doi:10.1093/scan/nsm024 SCAN (2007) 2, 292–302

Age-related differences in brain activity underlying identification of emotional expressions in faces

Michelle L. Keightley,[1,2,3] Kimberly S. Chiew,[2] Gordon Winocur,[3,4,6] and Cheryl L. Grady[3,4,5]

[1]Department of Occupational Science and Occupational Therapy, University of Toronto, [2]Toronto Rehabilitation Institute, [3]Rotman Research Institute, Baycrest Centre for Geriatric Care, [4]Department of Psychology, [5]Department of Psychiatry, University of Toronto, Toronto, and [6]Department of Psychology, Trent University, Peterborough, Ontario, Canada

We used fMRI to explore brain activity in young and old adults, while they viewed and labeled faces expressing different emotions as well as neutral expressions. Older adults had significantly greater difficulty identifying expressions of sadness, anger and disgust than young adults. Both groups performed at ceiling for happy expressions. The functional neuroimaging data revealed that both young and old adults recruited a pattern of activity that distinguished happy expressions from all other expressions, but the patterns were age-specific. Older adults showed increased activity in ventromedial prefrontal cortex, lingual gyrus and premotor cortex for happy expressions, whereas younger adults recruited a more widely distributed set of regions including the amgydala, ventromedial prefrontal cortex, lateral prefrontal regions and bilateral inferior parietal and superior temporal areas. Conversely, younger adults showed more activity in the dorsal anterior cingulate for other types of expressions, and older adults had more activity in dorsal cingulate, as well as middle and inferior frontal gyri, somatosensory cortex, insula and middle temporal regions. These results support previous research demonstrating age differences in brain activity during emotional processing, and suggest possible age-related differences in cognitive strategy during identification of happy faces, despite no effect of age on this ability.

Keywords: aging; emotion; fMRI; faces

Social cognition has been defined as the ability to interpret and predict others' behavior in terms of their beliefs and intentions, and to interact in complex social environments and relationships (Baron-Cohen *et al.*, 2000). The ability to understand and respond to the emotional content and cues present in the environment and to remember emotional information are integral parts of social cognition (Grady and Keightley, 2002; Adolphs, 2003). The amygdala is thought to be a critical component of a network of regions involved in social cognition, particularly for the processing of emotions in faces (Gobbini and Haxby, 2007). Lesions to the amygdala disrupt this ability (Adolphs *et al.*, 1994, 1999; Anderson and Phelps, 2000). Consistent with lesion work, functional neuroimaging studies in young adults have found amygdala activation when negative face expressions are viewed, particularly fear (Breiter *et al.*, 1996; Morris *et al.*, 1996; Whalen *et al.*, 1998b; Blair *et al.*, 1999; Pessoa *et al.*, 2002; Anderson *et al.*, 2003). Increased amygdala activity also has been observed in response to positive emotional stimuli, although less consistently (Hamann *et al.*, 2002; Winston *et al.*, 2003; Yang *et al.*, 2003; Zald, 2003). More recently, a patient with bilateral amygdala damage (S.M.) who showed impaired ability to detect fear, demonstrated normal performance once she was directed to look at the eyes when judging the facial expression. This latter finding suggests a more general role for the amygdala in directing attention to social and emotional cues (Vuilleumier, 2005).

The cognitive appraisal of visually complex emotional stimuli also is a critical component of social cognition, and is thought to be mediated in part by occipital cortex (Kosslyn *et al.*, 1996; Reiman *et al.*, 1997; Morris *et al.*, 1998; Sprengelmeyer *et al.*, 1998; Taylor *et al.*, 1998; Lane *et al.*, 1999; Paradiso *et al.*, 1999; Phan *et al.*, 2002). Prefrontal cortex also appears to play a general role in attention to emotion and emotional appraisal (Drevets and Raichle, 1998; Ochsner *et al.*, 2002; Cunningham *et al.*, 2004) and is often active during tasks of emotional processing (Lane *et al.*, 1997a, b, c; Reiman *et al.*, 1997). Emotional tasks also involve the anterior cingulate, particularly when some cognitive component, in addition to emotion perception, is added to the task (e.g. gender identification or recognition of emotional stimuli, Taylor *et al.*, 1998; Whalen *et al.*, 1998a; Bush *et al.*, 2000; Keightley *et al.*, 2003). It has been suggested (Phan *et al.*, 2002) that the anterior cingulate and medial prefrontal cortex, together with their extensive connections to subcortical limbic structures, may represent an interaction zone between affect and cognition.

Received 6 March 2007; Accepted 14 May 2007
Advance Access publication 24 August 2007

This work was supported by a grant from the Canadian Institutes of Health Research (MOP14036), a CIHR doctoral fellowship as well as a Toronto Rehabilitation Institute Postdoctoral Fellowship and University of Toronto/McMaster University Indigenous Health Research Development Program Post-Doctoral Fellowship, funded by the Canadian Institutes of Health Research-Institute of Aboriginal People's Health to M.L.K. Dr Grady also is supported by the Canada Research Chairs program. The authors thank the MRI technologists at Sunnybrook Health Science Centre for their assistance in carrying out this experiment.

Correspondence should be addressed to Michelle L. Keightley, Department of Occupational Science and Occupational Therapy, Rehabilitation Sciences Building (Centre for Function and Well-Being), University of Toronto, 160-500 University Avenue, 9th Floor, Toronto, Ontario M5G 1V7, Canada.
E-mail: michelle.keightley@utoronto.ca.

Finally, the insula is thought to be critically involved in perceiving disgust (Phillips *et al.*, 1997; Sprengelmeyer *et al.*, 1998; Calder *et al.*, 2000; Anderson *et al.*, 2003), likely due to its role in visceral and somatosensory responses (Adolphs, 2002).

The effect of aging on social cognition has received considerable interest in recent years, particularly the effect of age on perceiving emotions in faces. In one early study, McDowell *et al.* (1994) found that older adults identified happy expressions as accurately as younger adults, but they were less accurate at identifying negative and neutral expressions. Similar results have since been reported by a number of other investigators, with an age reduction in labeling negative expressions and an age preservation in labeling happy expressions the most consistent findings (Oscar-Berman *et al.*, 1990; McDowell *et al.*, 1994; Brosgole and Weisman, 1995; MacPherson *et al.*, 2002; Phillips *et al.*, 2002; Calder *et al.*, 2003; Keightley *et al.*, 2006). In addition, older adults show a decreased ability to detect threat from faces, compared to young adults (Ruffman and Edge, 2006). Moreover, the age reduction in labeling negative expressions is independent of general age-related cognitive changes in processing speed, basic face processing abilities, and reasoning about non-face stimuli (Sullivan and Ruffman, 2004; Keightley *et al.*, 2006).

Consistent with the behavioral differences, initial neuroimaging studies have demonstrated age-related alterations of activity in the amygdala and other emotion-related areas. Reduced amygdala activity in older adults when viewing negative faces, as well as reduced activity in occipital and parietal regions when viewing positive faces, compared to young adults, have been reported (Iidaka *et al.*, 2002; Gunning-Dixon *et al.*, 2003; Fischer *et al.*, 2005). An age reduction in amygdala activity has been reported for negative pictures, as well (Mather *et al.*, 2004). On the other hand, older adults have more activity in medial and lateral prefrontal cortex when viewing emotional faces (Gunning-Dixon *et al.*, 2003), particularly negative ones (Tessitore *et al.*, 2005). This increased prefrontal activity is interesting in light of similar findings of increased prefrontal activity in elderly individuals during non-emotional tasks (Grady and Craik, 2000; Cabeza, 2002). Given the presumed roles for prefrontal cortex in emotion processing mentioned above, these data suggest that older adults rely more on cognitive appraisal of emotional faces than do younger adults.

