin). T2-weighted flow-compensated spin-echo anatomical images (TR = 2,000 ms, TE = 85 ms) were acquired in 16 contiguous 7-mm axial slices. Functional images were acquired with the same slice prescription using a gradient-echo T2*-weighted spiral scan (TR = 1,000 ms, TE = 30 ms, flip angle = 60°, field of view = 24 cm). Functional images were motion corrected, and images for younger and older adults were normalized to the white matter of the same standard template brain using the Statistical Parametric Mapping toolbox (SPM99, Wellcome Department of Cognitive Neurology, London, United Kingdom), as we found that normalizing to the white matter yielded much better results for the older adults than normalizing to the gray matter template brain. Normalized images were interpolated to 2- × 2- × 4-mm voxels and spatially smoothed with an 8-mm full-width/half-maximum Gaussian filter. Effects were modeled using a boxcar convolved with a canonical hemodynamic response function for the 3-s trial epoch during which each picture was shown and rated.

RESULTS

Arousal Ratings

Overall, younger and older adults' average arousal ratings did not differ ($M_{younger} = 2.49$, $SE = 0.10$; $M_{older} = 2.40$, $SE = 0.11$), $F(1, 32) < 1$. Negative pictures were rated as most arousing ($M = 2.95$, $SE = 0.07$), followed by positive pictures ($M = 2.35$, $SE = 0.10$) and then neutral pictures ($M = 2.03$, $SE = 0.07$), $F(2, 64) = 82.56$, $MSE = 0.09$, $p < .001$, $\eta_p^2 = .72$. The exact nature of this pattern of arousal ratings, however, differed between younger and older adults, $F(2, 64) = 10.76$, $MSE = 0.09$, $p = .001$, $\eta_p^2 = .25$ (Fig. 1a). Younger adults rated the negative pictures as more arousing ($M = 3.19$, $SE = 0.10$) than did older adults ($M = 2.72$, $SE = 0.10$). In contrast, younger and older adults did not significantly differ in their ratings of positive ($M_{younger} =$

2.33, $SE = 0.14$; $M_{older} = 2.37$, $SE = 0.14$) or neutral ($M_{younger} = 1.95$, $SE = 0.11$; $M_{older} = 2.12$, $SE = 0.11$) pictures. These ratings obtained during functional neuroimaging show that these older adults, like
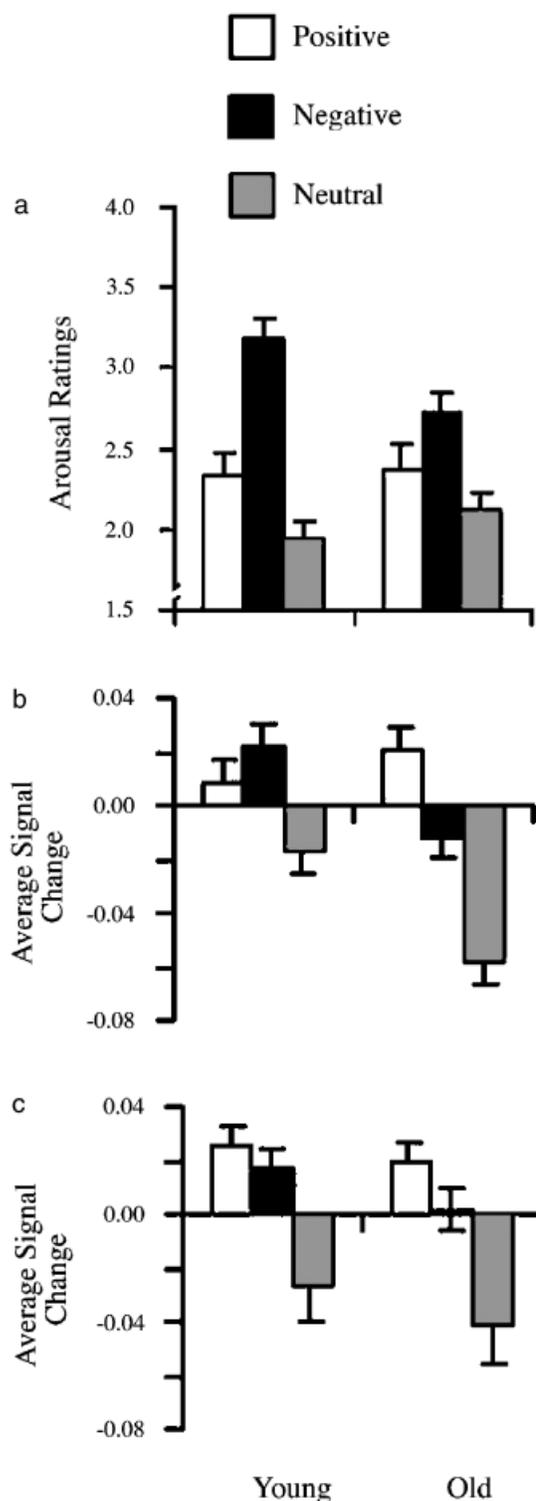

