# Amygdala Response to Facial Expressions in Children and Adults

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**Background:** *The amygdala plays a central role in the human response to affective or emotionally charged stimuli, particularly fear-producing stimuli. We examined the specificity of the amygdala response to facial expressions in adults and children.*

**Methods:** *Six adults and 12 children were scanned in a 1.5-T scanner during passive viewing of fearful and neutral faces using an EPI BOLD sequence. All scans were registered to a reference brain, and analyses of variance were conducted on the pooled data to examine interactions with age and gender.*

**Results:** *Overall, we observed predominantly left amygdala and substantia innominata activity during the presentation of nonmasked fearful faces relative to fixation, and a decrease in activation in these regions with repeated exposure to the faces. Adults showed increased left amygdala activity for fearful faces relative to neutral faces. This pattern was not observed in the children who showed greater amygdala activity with neutral faces than with fearful faces. For the children, there was an interaction of gender and condition whereby boys but not girls showed less activity with repeated exposure to the fearful faces.*

**Conclusions:** *This is the first study to examine developmental differences in the amygdala response to facial expressions using functional magnetic resonance imaging.* Biol Psychiatry 2001;49:309–316 *© 2001 Society of Biological Psychiatry*

**Key Words:** Development, amygdala, fMRI, emotion, faces, facial expression

## Introduction

The amygdala appears to play a central role in the human response to affective or emotionally charged stimuli, particularly fear-producing stimuli (Aggleton 1992; LeDoux 1994, 1996). Animal lesion data and human imaging studies have implicated the amygdala in the detection of fear and conditioned fear responses (Büchel et al 1998; Kapp et al 1992; Killcross et al 1997; LaBar et al 1998; LaBar and LeDoux 1996; Morris et al 1998b). Likewise, amygdala activity has been shown to increase with the presentation of graphic negative material in photographs or films (Irwin et al 1996; Lane et al 1997; Reiman et al 1997). Functional magnetic resonance imaging (fMRI) studies have demonstrated that even facial expressions of fear, which may not evoke subjective fear responses in the viewer, can increase amygdala activity in adults (Breiter et al 1996; Morris et al 1996, 1998b; Whalen et al 1998). Breiter et al (1996) demonstrated predominantly left activation of the amygdala during rapid presentation of fearful expressions relative to neutral expressions that attenuated or "habituated" with repeated presentations of the stimuli. More recently Whalen et al (1998) showed greater right amygdala activity to rapidly presented *masked* fearful faces in an fMRI paradigm, suggesting that the amygdala responds to fear-related stimuli even when these stimuli are not consciously perceived. Similar patterns of activity have been obtained using positron emission tomography (Morris et al 1996, 1998a, 1998b). These data converge with reports that patients with bilateral amygdala lesions generally demonstrate selective deficits for recognizing fearful facial expressions despite normal recognition of other emotional expressions (Adolphs et al 1994, 1995; Broks et al 1998; Calder et al 1996; Hamann et al 1996).

The developmental literature on face processing suggests that the ability to discriminate among discrete facial expressions continues to develop throughout childhood and early adolescence (Kolb et al 1992). However, the development of the amygdala response to facial expressions has not been studied. Given the evolutionary significance of fear-provoking or threatening stimuli, the response to fear stimuli may demonstrate earlier maturation than other emotional stimuli. Recently, Baird et al (1999) showed bilateral amygdala activation to fearful faces shown along with nonsense images in 12- to 17-year-old subjects using fMRI, suggesting that fearful faces activate the amygdala in adolescents. However, this study did not