To the best of our knowledge, no imaging experiment has assessed the ability of older and younger adults to label a broad range of emotional expressions. Thus, the purpose of the current study was to explore neural activity associated with the perception and labeling of multiple facial expressions in young and old adults, so that we could examine the neural processes associated with older adults' preservation for labeling happy expressions, as well as those underlying reductions in labeling negative expressions. In addition, we used an analytic approach that emphasizes whole-brain patterns of activity, rather than focusing on individual brain regions. As happy faces are identified with high accuracy regardless of age and cultural background (Biehl *et al.*, 1997), and are recognized more rapidly than negative expressions (Kirita and Endo, 1995), we expected to see patterns of activity unique to happy expressions in both young and older adults. In addition, based on previous neuroimaging data, we expected older adults to show different patterns of brain activity when labeling emotional expressions, involving reduced amygdala activity and greater prefrontal and anterior cingulate activity, particularly for negative faces.

METHODS

Participants in this experiment were 10 young adults (five men, five women) and 11 older adults (six women, five men; Table 1). All participants were Caucasian, except for two of the younger adults who were Asian. Participants were right-handed, with the exception of one young adult who was left-handed, and all gave informed consent in accordance with the ethics committees of Baycrest and Sunnybrook Health Sciences Centre. Participants were screened to rule out a history of psychiatric, neurological or other medical illness that might compromise cognitive function, or a history of substance abuse. We also assessed personality using the NEO Five Factor Inventory (Costa and McCrae, 1997) and emotional awareness using the 20-item Toronto Alexithymia Scale (TAS-20, Bagby *et al.*, 1994). Alexithymia is a personality construct that includes difficulty identifying and describing feelings and difficulty distinguishing between feelings and the bodily sensations of emotional arousal (Parker *et al.*, 1999). Mood was assessed using the Positive and Negative Affect Schedule (PANAS, Watson *et al.*, 1988) and mental status with the Mini Mental Status Examination (Folstein *et al.*, 1975). Younger adults had slightly more education than the older adults,

Table 1 Demographic and behavioral measures

Variable	Young	Old
Age (years)	27.2 (2.4)	69.6 (9.2)
Education (years)	19.0 (2.3)	16.3 (3.0)
MMSE	29.7 (0.5)	28.9 (1.1)
Vocabulary	23.0 (4.3)	23.4 (3.8)
TAS-20	38.0 (7.0)	38.8 (8.3)
PANAS positive	31.8 (6.8)	36.4 (5.5)
PANAS negative	12.5 (1.6)	12.7 (2.8)
Face expression labeling		
Happy	1.00	1.00
Surprise	0.92 (0.12)	0.95 (0.11)
Neutral	0.90 (0.16)	0.86 (0.18)
Anger	0.83 (0.19)	0.62 (0.18)*
Disgust	0.85 (0.18)	0.54 (0.24)*
Fear	0.78 (0.19)	0.68 (0.30)
Sad	0.83 (0.21)	0.61 (0.24)*

*Significant age difference, $P < 0.05$.
Values are means with s.d. in parentheses. Labeling measures are proportion correct.

$t(19) = 2.3$, $P < 0.05$, and displayed greater levels of extraversion $t(19) = 2.5$, $P < 0.05$, but there were no group differences on any of the other demographic or personality variables that we assessed (Table 1), which were all within normal limits.

Stimuli

Faces with positive, negative and neutral expressions were taken from the Japanese and Caucasian Facial Expressions of Emotion (JACFEE) and Neutral Faces (JACNeuF, Biehl *et al.*, 1997), a stimulus set that has been extensively normed in younger adults. The JACFEE contains 56 photographs, including eight photos each of anger, contempt, disgust, fear, happiness, sadness and surprise. For each emotion, the eight photos include four individuals of Japanese descent and four Caucasians, as well as equal numbers of men and women. Each of the individuals in the JACFEE contributes a neutral expression in the JACNeuF, for a total of 56 neutral faces. Thus, each individual posing a neutral expression was also viewed portraying one of the seven emotions. These faces were used in an 8-alternative forced-choice labeling task similar to those used previously to assess face emotion recognition in healthy individuals and patients with amygdala damage (Young *et al.*, 1995; Adolphs *et al.*, 1996; Calder *et al.*, 2003). Participants viewed faces one at a time and were instructed to assign an emotional label to each face. Faces were presented for 6 s in a random order, and interspersed with null events (fixation crosses, presented for 4 s each). Blocks of the label task were presented in three scanning runs (along with two other tasks not reported here). Across the three runs there were 128 total trials for the label task, with 16 trials for each of the seven emotions and 16 neutral trials (some faces were seen more than once—but no more than twice—in order to generate enough trials for reliable analysis in each emotion category). Overt labeling was assessed prior to scanning, and in the scanner participants were instructed to silently label the faces using the eight categories. Covert labeling was used during scanning to avoid verbal responses and the high memory demand of having to respond with key presses corresponding to the eight choices. We found no differences in labeling performance, in either young or old adults, based on the ethnicity of the presented faces, so for all analyses data were collapsed across Japanese and Caucasian faces.

fMRI data acquisition

Data were acquired with a Signa 1.5 T magnet using a standard head coil (CV/i hardware, LX8.3 software; General Electric Medical Systems, Waukesha, WI, USA). A high-resolution, 3D T1-weighted fast spoiled gradient echo image was first obtained so that functional maps could be displayed on brain anatomy (TR = 35 ms; TE = 6.0 ms; flip angle = 35°; acquisition matrix = 256 × 256 × 124; FOV = 22 cm × 16.5 cm; 124 axial slices; slice thickness = 1.4 mm). Functional imaging was performed to measure blood oxygenation level-dependent (BOLD) signal changes (Ogawa *et al.*, 1993), acquired with a single-shot T2*-weighted pulse sequence with spiral readout (TR = 2000 ms; TE = 40 ms; flip angle = 80°; effective acquisition matrix = 64 × 64 × 26; FOV = 20 cm; 26 slices; slice thickness = 5.0 mm).

Image analysis

Image preprocessing was performed using the Analysis of Functional Neuroimages software package (Cox, 1996). Time series data were spatially co-registered to correct for head motion using a 3D Fourier transform interpolation. Each volume in the time series was aligned to an early fiducial volume from the first imaging run in the scanning session. The alignment parameters were computed by an iterative weighted least squares fit to the reference volume. The peak range of head motion was less than 1.3 mm for all subjects. Motion corrected images were then spatially normalized to an fMRI spiral scan template generated from 30 subjects scanned locally. This template was registered to the MNI template used by SPM99. The transformation of each subject to the spiral template was achieved using a 12-parameter affine transform with sinc interpolation as implemented in SPM99, and smoothed with a Gaussian filter of 6 mm full-width-at-half-maximum (FWHM) to increase the signal-to-noise ratio. The initial 10 image volumes in each run, in which transient signal changes occur as brain magnetization reaches a steady state, were excluded from all analyses. The resulting voxel size after processing was $4 \times 4 \times 4\ mm^3$.