Fig. 1. Mean arousal ratings for each type of picture (a) and average signal change within the amygdala (b) and hippocampus (c) for younger and older adults while seeing positive, negative, and neutral pictures. Error bars indicate the standard error.

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[1]An independent group of 10 younger ($M = 21.2$, $SD = 2.78$) and 10 older ($M = 73.9$, $SD = 7.82$) adults rated the valence of these pictures on a scale from *extremely negative* to *extremely positive*. As expected, there was a large effect of valence category, $F(2, 36) = 185.83$, $MSE = 0.35$, $p < .001$, with the negative pictures rated as the most negative ($M = 2.00$, $SE = 0.11$), the neutral pictures given intermediate ratings ($M = 4.28$, $SE = 0.15$), and the positive pictures rated as most positive ($M = 5.53$, $SE = 0.17$). There was no main effect of age ($F < 1$) or interaction of age and valence category ($F < 1$), indicating that younger and older adults had similar patterns of ratings across the positive, negative, and neutral categories. Furthermore, an item analysis revealed that older and younger adults' average ratings were highly correlated for the 192 pictures ($r = .92$, $p < .001$).

those in prior studies, had selectively diminished responses to negative information.

Region-of-Interest Analyses

The amygdala was analyzed as a region of interest (ROI; Fig. 2). Each ROI was created using a computer-generated image based on the Talairach-defined coordinates. The images were smoothed with an 8-mm full-width/half-maximum Gaussian filter and were truncated at an intensity level of 0.25. The average percentage signal change was computed for these voxels for each trial type (the baseline signal was the average across all trials for those voxels). Mean signal change was initially analyzed in a Valence (emotional, neutral) × Laterality (left, right) × Age (younger, older) analysis of variance (ANOVA). There was significantly greater signal change for emotional trials than neutral trials, $F(1, 32) = 16.60$, $MSE = 0.00$, $p < .001$, $\eta_p^2 = .34$. There were no effects of age or laterality.

Distinguishing between positive and negative trials, however, revealed different activation patterns in the amygdala for older and younger adults. A Valence (negative, positive) × Laterality (left, right) × Age (younger, older) ANOVA revealed a significant interaction of age and valence, $F(1, 32) = 5.08$, $MSE = 0.00$, $p < .05$, $\eta_p^2 = .14$ (Fig. 1b). For older adults, average signal change in the amygdala was greater for positive pictures ($M = .020$, $SE = .009$) than for negative pictures ($M = -.012$, $SE = .012$), $F(1, 16) = 4.47$, $MSE = 0.02$, $p = .05$,

$\eta_p^2 = .22$. In contrast, younger adults' average signal change did not significantly differ for positive pictures ($M = .009$, $SE = .009$) versus negative pictures ($M = .022$, $SE = .012$). Direct comparisons between the age groups revealed greater signal change among younger than older adults for negative pictures, $F(1, 32) = 4.25$, $MSE = 0.00$, $p < .05$, $\eta_p^2 = .12$, but comparisons for positive pictures revealed no significant age differences. There were no other significant effects. Thus, older adults showed a selective diminishment in their amygdala response to negative information.

One possible explanation of this finding is that limbic regions are subject to dedifferentiation with age. Older adults often activate a more diffuse set of regions when completing the same task as younger adults (Cabeza, 2002). For example, Grady et al. (1994) found that older adults showed weaker activity than younger adults in the occipital cortex but stronger activity in more anterior brain regions during face matching. Thus, it is possible that older adults would show more activation than younger adults in response to negative pictures in the hippocampus, a region closely allied with the amygdala. When we examined the average signal change in the hippocampus (see Fig. 2 for the ROI), we did not find any evidence for dedifferentiation, however. Older adults showed levels of signal change similar to those of younger adults (Fig. 1c), and there was no age-by-valence interaction ($F < 1$).