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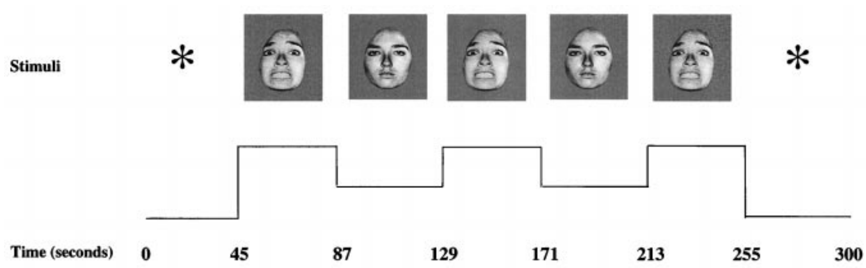


Figure 1. Example fearful and neutral face stimuli and task design used for functional magnetic resonance imaging scanning blocks.

compare the response to different facial expressions or examine developmental differences across this age range or between younger and older subjects. Understanding the normal development of affective processing (and affective regulation) as well as the neurobiological underpinnings of these developmental processes is a keystone in the investigation of the emergence of affective dysregulation, particularly affective disorders in childhood and adolescence.

The purpose of this study was to examine the developmental specificity of the amygdala response to fearful facial expressions in children and adults. We hypothesized, from the developmental literature that discrimination of negative emotional expressions appears to demonstrate a relatively prolonged development (e.g., Charlesworth and Kreutzer 1973; Field and Walden 1982), that children may have less discrete representations or skill at judging fearful and neutral expressions. To our knowledge this is the first study to examine developmental differences in the amygdala response to facial expressions using fMRI with children.

## Methods and Materials

### *Subjects*

Six male adults (mean = 24 years, SD = 6.6 years) and 12 children (mean = 11 years, SD = 2.4 years) recruited in the Pittsburgh area were scanned in a 1.5-T scanner during passive viewing of fearful and neutral faces. The children, six female and six male, ranged in pubertal development from Tanner stages[1] I/I to V/IV. Male and female subjects did not differ in mean age or Tanner stage. Data from an additional three adults (three female) and four children (two female) were not included due to excessive motion artifact ($>$0.5 voxels; $n = 5$) or claustrophobia ($n = 1$) or because the subject fell asleep during the task ($n = 1$). Subjects were screened for any personal or family history of psychiatric or medical illness, and for any contraindications for an MRI. Written child assent and parental consent were acquired before the study.

[1] Tanner stages (Tanner 1986) are used as a means of classifying pubertal development separate from chronologic age. Children are assigned two scores, one reflecting the degree of genital development and the other reflecting the development of pubic hair. Tanner stage assignments can then be used as a measure of physical and hormonal maturation.

### *Behavioral Paradigm*

The task consisted of the rapid and successive presentation of faces in blocks of neutral and emotional expressions. The face stimuli consisted of digitized fearful and neutral faces taken from the Ekman and Friesen (1976) study (Figure 1). A total of eight different actors (four male and four female) demonstrating both fearful and neutral expressions were used. The hair was stripped from the images to remove any nonfacial features, and both fear and exaggerated fear poses were used for each actor (Calder et al 1997), resulting in a total of 16 fear stimuli and eight neutral stimuli. Stimuli were presented for 200 msec with an interstimulus interval of 800 msec (flashing fixation point). Each block of trials consisted of the presentation of a flashing fixation point for 45 sec followed by alternating 42-sec blocks of either neutral or fearful expressions and a final 45-sec epoch of fixation (Figure 1). This procedure was repeated in three runs of trials with the presentation order counterbalanced across runs and across subjects (i.e., F-N-F-N-F or N-F-N-F-N). Following Breiter and colleagues' (Breiter et al 1996) design, no overt response was required. Instead, subjects were instructed to fixate centrally to try to get an overall sense of the faces.[2]