For statistical analysis we used a multivariate approach, partial least squares, or PLS (McIntosh *et al.*, 1996, 1999), in order to identify whole brain patterns of activity that varied across the emotion conditions. PLS operates on the covariance between brain voxels and the experimental design to identify latent variables, or LVs (similar to principal components), that optimally relate the two sets of measurements. In using PLS, we did not specify contrasts across conditions or groups in advance; rather, the algorithm extracts LVs explaining the covariance between conditions and brain activity, in order of the amount of covariance explained (with the first LV accounting for the most covariance). Each LV identifies a pattern of differences in brain activity across the conditions and specifies which brain voxels show this effect. Each brain voxel has a weight, known as a salience, which is proportional to the covariance of activity with the task contrast on each LV. Multiplying the BOLD contrast value in each brain voxel for each subject by the salience for that voxel, and summing across all voxels gives a 'brain' score for each subject on a given LV.

The PLS analysis examined activity across the face conditions in both young and old adults, allowing us to determine patterns of brain activity that differed across groups as well as across the emotion conditions. Data from the contempt condition were not included in either

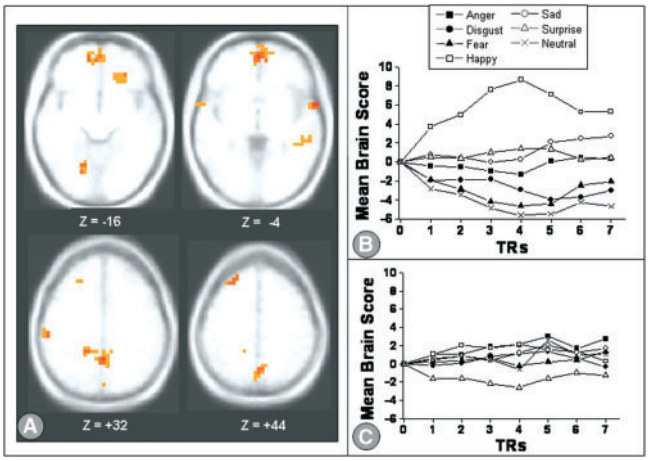

Fig. 1 (A) Areas from LV1 ($P < 0.002$) with differential activity across emotional expressions are shown on the average structural MRI from the young group. Labels under each image refer to the level relative to the anterior commissure–posterior commissure (AC–PC) line. All areas shown had increased activity during labeling happy expressions in young adults, but older adults showed little contribution to this pattern. All data in these images were taken from the bootstrap ratios from the 4th TR. (B) Plot of mean brain scores for all conditions in young adults. The mean brain score for happy expressions diverges from the other emotions as early as the first TR (2–4 s poststimulus onset). (C) Plot of mean brain scores across the expression conditions in old adults.

the behavioral or MRI analyses, as performance on this condition was poor for all participants (i.e. no better than 50% correct, on average). PLS was carried out on the remaining face conditions after averaging all 16 events for each emotion, using the definitions of each emotion from the normative data (Matsumoto and Ekman, 1988). The first eight TRs of each event were included in the analysis to capture the hemodynamic response (i.e. 0–16 s), with activity at each time point normalized to activity in the first TR (labeled TR0 in the figures). PLS as applied to event-related data results in a set of brain regions related to the task contrasts for each TR on each LV (McIntosh *et al.*, 2004). To determine contrasts across conditions, mean brain scores were plotted across the eight TRs used in the analysis (Figure 1). The significance for each LV as a whole was determined by using a permutation test (McIntosh *et al.*, 1996). As 500 permutations were used, the smallest *P*-value obtainable for each LV was $P < 0.002$. In addition to the permutation test, a second and independent step was to determine the reliability of the saliences for the brain voxels characterizing each pattern identified by the LVs. To do this, all saliences for each TR were submitted to a bootstrap estimation of the standard errors (Efron and Tibshirani, 1986). Peak voxels with a salience/SE ratio > 3.0 were considered to be reliable, as this approximates $P < 0.005$ (Sampson *et al.*, 1989). Local maxima for reliable clusters containing at least 10 voxels on each LV were defined as the voxel with a salience/SE ratio higher than any other voxel in a 2-cm cube centered on that voxel. Locations of these maxima are reported in terms of coordinates in MNI (Montreal Neurological Institute) space.

RESULTS

Performance on the labeling task collected prior to the scans (Table 1) was analyzed with a repeated measures of analysis of variance (ANOVA), with age group as the between-subject factor and emotion condition as the within-subject factor. Scores for happy faces were not included in this analysis, as both groups showed perfect identification of these faces. For the remaining conditions, there was a significant main effect of emotional expression, $F(5,95) = 6.0$, $P < 0.001$, and the main effect of age was significant $F(1,19) = 9.4$, $P < 0.01$. However, the interaction of age and emotion also was significant, $F(5,95) = 2.5$, $P < 0.05$. To examine this interaction we tested simple main effects for each emotion (except happy and contempt). Compared to younger adults, older adults had reduced identification of anger ($F(1,19) = 6.7$, $P < 0.02$), disgust ($F(1,19) = 10.7$, $P < 0.01$), and sadness ($F(1,19) = 5.4$, $P < 0.05$). Identification of surprise, fear and neutral expressions did not differ between the groups (Fs < 1).

In the analysis of fMRI data, LV1 ($P < 0.002$) revealed brain activity that differentiated happy expressions from all other expressions in young adults (Figure 1B), but did not distinguish the face expressions in older adults (Figure 1C). When young adults identified happy expressions, activity was increased in a widely distributed set of brain regions, including ventromedial prefrontal cortex, anterior and posterior cingulate gyrus, left postcentral gyrus, and bilateral middle frontal gyri (Figure 1A and Table 2). Other brain regions demonstrating increased activity for happy faces bilaterally included the cuneus, precuneus, inferior parietal lobe and superior temporal gyrus. Activity was decreased for happy expressions and/or increased during the other conditions only in the left dorsal anterior cingulate gyrus (Table 2). No changes in amygdala activity were noted using a cluster size of 10 voxels; however, smaller clusters of increased activity for happy faces were noted in the right amygdala (X: 24, Y: −8, Z: −24, ratio = 4.5 at TR4, 4 voxels) and in the left hemisphere in a region extending into both the amygdala and hippocampus (X: −24, Y: −16, Z: −24, TRs 2–7, ratio = 5.7 at TR5, 5 voxels, Figure 2).

LV2 ($P < 0.02$) differentiated happy expressions from other expressions only in the older adults (Figure 3). In old adults, happy expressions, and those of disgust to a lesser extent, were associated with increased activity in ventromedial prefrontal cortex, lingual gyrus and bilateral premotor cortex (Table 3). For the other negative expressions and neutral expressions, increased activity was seen in a large number of areas, including dorsal anterior cingulate, middle and inferior frontal gyri, somatosensory cortex, middle temporal gyri and the insula. No activity changes were noted in the amygdala in older adults, even after lowering the cluster size criterion.

Although the patterns of activity distinguishing happy faces differed in young and older adults, there appeared to be some regions where both groups had increased activity.