Older adults' reduced amygdala activation for negative scenes could be the consequence of many factors, including age-related
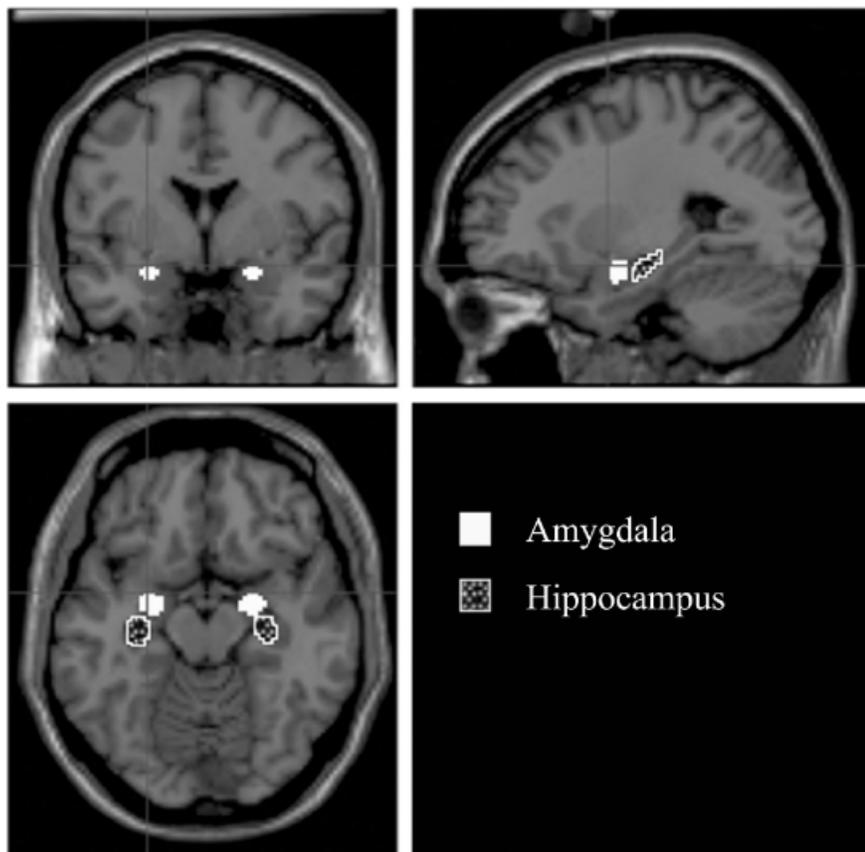

Fig. 2. The amygdala and hippocampus regions of interest displayed in coronal (upper left), sagittal (upper right), and axial (lower left) views of the brain.
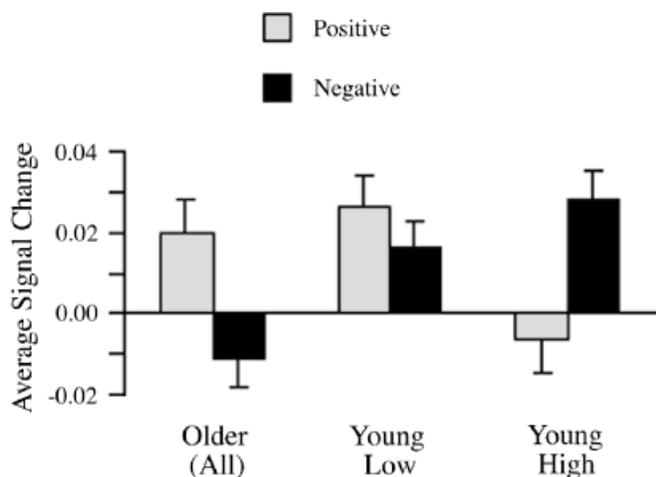
Fig. 3. Average signal change within the amygdala while seeing positive and negative pictures. Results are shown separately for older adults, younger adults equated with older adults for the difference between their arousal ratings of negative and positive pictures (''Young Low''), and younger adults with larger differences in ratings of negative and positive pictures (''Young High''). Error bars indicate the standard error.

atrophy of neural systems important for processing negative scenes or age-related reductions in psychophysiological responsiveness to arousing materials (Levenson, Carstensen, & Gottman, 1994; Levenson, Friesen, Ekman, & Carstensen, 1991; Tsai, Levenson, & Carstensen, 2000). Alternatively, it may reflect a more optional psychological process that observers may engage in when viewing negative scenes. To test these alternative interpretations, we examined whether younger adults with arousal ratings similar to those of older adults also showed a similar pattern of activity in the amygdala. If the activation pattern of these younger adults resembled that of the older adults, then the psychological interpretation would be favored over the biological aging interpretations.