### *Image Acquisition, Processing, and Analysis*

Scans were acquired on a 1.5-T GE Signa scanner (General Electric Systems, Milwaukee) modified for echo planar imaging (Advanced NMR, Wilmington, MA) using a quadrature head coil. A $T_1$-weighted sagittal localizer image was used to prescribe the functional slice locations. $T_1$-weighted structural images were acquired in 4-mm contiguous coronal slices through the whole brain (echo time [TE] min, repetition time [TR] 500, matrix 256 $\times$ 256, field of view [FOV] 20) for purposes of localizing the functional activity and aligning images in Talairach space (Talairach and Tournoux 1988). Functional images ($T_2$*) were acquired at 12 of these slice locations spanning the entire amygdala ($\sim$A20 to P24 in Talairach coordinates) using an EPI BOLD sequence (TE 40, TR 3000, flip angle 90°, matrix 128 $\times$ 64, FOV 20, 4-mm skip 0, voxel size 3.125 $\times$ 3.125 $\times$ 4.0 mm). There were three runs of 100 images totaling 300 images per slice. Images were motion corrected and normalized. All 18 subjects had less than 0.5 voxels of in-plane motion. All images were registered to a representative reference brain using Automated Image Registration software (Woods et al 1992), and

[2] Breiter et al (1996) instructed subjects to get a gestalt of the images. We used language more appropriate to the developmental level of the child participants.

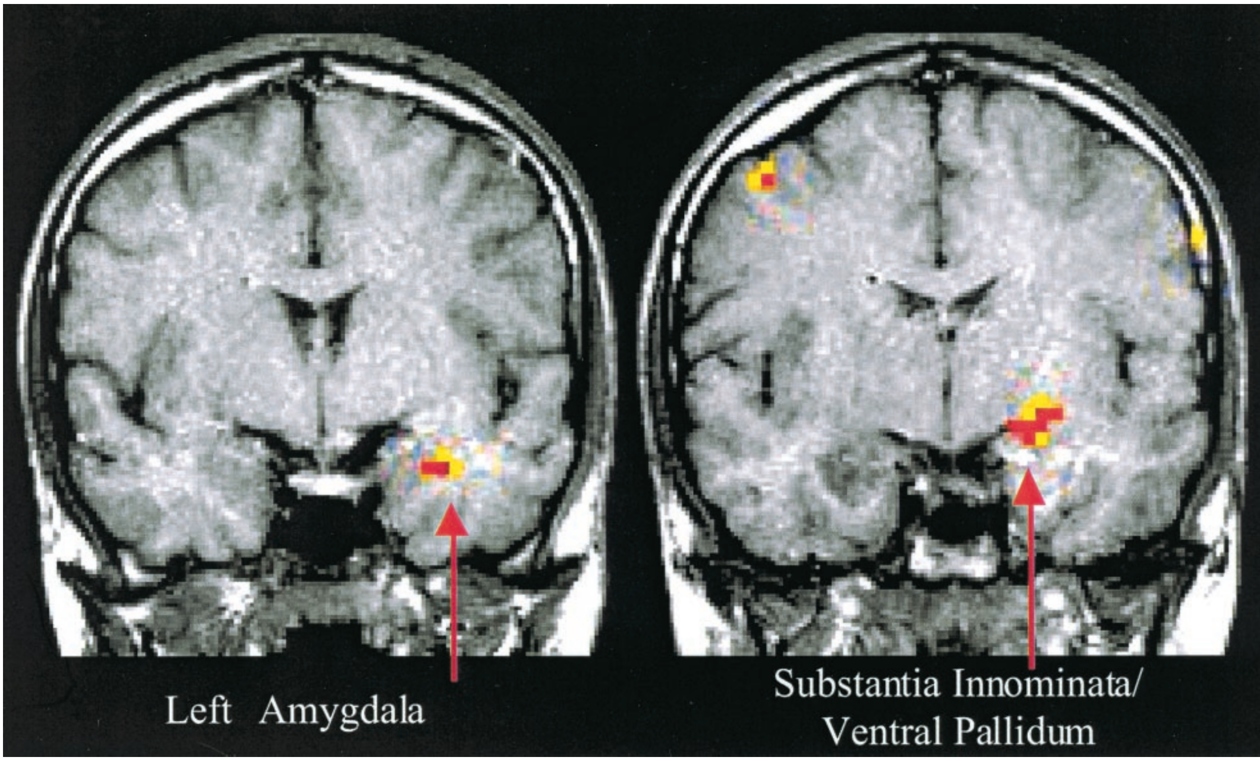


Figure 2. Left amygdala and amygdala/substantia innominata/ventral pallidum activity for male children and adults for the contrast of fearful faces minus fixation.