Table 2 Brain regions where activity differentiates happy from all other expressions in young adults (LV1)

Region	BA	X	Y	Z	Ratio	TRs*
Happy > Other Conditions						
R Orbitofrontal cortex	11	12	32	−16	−6.14	3,**5**,6
R Middle frontal gyrus	10	28	44	20	−6.23	3
R Middle frontal gyrus	10	32	56	8	−4.53	**3**,4,5,6,7
L Superior frontal gyrus	8	−24	40	44	−4.55	4
Medial frontal gyrus	10	0	68	4	−8.59	**3**,4
L Medial frontal gyrus	6	−4	−4	56	−6.52	3,**4**,5,6
R Ventral anterior cingulate	25	8	24	−12	−4.42	2,3,5,**6**,7
R Insula		28	8	0	−5.87	**6**,7
R Cuneus	17, 19	24	−72	8	−6.43	5
L Cuneus	19	−28	−88	28	−5.53	**5**,6
L Precuneus	31, 7	−4	−52	36	−5.65	2,3,4,**5**
R Precuneus	18, 7	20	−72	24	−4.69	**2**,5,7
L Lingual gyrus	17	−20	−72	−12	−6.12	**3**,4,5,7
R Inferior parietal lobe	40	60	−32	32	−5.53	3
L Postcentral gyrus	2	−60	−24	32	−5.26	3,**4**,5
R Superior temporal gyrus	22	60	4	−4	−6.39	3,**4**
L Superior temporal gyrus	22	−48	−20	4	−4.47	4
L Posterior cingulate	31	−16	−44	36	−8.08	4,**5**,6
Happy < Other Conditions						
L Dorsal anterior cingulate	32	−8	24	40	4.59	2,**3**

*TRs where area is reliable; If more than one TR is listed, the TR in bold and underlined is the TR where the ratio was maximal.
R = Right; L = Left; BA = Brodmann's area; Ratio = bootstrap ratio indicating reliability of each voxel (the largest ratio across the TRs is reported in the table). X (right/left): Negative values are in the Left Hemisphere; Y (anterior/posterior): Negative values are posterior to the zero point (located at the anterior commissure); Z (superior/inferior): Negative values are inferior to the plane defined by the anterior and posterior commissures. Coordinates are in MNI space.

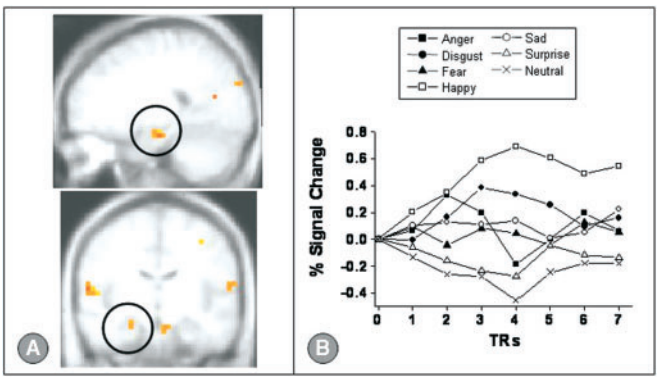

Fig. 2 (A) A region of the left amygdala/hippocampus where young adults had increased activity during labeling of happy expressions, shown on a mean sagittal image from the young adults (Y = −24, TR5). (B) The graph shows percent signal change (from baseline) in this region for all conditions in young adults.

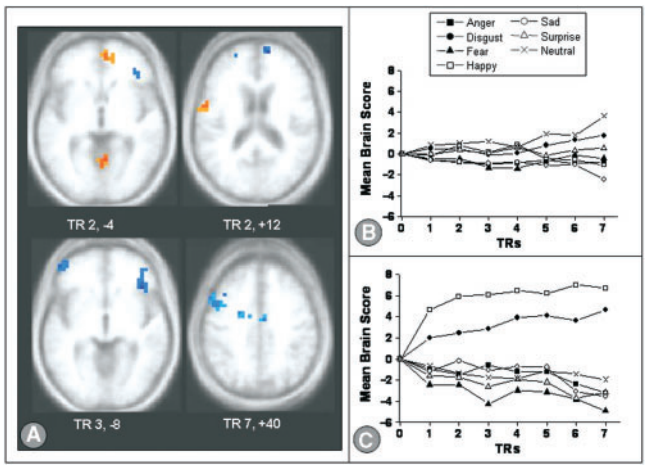

Fig. 3 (A) Areas from LV2 ($P = 0.02$) with differential activity across emotional expressions are shown on the average structural MRI from the old group. Labels under each image refer to the TR from which the data were taken and the level relative to the AC–PC line. Red brain areas had increased activity during labeling happy expressions in old adults, and disgust expressions to a lesser extent, and blue areas had more activity during labeling of the other expressions. (B) Plot of mean brain scores for all conditions in young adults, who showed little contribution to this pattern. (C) Plot of mean brain scores across the expression conditions in old adults. The mean brain scores for happy and disgust expressions diverge from the other emotions as early as the first TR (2–4 s poststimulus onset).

In the ventromedial PFC (Prefrontal Cortex) and lingual gyrus, there was overlap in the areas showing increased activity for happy faces in the two groups (Figure 4). In addition, decreased activity for happy faces, compared to other expressions, was found in very similar regions of dorsal anterior cingulate cortex in the two groups (for a further discussion of overlapping regions and differential timing of activations of young and old adults, please see Supplementary Material including Figures 5 and 6).

Finally, as neither of the patterns described earlier identified any differences for those emotions where older adults performed more poorly than the younger adults, we carried out three additional analyses directly comparing these emotions (anger, disgust and sadness) to the other emotions (except for happy) to look for differences in activity between the age groups. None of these analyses

Table 3 Brain regions where activity differentiates happy and disgust from all other expressions in old adults (LV2)

Region	BA	X	Y	Z	Ratio	TRs*
Happy and Disgust > Other Conditions						
R Medial frontal gyrus	10	4	52	−4	4.67	2
R Lingual gyrus	19	4	−60	−4	5.44	2
R Precentral gyrus	6	56	−8	28	4.35	3
L Precentral gyrus	6	−60	0	12	5.1	2
Happy and Disgust < Other Conditions						
L Dorsal anterior cingulate	24/32	−8	16	40	−5.61	1,2,3,5,**6**
R Dorsal anterior cingulate	24	4	−8	40	−4.42	6,**7**
R Middle frontal gyrus	10	12	60	12	−6.64	2
L Inferior frontal gyrus	47	−52	52	−8	−5.92	3,**5**
R Inferior frontal gyrus	47	40	28	−8	−7.50	2,**3**
R Middle frontal gyrus	46	44	40	16	−5.08	3,**5**
L Middle frontal gyrus	8/9	−48	8	36	−8.62	6,**7**
R Postcentral gyrus	2/40	24	−28	48	−10.29	7
L Precentral gyrus	4	−28	−12	52	−6.47	7
L Superior frontal gyrus	8	−32	8	48	−4.79	4
R Superior temporal gyrus	22	40	−40	20	−5.42	6,**7**
R Middle temporal gyrus	21	44	−36	0	−6.45	6
L Middle temporal gyrus	21	−40	−44	4	−4.44	2,6,**7**
R Middle temporal gyrus	39	36	−72	16	−6.55	5,**6**,7
L Thalamus		−20	−32	4	−5.98	7

*TRs where area is reliable; If more than one TR is listed, the TR in bold and underlined is the TR where the ratio was maximal.
R = Right; L = Left; BA = Brodmann's area; Ratio = bootstrap ratio indicating reliability of each voxel (the largest ratio across the TRs is reported in the table). X (right/left): Negative values are in the Left Hemisphere; Y (anterior/posterior): Negative values are posterior to the zero point (located at the anterior commissure); Z (superior/inferior): Negative values are inferior to the plane defined by the anterior and posterior commissures. Coordinates are in MNI space.