We selected those 8 younger adults with the smallest differences in ratings for negative and positive pictures ($M_{\text{difference}} = 0.45$, $SE = 0.11$). These participants were equated with older adults for their rating difference scores ($F < 1$). Comparing the amygdala signal change of these participants with the signal change in the whole older group using a Valence (negative, positive) × Age (younger, older) ANOVA revealed no age-by-valence interaction ($F < 1$). In contrast, repeating this ANOVA using the data from the remaining younger adults, who had the largest difference between their arousal ratings for negative and positive pictures ($M_{\text{difference}} = 1.22$, $SE = 0.10$), revealed a significant age-by-valence interaction, $F(1, 24) = 8.33$, $MSE = 0.00$, $p < .01$, $\eta_p^2 = .26$. As shown in Figure 3, those younger adults with arousal ratings similar to those of older adults also had patterns of amygdala activity that were similar to those of older adults; the younger adults with arousal ratings less like those of older adults had patterns of amygdala activity that were less like those of older adults.

DISCUSSION

The present findings indicate that older adults diminish their encoding of negative emotional experience during the first moments of that experience. This was evident in the reduced arousal ratings and the reduced amygdala response for negative pictures that occurred during the encoding of the pictures. For younger adults, amygdala activation during picture encoding is associated with superior memory for emotionally positive and negative information (Cahill et al., 1996; Canli et al., 2000; Hamann, Ely, Grafton, & Kilts, 1999). This suggests that older adults' on-line reductions in response to negative pictures should lead to disproportionately diminished later memory for negative information, as has been found in behavioral studies with the elderly (Charles et al., 2003; Mather & Carstensen, 2003).

Two studies found that older adults showed less amygdala activation than younger adults when viewing negative faces (Iidaka et al., 2002) or a blocked set of emotional faces composed of mostly negative faces (Gunning-Dixon et al., 2003). The present study suggests that these age differences do not reflect an overall decline in the functioning of the amygdala, but instead reflect a shift in the type of emotional stimuli to which it is most responsive.

Previous studies have shown that for younger adults, the level of emotional arousal is positively correlated with amygdala activation (Canli et al., 2000; Lane, Chua, & Dolan, 1999). We also found a relationship between arousal and amygdala activation. Older adults rated the negative pictures as less arousing than did younger adults and showed diminished amygdala responses to these pictures. Furthermore, the age difference in amygdala activity disappeared when we compared older adults to those younger adults whose arousal ratings for negative pictures were as low as those of older adults. Nevertheless, the pattern of activity seen in the amygdala cannot be entirely explained by arousal levels, as older adults showed more activity for positive than negative pictures, even though the positive pictures were actually less arousing for them than the negative pictures.

Prior studies of brain correlates of human aging paint a picture of decline and document that age-associated deterioration in the brain is related to diminished capacities in memory and cognition. So strong is the presumption that age differences reflect biologically based deficits that consideration of alternative explanations is rarely given. A growing behavioral literature, however, suggests that motivation and social context exert powerful influences on performance in the elderly, and in some cases can account fully for observed differences between age groups (Rahhal, Hasher, & Colcombe, 2001; Rahhal, May, & Hasher, 2002). The current findings suggest that changes in brain activation patterns with age may also be influenced by factors other than biological decline, as the responsiveness of older adults' amygdalae decreased for negative pictures but not for positive pictures. Another indication that shifts in processing styles led to older adults' change in amygdala activation is the fact that younger adults with behavioral responses most similar to those of older adults had amygdala activation patterns resembling those of older adults.

According to socioemotional selectivity theory (Carstensen, Isaacowitz, & Charles, 1999), boundaries on time (in the case of aging, life expectancy) shift goals. When time is perceived as expansive, as it typically is in youth, acquiring information and expanding horizons are prioritized. When constraints on time are perceived, as is typically the case in old age, negative experiences are no longer useful investments in the future. Emotion regulation becomes a higher priority, and older people appear to diminish the processing of negative information that might reduce positive affect. The findings in the present study demonstrate how changes in priorities across the life span may be related to changes in the neural substrates of emotion.

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