voxelwise analyses of variance (ANOVAs) were conducted on these pooled data using normalized signal intensity as the dependent variable (Braver et al 1997; Casey et al 2000). Separate analyses were conducted comparing male adults and male children and comparing male and female children to examine interactions of stimulus type (fearful faces, neutral faces, fixation) with age or gender, respectively. Significant activations were defined by at least three contiguous voxels and $\alpha = .05$ (Forman et al 1995). Amygdala activation was defined on the reference brain using Talairach coordinates and consensus among three raters (BJC, KMT, PJW). Significant regions that extended outside of the brain or had large SDs were excluded.

## Results

### *Adults and Children*

A 2 × 2 (Group × Condition)[3] ANOVA comparing male adults ($n = 6$) and male children ($n = 6$) revealed significant activity in the left amygdala and substantia innominata for fearful faces relative to fixation (Figure 2) and a decrease in signal with repeated presentations of the fearful faces[4] (Table 1). Neutral faces showed a similar pattern of activation relative to fixation trials ($F = 23.71$, $p < .001$). A significant interaction was observed in the left amygdala between stimulus type and age for the comparison of fearful and neutral expressions (Table 1) (Group × Condition, Fear vs. Neutral). Post hoc $t$ tests indicate that adults demonstrated significantly greater activity for fearful faces relative to neutral faces ($p < .001$). However, the children demonstrated greater amygdala activity for neutral faces than for fearful expressions ($p < .0001$) (Figure 3). Neither age nor Tanner stage predicted the magnitude of the percent change in signal in this sample.

### *Male and Female Children*

Separate 2 × 2 (Gender × Condition) ANOVAs were conducted comparing male and female children on these same stimulus comparisons. Fearful expressions activated the left amygdala relative to fixation (Table 2). Similar results were obtained for the comparison of neutral faces and fixation ($F = 12.72$, $p < .01$). No significant effects were observed for fearful faces. The BOLD signal decreased bilaterally in the amygdala between the first and second epochs of fear (Table 2) (Condition, Fear1 vs. Fear

[3] Separate ANOVAs were conducted to compare the relevant conditions: fear versus neutral, fear versus fixation, fear 1 versus fear 2, neutral versus fixation, and neutral 1 versus neutral 2.

[4] Effects of repeated presentation were assessed by comparing the response during the first epoch of a stimulus type to the second epoch of the same stimulus in each run.

Table 1. Location of Magnetic Resonance Signal Change for Significant Main Effects and Interactions in the Adults and Children

| Regions of interest | Talairach coordinates X | Y | Z | Maximum *F* value | Number of voxels |
|---|---|---|---|---|---|
| Main effect of Condition (Fear vs. Fixation) | | | | | |
| L ventrolateral amygdala | 30 | 0 | −19 | 16.98[a] | 5 |
| L dorsal amygdala/substantia innominata | 23 | −8 | −10 | 17.23[a] | 27 |
| Main effect of Condition (Fear 1 vs. Fear 2) | | | | | |
| L ventral amygdala/periamygdaloid cortex | 18 | −2 | −26 | 15.97[a] | 22 |
| Interaction of Group × Condition (Fear vs. Neutral) | | | | | |
| L amygdala/substantia innominata | 14 | −6 | −11 | 20.50[a] | 5 |
| L substantia innominata | 27 | −6 | −5 | 34.20[b] | 13 |

L, left.
[a] $p < .005$.
[b] $p < .001$.