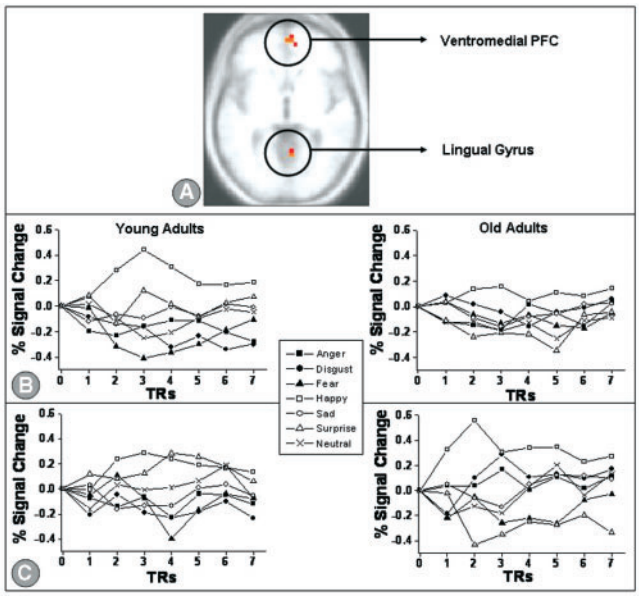

Fig. 4 (A) Two regions of medial cortex where both young and older adults showed increased activity during labeling of happy expressions are shown on a mean image from the older adults. Regions were defined by determining those voxels where both young adults (TR 4) and older adults (TR 2) showed reliable activity. (B) Plots of percent signal change (from baseline) in the ventromedial PFC region with maximal overlap (X = 0, Y = 56, Z = −4) for all conditions in young and old adults. (C) Plots of percent signal change (from baseline) in the lingual gyrus region with maximal overlap (X = 4, Y = −60, Z = −4) across the expression conditions in young and old adults.

resulted in significant LVs; however, there were a few regions from each that showed reliable bootstrap ratios. These can be found in Supplementary Table 4.

DISCUSSION

In this experiment, we measured brain activity associated with identifying a broad range of emotional face expressions. Consistent with the highly accurate identification of happy faces generally seen in adults, and found here, the main pattern of brain activity in both age groups distinguished happy faces from those expressing all other emotions. Our results also are in line with previous reports of age differences in brain activity associated with processing emotional faces. Although some areas, such as ventromedial PFC and lingual gyrus, were active for happy faces in both groups, young adults additionally activated the amygdala, lateral PFC, posterior cingulate, temporal and parietal regions. In contrast, lateral PFC and temporal regions were active in the older adults when labeling emotions other than happiness. The lack of significant findings that characterize differences between young and old adults during negative emotional processing is surprising in light of previous studies (i.e. Gunning-Dixon *et al.*, 2003; Iidaka *et al.*, 2002) and behavioral results indicating decreased performance for older adults. However, this may be related to methodological differences. In particular, because we examined brain activity across all the basic emotions, we were able to identify the

dominant patterns of brain activity characterizing the process of labeling a broad range of emotions, shedding new light on the functional neuroanatomy of emotional face processing and how this may be modulated by age.

Neural correlates of identifying facial expressions in young adults

Most neuroimaging studies have found amygdala activation in young adults when viewing negative faces (Breiter *et al.*, 1996; Morris *et al.*, 1996; Whalen *et al.*, 1998b; Blair *et al.*, 1999; Critchley *et al.*, 2000; Pessoa *et al.*, 2002; Anderson *et al.*, 2003). We found increased activity in small regions of the amygdala bilaterally in the younger adults, but for happy faces, not negative ones. This is surprising, given the evidence that the amygdala is activated by negative facial expressions. On the other hand, it is not entirely unexpected as increased amygdala activity has been found also for positive faces (Hamann *et al.*, 2002; Pessoa *et al.*, 2002; Winston *et al.*, 2003; Yang *et al.*, 2003; Zald, 2003). Indeed, a recent study suggested that both right and left amygdala play a role in processing a wide range of emotional expressions, not just negative ones (Shaw *et al.*, 2005). A recent model of amygdala function proposes that the right amygdala mediates autonomic responses to emotional stimuli whereas the left mediates conscious cognitive appraisal of emotional stimuli (Glascher and Adolphs, 2003). Based on this model, our results suggest that in young adults, happy faces engage both autonomic responses (via the right amygdala) and cognitive evaluation (via left amygdala engagement).

The pattern of brain activity that characterized happy faces in young adults also included a number of other regions previously shown to be active during emotional processing, such as ventromedial PFC and somatosensory cortex. For example, ventromedial PFC is interconnected anatomically with the amygdala (Amaral *et al.*, 1992) and is involved in emotional decision making (Cicerone and Tanenbaum, 1997; Bechara *et al.*, 1999; Price, 1999; Winston *et al.*, 2003). It was shown recently (Lewis *et al.*, 2005) that ventromedial PFC was activated during encoding of positive words and this activity was associated with later memory for these words, in line with our finding of more activity to happy faces. Our result also is consistent with a model of ventral PFC function that ascribes a role for ventromedial PFC in assessing and representing reward (O'Doherty *et al.*, 2001; Kringelbach and Rolls, 2004). Our results suggest that ventromedial PFC is engaged for processing the primary reward properties of happy faces, perhaps in conjunction with activity in the right amygdala. Somatosensory activity during labeling of happy faces is consistent with the somatic marker hypothesis (Damasio, 1996) which states that people identify emotions in others by simulating these emotions in themselves via involvement of somatosensory cortex (Adolphs *et al.*, 2000). The role of the posterior cingulate in emotion is not entirely clear, but the frequent activation of this region in studies of either emotion or autobiographical memory (Maddock, 1999) suggests that it may integrate these two functions. Increased activity in visual cortex during happy face identification, such as we found in the lingual gyrus, is consistent with other work showing modulation of visual regions during emotional tasks (Morris *et al.*, 1998; Anderson *et al.*, 2003) or when participants are viewing personally-relevant faces (Gobbini *et al.*, 2004). Finally, the dorsal anterior cingulate is thought to mediate monitoring and error checking during a variety of cognitive tasks (Bush *et al.*, 2000; Carter *et al.*, 2001; Paus, 2001), so that reduced activity in this region for happy faces likely reflects a reduced need for these processes, when the expression can be easily labeled. Thus, we were able to identify a widespread group of regions whose combined activity facilitates happy face labeling and that reflects the multiple processes that are likely recruited for this purpose.

Age differences in identifying emotional expressions

Older adults were able to identify happy expressions with the same accuracy as younger adults, and showed a pattern of brain activity that distinguished happy expressions from the others, as was found for the younger adults. This pattern in the older group was similar in some ways to that seen in the young, including increased activity in ventromedial PFC and lingual gyrus, and decreased activity in dorsal anterior cingulate. These similarities indicate that the processes subserved by these regions for the identification of happy faces changes little with age. One explanation for this type of preserved processing of positive emotions by older adults is that they have more experience with emotional regulation and have learned to emphasize positive emotions over negative ones (Carstensen *et al.*, 2003). However, it is not yet possible to know whether this is due to a positive motivational bias that affects brain activity, or to a spared ability to engage a distinct set of brain areas when a happy face is encountered, which could influence motivational factors.

In addition to some similarities, there were notable differences in the brain activity associated with processing face expressions in the young and old adults, including the fact that older adults showed no reliable modulations of activity in the amygdala. This is consistent with other studies showing an age reduction in this region (Iidaka *et al.*, 2002; Gunning-Dixon *et al.*, 2003), although other work would have suggested more amygdala activity for positive stimuli, in older adults compared to younger adults (Mather *et al.*, 2004). A number of studies have now shown that task demands can influence activity in the amygdala when participants process emotional stimuli (Bush *et al.*, 1998; Vuilleumier *et al.*, 2001; Ochsner *et al.*, 2002; Keightley *et al.*, 2003), and it is likely that these demands will also influence age differences in how this region responds to emotional stimuli. Therefore, differences across studies in task demands may account for some of the variability in results;

nevertheless all studies to date, including the current one, are consistent in that age differences are found in amygdala activity. This suggests that older adults' behavioral responses to emotional stimuli are mediated by age differences in the brain's basic response to these stimuli.