2). However, main effects were mediated by a significant interaction with gender (Gender × Condition, Fear 1 vs. Fear 2). Post hoc *t* tests indicated that boys demonstrated attenuation of the amygdala response with repeated presentation of the fearful expressions ($p < .05$) but girls did not (Figure 4).

### *Facial Expression Detection Task*

All of the children in this study completed a behavioral detection task using an identical set of facial expressions. Subjects detected neutral faces embedded in mostly fearful faces (75%) or fearful faces embedded in mostly neutral faces. The children had a mean accuracy of 76.5%, with slightly more errors in detection of the neutral faces (78% for detection of fearful faces and 73% for detection of neutral faces). No precise accuracy data were recorded for adult subjects on this task; however, the paradigm was initially piloted in adults to assess feasibility and adults were noted to be highly accurate in their responses.

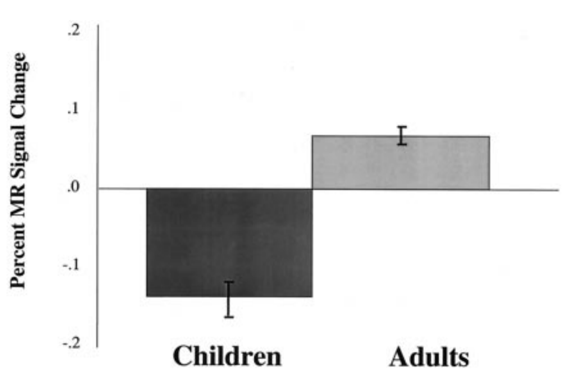


Figure 3. Interaction effect of facial expression and age in the left amygdala and substantia innominata. Adults demonstrated greater activation for fearful faces than for neutral faces, whereas boys showed larger BOLD responses for neutral faces. Bars indicate the SEMs. MR, magnetic resonance.

## Discussion

Overall, our results replicate previous neuroimaging studies (Breiter et al 1996; Morris et al 1996, 1998a, 1998b; Whalen et al 1998) showing increased activity in regions of the amygdala extending into the substantia innominata during the presentation of fearful faces and a decrease in activation in this amygdala response with repeated exposure to fearful faces (for a discussion of the significance of substantia innominata activation, see Whalen et al 1998). The predominantly left lateralized activity observed especially for the male subjects during passive viewing of the unmasked fearful faces is consistent with Breiter and colleagues' (Breiter et al 1996) previous study of adult males. The current results suggest more bilateral activity in the child group that included both male and female subjects. Baird et al (1999) also reported both left and right amygdala activity for faces versus nonsense images in male and female adolescents. Recently, Whalen et al (1998) showed predominantly right amygdala activity in response to *masked* fearful faces, even though subjects showed no explicit awareness of the emotional faces. One hypothesis that has been proposed to account for the laterality of findings in these studies is that left and right amygdala activations mediate conscious and unconscious or, alternatively, top down and bottom up processing, respectively (Morris et al 1998b, 1999). We do not address this hypothesis specifically but rather suggest less specificity in the amygdala response for children relative to adults.

There was a developmental difference in the amygdala response to fearful and neutral faces. Adults showed

Table 2. Location of Magnetic Resonance Signal Change for Significant Main Effects and Interactions in Male and Female Children

| Regions of interest | Talairach coordinates X | Y | Z | Maximum F value | Number of voxels |
|---|---|---|---|---|---|
| Main effect of Condition (Fear vs. Fixation) | | | | | |
| L amygdala | 20 | 0 | −17 | 11.90[a] | 5 |
| Main effect of Condition (Fear 1 vs. Fear 2) | | | | | |
| R amygdala | −21 | −5 | −18 | 9.67[b] | 6 |
| L ventral amygdala | 24 | −5 | −21 | 12.86[c] | 3 |
| Main effect of Gender (Female vs. Male) | | | | | |
| R amygdala | −24 | −3 | −17 | 23.91[d] | 14 |
| L amygdala | 28 | −4 | −14 | 13.20[c] | 13 |
| Interaction of Gender × Condition (Fear 1 vs. Fear 2) | | | | | |
| L ventral amygdala | 26 | 0 | −20 | 7.56[b] | 3 |

L, left; R, right.
[a] $p < .01$.
[b] $p < .05$.
[c] $p < .005$.
[d] $p < .001$.

increased amygdala activity for fearful faces. This pattern was not observed in the children who showed more amygdala activity in response to neutral faces than in response to fearful ones. The original adult study by Breiter et al (1996) reported amygdala activation to both neutral and fearful faces, but more activity for the fearful expressions. In our study both children and adults activated the amygdala for fearful and neutral faces relative to fixation. These findings may be consistent with Whalen's interpretation that the amygdala is sensitive to ambiguous stimuli rather than emotionally valenced stimuli per se (Whalen 1998). Amygdala activity is not observed routinely with all negatively valenced stimuli but instead appears when the contingencies between a stimulus and a negative outcome are altered or unpredictable (LaBar et al 1998). It has been suggested that a fearful face may be more ambiguous and biologically relevant than other expressions such as anger (Whalen 1998), resulting in increased vigilance and, hence, increased activity of the amygdala. One explanation for the observed age differences may be that the children find neutral faces to be as ambiguous or even more ambiguous than fearful faces. An important aspect of child development is the ability to read the emotional signals of adults and peers as a cue to the safety and nature of a new environment. It may be that, for children, a neutral facial expression does not yet represent a signal of neutrality, and instead produces activation consistent with continued attempts to decode or interpret (i.e., increased vigilance).

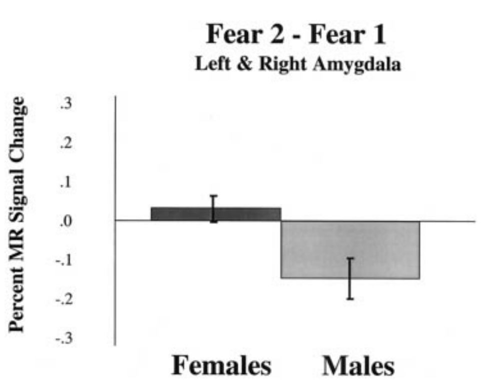


Figure 4. Interaction effect demonstrating habituation to fear stimuli in boys but continued activation to fearful facial expressions in girls. Bars indicate the SEMs. MR, magnetic resonance.

Consistent with this hypothesis, our behavioral data collected outside the scanner suggest that children have difficulty categorizing facial expressions as neutral or fearful. Baird et al (1999) also report that adolescents in their study were only 74% accurate in postscan ratings of their stimuli, despite the fact that only fearful faces were presented. The developmental literature on discrimination of facial expression suggests that adult levels of discrimination may not be reached until early adolescence. Although infants and young children show reliable discriminations between positive and negative expressions such as happy and angry faces (e.g., Nelson 1987), discrimination among expressions with similar valence shows continued development (Charlesworth and Kreutzer 1973; Field and Walden 1982; Kolb et al 1992; Nelson 1987).

We employed a passive viewing task of rapidly presented faces with the goal of replicating a previous fMRI study with adults (Breiter et al 1996). The rapid presentation rate, chosen in part to minimize eye movements, makes a behavioral response difficult, especially for children. Clearly, adding a behavioral component to the task could provide some clues as to how subjects are processing the faces, and whether adults and children are interpreting the expressions in a similar manner. In general, for neuroimaging studies it appears that active task performance results in greater signal change than passive viewing (e.g., Ishai et al 1999), perhaps due to differences in arousal. However, the choice of behavioral task can significantly affect the observed activation. For example, data from Hariri et al (2000) show that signal change in the amygdala is greater during perceptual matching of emotional expressions than during verbal labeling of the emotional expressions, suggesting that amygdala activity can be modulated by top down processing. For future research, investigators might consider an active task that is nominally unrelated to the emotional valence of the stimulus to maximize the signal change without introducing regulatory processes, such as gender judgments of faces (e.g., Hart et al 2000; Morris et al 1996). However, the primary disadvantage of a passive viewing task in this study is the lack of information regarding the subject's perception of or interpretation of the emotional expression. This problem still remains with the introduction of a task unrelated to emotion discrimination.