Our data also indicated that there are age differences in the neural correlates of emotion beyond those seen in the amygdala. Older adults demonstrated a more widely distributed pattern of activity for negative and neutral expressions, compared to younger adults, which included increased activity in bilateral middle frontal and temporal regions, as well as somatosensory cortex. Increased activity in some of these regions, such as somatosensory cortex, was seen in response to happy expressions in young adults. As noted earlier, activity in this region may indicate that individuals rely on simulating emotions observed in other people to identify those emotions (Adolphs, 2002), and the age difference seen here suggests that older adults, unlike younger adults, may rely on this strategy for emotions other than happy. Increased prefrontal activity in older compared to younger adults during emotional processing was found in earlier studies (Iidaka *et al.*, 2002; Mather *et al.*, 2004), and we found differences here as well. In our study, these frontal differences were seen not so much in terms of degree, but in terms of which emotions elicited this frontal activity. That is, younger adults activated the middle frontal gyri when identifying happy expressions, whereas older adults activated middle and inferior frontal gyri when identifying neutral and most negative expressions. Although these differences cannot be directly related to their ability to identify the expressions (e.g. there were no age differences in the identification of neutral faces), they do suggest that younger and older adults utilize different brain networks for identifying emotions in faces, similar to findings of increased prefrontal activity in elderly individuals during non-emotional tasks (Grady and Craik, 2000; Cabeza, 2002).

It was surprising to find that the pattern of neural activity found for happy expressions in older adults also was associated with faces expressing disgust, and the reason for this is not clear. This finding could be related to evidence that older adults are sometimes better at identifying expressions of disgust than are younger adults (Calder *et al.*, 2003), although in the current study expressions of disgust were identified with less accuracy by older compared to younger adults. Nevertheless, a similar brain pattern for disgust and happy faces, which are always easily identified by older adults, lends some support to the idea that the ability to recruit this pattern may benefit both types of expression recognition.

One limitation of the current study that should be noted is that the faces used in the labeling task have been standardized in younger adults across a variety of cultures (Biehl *et al.*, 1997), but not in older adults. Indeed, when we began the study there were no face stimulus sets for which norms were available from old adults. Although no data are available regarding valence or arousal ratings in older adults for all of the faces used here, we have obtained ratings for a large stimulus set of emotional and neutral faces, which includes some of the faces used in the current experiment (Grady *et al.*, 2007). These ratings did not differ significantly with age, suggesting that the age differences in brain activity observed in the current study were not due to age differences in the perceived intensity of the emotion or arousal to the faces. Nevertheless, it is clear that collecting normative data from older adults on labeling specific emotions would be useful for future work. Furthermore, it is unclear what influence labeling age-congruent faces would have on the current findings. As the stimulus set contained primarily young and middle-aged adults, future research should examine younger and older adults' accuracy for rating emotional expressions portrayed by older adults.

CONCLUSIONS

We found that both young and older adults identified happy facial expressions with high accuracy, consistent with other work in this field (Kirita and Endo, 1995; Leppanen and Hietanen, 2004; Suzuki *et al.*, 2006). Recently, Suzuki *et al.* (2006) found that happy face recognition is independent of all other emotions, using a technique that controls for effects of task difficulty, and a recent MEG study found that viewing happy faces resulted in a larger amplitude of a face-specific evoked component compared to either faces expressing disgust or neutral faces (Lewis *et al.*, 2003). This evidence, taken together with our fMRI results, suggests that the perception of happy face expressions may be distinct on a neural level and that this leads to a behavioral advantage in recognizing these faces. Although some regions such as ventromedial PFC were active for happy faces in both groups, the overall patterns for happy faces differed with age and this pattern was less specific in older adults, being also engaged in response to expressions of disgust. In addition, age differences were found in the amgydala and prefrontal cortex. Taken together the results suggest that older adults may rely on different cognitive strategies to identify both positive and negative emotional expressions in faces.

SUPPLEMENTARY DATA

Supplementary data are available in *SCAN* online.

Conflict of Interest

None declared.

REFERENCES

Adolphs, R. (2002). Neural systems for recognizing emotion. *Current Opinion in Neurobiology*, *12*, 169–77.

Adolphs, R. (2003). Cognitive neuroscience of human social behaviour. *Nature Reviews Neuroscience*, *4*, 165–78.

Adolphs, R., Damasio, H., Tranel, D., Cooper, G., Damasio, A.R. (2000). A role for somatosensory cortices in the visual recognition of emotion as

revealed by three-dimensional lesion mapping. *Journal of Neuroscience*, *20*, 2683–90.
Adolphs, R., Damasio, H., Tranel, D., Damasio, A.R. (1996). Cortical systems for the recognition of emotion in facial expressions. *Journal of Neuroscience*, *16*, 7678–87.
Adolphs, R., Tranel, D., Damasio, H., Damasio, A. (1994). Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. *Nature*, *372*, 669–72.
Adolphs, R., Tranel, D., Hamann, S., et al. (1999). Recognition of facial emotion in nine individuals with bilateral amygdala damage. *Neuropsychologia*, *37*, 1111–7.
Amaral, D.G., Price, J.L., Pitkanen, A., Carmichael, S.T. (1992). Anatomical organization of the primate amygdaloid complex. In: Aggleton, J.P., editor. *The Amygdala. Neurobiological Aspects of Emotion, Memory and Mental Dysfunction*. New York: John Wiley & Sons, Inc., pp. 1–66.
Anderson, A.K., Christoff, K., Panitz, D., De Rosa, E., Gabrieli, J.D. (2003). Neural correlates of the automatic processing of threat facial signals. *Journal of Neuroscience*, *23*, 5627–33.
Anderson, A.K., Phelps, E.A. (2000). Expression without recognition: contributions of the human amygdala to emotional communication. *Psychological Science*, *11*, 106–11.
Bagby, R.M., Parker, J.D., Taylor, G.J. (1994). The twenty-item Toronto Alexithymia Scale–I. Item selection and cross-validation of the factor structure. *Journal of Psychosomatic Research*, *38*, 23–32.
Baron-Cohen, S., Ring, H.A., Bullmore, E.T., Wheelwright, S., Ashwin, C., Williams, S.C. (2000). The amygdala theory of autism. *Neuroscience Biobehavioral Review*, *24*, 355–64.
Bechara, A., Damasio, H., Damasio, A.R., Lee, G.P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *Journal of Neuroscience*, *19*, 5473–81.
Biehl, M., Matsumoto, D., Ekman, P., et al. (1997). Matsumoto and Ekman's Japanese and Caucasian Facial Expressions of Emotion (JACFEE): reliability data and cross-national differences. *Journal of Nonverbal Behavior*, *21*, 3–21.
Blair, R.J.R., Morris, J.S., Frith, C.D., Perrett, D.I., Dolan, R.J. (1999). Dissociable neural responses to facial expressions of sadness and anger. *Brain*, *122*, 883–93.
Breiter, H.C., Etcoff, N.L., Whalen, P.J., et al. (1996). Response and habituation of the human amygdala during visual processing of facial expression. *Neuron*, *17*, 875–87.
Brosgole, L., Weisman, J. (1995). Mood recognition across the ages. *International Journal of Neuroscience*, *82*, 169–89.
Bush, G., Luu, P., Posner, M.I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Science*, *4*, 215–22.
Bush, G., Whalen, P.J., Rosen, B.R., Jenike, M.A., McInerney, S.C., Rauch, S.L. (1998). The counting stroop: an interference task specialized for functional neuroimaging- validation study with functional MRI. *Human Brain Mapping*, *6*, 270–82.
Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychology and Aging*, *17*, 85–100.
Calder, A.J., Keane, J., Manes, F., Antoun, N., Young, A.W. (2000). Impaired recognition and experience of disgust following brain injury. *Nature Neuroscience*, *3*, 1077–8.
Calder, A.J., Keane, J., Manly, T., et al. (2003). Facial expression recognition across the adult life span. *Neuropsychologia*, *41*, 195–202.
Carstensen, L.L., Fung, H.F., Charles, S.T. (2003). Socioemotional selectivity theory and the regulation of emotion in the second half of life. *Motivation and Emotion*, *27*, 103–23.
Carter, C.S., MacDonald, A.W.,3rd, Ross, L.L., Stenger, V.A. (2001). Anterior cingulate cortex activity and impaired self-monitoring of performance in patients with schizophrenia: an event-related fMRI study. *American Journal of Psychiatry*, *158*, 1423–8.
Cicerone, K.D., Tanenbaum, L.N. (1997). Disturbance of social cognition after traumatic orbitofrontal brain injury. *Archives of Clinical Neuropsychology*, *12*, 173–88.
Costa, P.T., McCrae, R.R. (1997). Stability and change in personality assessment: the revised NEO personality inventory in the year 2000. *Journal of Personality Assessment*, *68*, 86–94.
Cox, R.W. (1996). AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Computers and Biomedical Research*, *29*, 162–73.
Critchley, H., Daly, E., Phillips, M., et al. (2000). Explicit and implicit neural mechanisms for processing of social information from facial expressions: a functional magnetic resonance imaging study. *Human Brain Mapping*, *9*, 93–105.
Cunningham, W.A., Raye, C.L., Johnson, M.K. (2004). Implicit and explicit evaluation: FMRI correlates of valence, emotional intensity, and control in the processing of attitudes. *Journal of Cognitive Neuroscience*, *16*, 1717–29.
Damasio, A.R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences*, *351*, 1413–20.
Drevets, W.C., Raichle, M.E. (1998). Reciprocal suppression of regional cerebral blood flow during emotional versus higher cognitive processes: implications for interaction between emotion and cognition. *Cognition and Emotion*, *12*, 353–85.
Efron, B., Tibshirani, R. (1986). Bootstrap methods for standard errors, confidence intervals and other measures of statistical accuracy. *Statistical Science*, *1*, 54–77.
Fischer, H., Sandblom, J., Gavazzeni, J., Fransson, P., Wright, C.I., Backman, L. (2005). Age-differential patterns of brain activation during perception of angry faces. *Neuroscience Letters*, *386*, 99–104.
Folstein, M.F., Folstein, S.E., McHugh, P.R. (1975). "Mini Mental State"- a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189–98.
Glascher, J., Adolphs, R. (2003). Processing of the arousal of subliminal and supraliminal emotional stimuli by the human amygdala. *Journal of Neuroscience*, *23*, 10274–82.
Gobbini, M.I., Haxby, J.V. (2007). Neural systems for recognition of familiar faces. *Neuropsychologia*, *45*, 32–41.
Gobbini, M.I., Leibenluft, E., Santiago, N., Haxby, J.V. (2004). Social and emotional attachment in the neural representation of faces. *Neuroimage*, *22*, 1628–35.
Grady, C.L., Craik, F.I.M. (2000). Changes in memory processing with age. *Current Opinion in Neurobiology*, *10*, 224–31.
Grady, C.L., Hongwanishkul, D., Keightley, M.L., Lee, W., Hasher, L. (2007). The effect of age on memory for emotional faces. *Neuropsychology*, *21*, 371–80.
Grady, C.L., Keightley, M.L. (2002). Studies of altered social cognition in neuropsychiatric disorders using functional neuroimaging. *Canadian Journal of Psychiatry*, *47*, 327–36.
Gunning-Dixon, F.M., Gur, R.C., Perkins, A.C., et al. (2003). Age-related differences in brain activation during emotional face processing. *Neurobiology and Aging*, *24*, 285–95.
Hamann, S.B., Ely, T.D., Hoffman, J.M., Kilts, C.D. (2002). Ecstasy and agony: activation of the human amygdala in positive and negative emotion. *Psychological Science*, *13*, 135–41.
Iidaka, T., Okada, T., Murata, T., et al. (2002). Age-related differences in the medial temporal lobe responses to emotional faces as revealed by fMRI. *Hippocampus*, *12*, 352–62.
Keightley, M.L., Winocur, G., Burianova, H., Hongwanishkul, D., Grady, C. (2006). Age effects on social cognition: faces tell a different story. *Psychology and Aging*, *21*, 558–72.
Keightley, M.L., Winocur, G., Graham, S.J., Mayberg, H.S., Hevenor, S.J., Grady, C.L. (2003). An fMRI study investigating cognitive modulation of brain regions associated with emotional processing of visual stimuli. *Neuropsychologia*, *41*, 585–96.
Kirita, T., Endo, M. (1995). Happy face advantage in recognizing facial expressions. *Acta Psychologia*, *89*, 149–63.
Kosslyn, S.M., Shin, L.M., Thompson, W.L., et al. (1996). Neural effects of visualizing and perceiving aversive stimuli: a PET investigation. *Neuroreport*, *7*, 1569–76.