The developmental literature examining other aspects of face processing, particularly face recognition, suggests that a slight dip in these skills occurs around early adolescence (e.g., Carey and Diamond 1980; Carey et al 1980; Flin 1985) and for children's memory for unfamiliar faces (Flin 1980). Further, it appears that this developmental decrement in face processing skills is linked to pubertal development, with the decrement in face encoding being associated with being in the active stages of pubertal development as opposed to age (Diamond et al 1983). One hypothesis about the pubertal dip in face processing is related to an alteration in the affective salience of familiar and unfamiliar faces during pubertal maturation; however, no studies have examined the developmental pattern in the processing of facial emotion. The small sample size and relatively wide range of ages and Tanner scores in the current sample preclude appropriate comparisons of these factors in this study. Further developmental investigations will be needed to assess whether the observed differences in amygdala activity reflect a similar dip in emotion recognition with the onset of adolescence. Alternative explanations for the observed group differences might include developmental changes in attention or modes of visual processing (Carey and Diamond 1977; Schwarzer 2000). However, these possibilities are difficult to evaluate in the absence of any behavioral response during the face viewing task.

For the children, a gender difference was observed in the attenuation of the amygdala response to repeated presentations of fearful faces. Boys showed the previously reported (Breiter et al 1996) decrease in amygdala activity with repeated presentations, but girls showed relatively stable activation for fearful expressions. The adult imaging studies examining facial expressions of emotion have routinely been limited to male subjects (Breiter et al 1996; Morris et al 1996, 1998b; Whalen et al 1998). However, studies examining gender differences in affective stimuli or self-induced emotional states suggest that adult women activate the limbic system more than men during similar reported mood states (e.g., George et al 1996; Orozco and Ehlers 1998). In addition, behavioral data from the face recognition literature suggest that, until approximately age 13, boys and girls show equal recognition of faces with neutral expressions. However, young adult female subjects tend to show superior face recognition relative to male subjects (Chance et al 1982). Although many neuroimaging studies of face recognition and face processing have included both male and female subjects, few if any of these studies directly test for gender differences in signal change. Clearly, the current findings of gender differences in the amygdala response for children need to be replicated in a larger sample with both adults and children before significant conclusions can be drawn.

Results of this study have important implications for neuroimaging studies of children with affective disorders. Several adult imaging studies have implicated the amygdala in both anxiety (Birbaumer et al 1998; Rauch et al 1996; Shin et al 1997) and depression (Drevets et al 1992). The time course and developmental processes leading to these brain changes have yet to be identified. The developmental period near puberty is strongly associated with a sharp increase in the rates of depression (particularly in girls). However, the neurobiological underpinnings of this increased vulnerability for affective dysregulation are not understood. Clearly, establishing the normal functional development of the amygdala is an important step in laying the groundwork for imaging studies of pediatric patient populations, particularly those involving affect regulation. Among the tools to examine the normal and abnormal development of affective processes, neuroimaging of emotional faces appears to be a promising approach.

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## References

Adolphs R, Tranel D, Damasio H, Damasio A (1994): Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. *Nature* 372:669–672.

Adolphs R, Tranel D, Damasio H, Damasio A (1995): Fear and the human amygdala. *J Neurosci* 15:5879–5891.