Kringelbach, M.L., Rolls, E.T. (2004). The functional neuroanatomy of the human orbitofrontal cortex: evidence from neuroimaging and neuropsychology. *Progress in Neurobiology*, *72*, 341–72.
Lane, R.D., Chua, P.M., Dolan, R.J. (1999). Common effects of emotional valence, arousal and attention on neural activation during visual processing of pictures. *Neuropsychologia*, *37*, 989–97.
Lane, R.D., Fink, G.R., Chau, P.M., Dolan, R.J. (1997a). Neural activation during selective attention to subjective emotional responses. *Neuroreport*, *8*, 3969–72.
Lane, R.D., Reiman, E.M., Ahern, G.L., Schwartz, G.E., Davidson, R.J. (1997b). Neuroanatomical correlates of happiness, sadness, and disgust. *American Journal of Psychiatry*, *154*, 926–33.
Lane, R.D., Reiman, E.M., Bradley, M.M., et al. (1997c). Neuroanatomical correlates of pleasant and unpleasant emotion. *Neuropsychologia*, *35*, 1437–44.
Leppanen, J.M., Hietanen, J.K. (2004). Positive facial expressions are recognized faster than negative facial expressions, but why? *Psychological Research*, *69*, 22–9.
Lewis, P.A., Critchley, H.D., Smith, A.P., Dolan, R.J. (2005). Brain mechanisms for mood congruent memory facilitation. *Neuroimage*, *25*, 1214–23.
Lewis, S., Thoma, R.J., Lanoue, M.D., et al. (2003). Visual processing of facial affect. *Neuroreport*, *14*, 1841–5.
MacPherson, S.E., Phillips, L.H., Della Sala, S. (2002). Age, executive function, and social decision making: a dorsolateral prefrontal theory of cognitive aging. *Psychology and Aging*, *17*, 598–609.
Maddock, R.J. (1999). The retrosplenial cortex and emotion: new insights from functional neuroimaging of the human brain. *Trends in Neuroscience*, *22*, 310–6.
Mather, M., Canli, T., English, T., et al. (2004). Amygdala responses to emotionally valenced stimuli in older and younger adults. *Psychological Science*, *15*, 259–63.
Matsumoto, D., Ekman, P. (1988). *Japanese and Caucasian Facial Expressions of Emotion (JACFEE) and Neutral Faces (JACNeuF)*. [CD]. (Available from the Human Interaction laboratory, University of California, San Francisco, 401 Parnassus Avenue, San Francisco, CA 94143).
McDowell, C.L., Harrison, D.W., Demaree, H.A. (1994). Is right hemisphere decline in the perception of emotion a function of aging? *International Journal of Neuroscience*, *79*, 1–11.
McIntosh, A.R. (1999). Mapping cognition to the brain through neural interactions. *Memory*, *7*, 523–548.
McIntosh, A.R., Bookstein, F.L., Haxby, J.V., Grady, C.L. (1996). Spatial pattern analysis of functional brain images using partial least squares. *Neuroimage*, *3*, 143–57.
McIntosh, A.R., Chau, W.K., Protzner, A.B. (2004). Spatiotemporal analysis of event-related fMRI data using partial least squares. *Neuroimage*, *23*, 764–75.
Morris, J.S., Friston, K.J., Buchel, C., et al. (1998). A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain*, *121*, 47–57.
Morris, J.S., Frith, C.D., Perrett, D.I., et al. (1996). A differential neural response in the human amygdala to fearful and happy facial expressions. *Nature*, *383*, 812–5.
Ochsner, K.N., Bunge, S.A., Gross, J.J., Gabrieli, J.D. (2002). Rethinking feelings: an FMRI study of the cognitive regulation of emotion. *Journal of Cognitive Neuroscience*, *14*, 1215–29.
O'Doherty, J., Kringelbach, M.L., Rolls, E.T., Hornak, J., Andrews, C. (2001). Abstract reward and punishment representations in the human orbitofrontal cortex. *Nat Neuroscience*, *4*, 95–102.
Ogawa, S., Menon, R.S., Tank, D.W., et al. (1993). Functional brain mapping by blood oxygenation level-dependent contrast magnetic resonance imaging. *Biophysics Journal*, *64*, 803–12.
Oscar-Berman, M., Hancock, M., Mildworf, B., Hutner, N., Weber, D.A. (1990). Emotional perception and memory in alcholism and aging. *Alcoholism-Clinical and Experimental Research*, *14*, 383–93.
Paradiso, S., Johnson, D.L., Andreasen, N.C., et al. (1999). Cerebral blood flow changes associated with attribution of emotional valence to pleasant, unpleasant, and neutral visual stimuli in a PET study of normal subjects. *American Journal of Psychiatry*, *156*, 1618–29.
Parker, J.D., Keightley, M.L., Smith, C.T., Taylor, G.J. (1999). Interhemispheric transfer deficit in Alexithymia: an experimental Study. *Psychosomatic Medicine*, *61*, 464–8.
Paus, T. (2001). Primate anterior cingulate cortex: where motor control, drive and cognition interface. *Nature Reviews Neuroscience*, *2*, 417–24.
Pessoa, L., McKenna, M., Gutierrez, E., Ungerleider, L.G. (2002). Neural processing of emotional faces requires attention. *Proceedings of the National Academy of Sciences of the United States of America*, *99*, 11458–63.
Phan, K.L., Wager, T., Taylor, S.F., Liberzon, I. (2002). Functional neuroanatomy of emotion: a meta-analysis of emotion activation studies in PET and fMRI. *NeuroImage*, *16*, 331–48.
Phillips, L.H., MacLean, R.D., Allen, R. (2002). Age and the understanding of emotions: neuropsychological and sociocognitive perspectives. *Journal of Gerontology Series B-Psyhological Sciences and Social Science*, *57*, 526–30.
Phillips, M.L., Young, A.W., Senior, C., et al. (1997). A specific neural substrate for perceiving facial expressions of disgust. *Nature*, *389*, 495–8.
Price, J.L. (1999). Prefrontal cortical networks related to visceral function and mood. *Annals of the New York Academy of Sciences*, *877*, 383–96.
Reiman, E.M., Lane, R.D., Ahern, G.L., et al. (1997). Neuroanatomical correlates of externally and internally generated human emotion. *American Journal of Psychiatry*, *154*, 918–25.
Ruffman, T.S.,, Sullivan, S., Edge, N. (2006). Differences in the way older and younger adults rate threat in faces but not situations. *Journal of Gerontology Series B-Psychological Sciences And Social Science*, *61*, P187–94.
Sampson, P.D., Streissguth, A.P., Barr, H.M., Bookstein, F.L. (1989). Neurobehavioral effects of prenatal alchohol: Part II. Partial least squares analysis. *Neurotoxicology and Teratology*, *11*, 477–91.
Shaw, P., Bramham, J., Lawrence, E.J., Morris, R., Baron-Cohen, S., David, A.S. (2005). Differential effects of lesions of the amygdala and prefrontal cortex on recognizing facial expressions of complex emotions. *Journal of Cognitive Neuroscience*, *17*, 1410–9.
Sprengelmeyer, R., Rausch, M., Eysel, U.T., Przuntek, H. (1998). Neural structures associated with recognition of facial expressions of basic emotions. *Proceedings of the Royal Society on London B Biological Science*, *265*, 1927–31.
Sullivan, S., Ruffman, T. (2004). Emotion recognition deficits in the elderly. *International Journal of Neuroscience*, *114*, 403–32.
Suzuki, A., Hoshino, T., Shigemasu, K. (2006). Measuring individual differences in sensitivities to basic emotions in faces. *Cognition*, *99*, 327–53.
Taylor, S.F., Liberzon, I., Fig, L.M., Decker, L.R., Minoshima, S., Koeppe, R.A. (1998). The effect of emotional content on visual recognition memory: a PET activation study. *NeuroImage*, *8*, 188–97.
Tessitore, A., Hariri, A.R., Fera, F., et al. (2005). Functional changes in the activity of brain regions underlying emotion processing in the elderly. *Psychiatry Research*, *139*, 9–18.
Vuilleumier, P. (2005). Staring fear in the face. *Nature*, *433*, 22–3.
Vuilleumier, P., Armony, J.L., Driver, J., Dolan, R.J. (2001). Effects of attention and emotion on face processing in the human brain: an event-related fMRI study. *Neuron*, *30*, 829–41.
Watson, D., Clark, L.A., Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, *54*, 1063–70.
Whalen, P.J., Bush, G., McNally, R.J., et al. (1998a). The emotional counting stroop paradigm: a functional magnetic resonance imaging probe of the anterior cingulate affective division. *Biological Psychiatry*, *44*, 1219–28.
Whalen, P.J., Rauch, S.L., Etcoff, N.L., McInerney, S.C., Lee, M.B., Jenike, M.A. (1998b). Masked presentations of emotional facial

expressions modulate amygdala activity without explicit knowledge. *Journal of Neuroscience*, *18*, 411–418.

Winston, J.S., O'Doherty, J., Dolan, R.J. (2003). Common and distinct neural responses during direct and incidental processing of multiple facial emotions. *NeuroImage*, *20*, 84–97.

Yang, T.T., Menon, V., Reid, A.J., Gotlib, I.H., Reiss, A.L. (2003). Amygdalar activation associated with happy facial expressions in adolescents: a 3-T functional MRI study. *Journal of the American Academy of Child and Adolescent Psychiatry*, *42*, 979–85.

Young, A.W., Aggleton, J.P., Hellawell, D.J., Johnson, M., Broks, P., Hanley, J.R. (1995). Face processing impairments after amygdalotomy. *Brain*, *118*, 15–24.

Zald, D.H. (2003). The human amygdala and the emotional evaluation of sensory stimuli. *Brain Research. Brain Research Reviews*, *41*, 88–123.