Aggleton JP (1992): *The Amygdala: Neurobiological Aspects of Emotion, Memory, and Mental Dysfunction.* New York: Wiley-Liss.

Baird AA, Gruber SA, Fein DA, Maas LC, Steingard RJ, Renshaw PF, et al (1999): Functional magnetic resonance imaging of facial affect recognition in children and adolescents. *J Am Acad Child Adolesc Psychiatry* 38:195–199.

Birbaumer N, Grodd W, Diedrich O, Klose U, Erb M, Lotze M, et al (1998): FMRI reveals amygdala activation to human faces in social phobics. *Neuroreport* 9:1223–1226.

Braver TS, Cohen JD, Nystrom LE, Jonides J, Smith EE, Noll DC (1997): A parametric study of prefrontal cortex involvement in human working memory. *Neuroimage* 5:49–62.

Breiter HC, Etcoff NL, Whalen PJ, Kennedy WA, Rauch SL, Buckner RL, et al (1996): Response and habituation of the human amygdala during visual processing of facial expression. *Neuron* 17:875–887.

Broks P, Young AW, Maratos EJ, Coffey PJ, Calder AJ, Issac CL, et al (1998): Face processing impairments after encephalitis: Amygdala damage and recognition of fear. *Neuropsychologia* 36:59–70.

Büchel C, Morris J, Dolan RJ, Friston KJ (1998): Brain systems mediating aversive conditioning: An event-related fMRI study. *Neuron* 20:947–957.

Calder AJ, Young AW, Rowland D, Perrett DI (1997): Computer-enhanced emotion in facial expressions. *Proc R Soc Lond B Biol Sci* 264(1383):919–925.

Calder AJ, Young AW, Rowland D, Perrett DI, Hodges JR, Etcoff NL (1996): Facial emotion recognition after bilateral amygdala damage: Differentially severe impairment of fear. *Cogn Neuropsychol* 13:699–745.

Carey S, Diamond R (1977): From piecemeal to configural representation of faces. *Science* 195:312–314.

Carey S, Diamond R (1980): Maturational determination of the developmental course of face encoding. In: Caplan D, editor. *Biological Studies of Mental Processes.* Cambridge, MA: MIT Press, pp 60–93.

Carey S, Diamond R, Woods B (1980): Development of face recognition—a maturational component? *Dev Psychol* 16: 257–269.

Casey BJ, Thomas KM, Welsh TF, Badgaiyan RD, Eccard CH, Jennings JR, et al (2000): Dissociation of response conflict, attentional selection, and expectancy with functional magnetic resonance imaging. *Proc Natl Acad Sci U S A* 97:8728–8733.

Chance JE, Turner AL, Goldstein AG (1982): Development of differential recognition for own- and other-race faces. *J Psychol* 112:29–37.

Charlesworth WR, Kreutzer MA (1973): Facial expressions in infants and children. In: Ekman P, editor. *Darwin and Facial Expressions.* New York: Academic Press, pp 91–168.

Diamond R, Carey S, Back KJ (1983): Genetic influences on the development of spatial skills during early adolescence. *Cognition* 13:167–185.

Drevets WC, Videen TO, Price JL, Preskorn SH, Carmichael ST, Raichle ME (1992): A functional anatomical study of unipolar depression. *J Neurosci* 12:3628–3641.

Ekman P, Friesen WV (1976): *Pictures of Facial Affect.* Palo Alto, CA: Consulting Psychologists Press.

Field TM, Walden TA (1982): Production and discrimination of facial expressions by preschool children. *Child Dev* 53:1299–1311.

Flin RH (1980): Age effects in children's memory for unfamiliar faces. *Dev Psychol* 16:373–374.

Flin RH (1985): Development of face recognition: An encoding switch? *Br J Psychol* 76:123–134.

Forman SD, Cohen JD, Fitzgerald M, Eddy WF, Mintun MA, Noll DC (1995): Improved assessment of significant activation in functional magnetic resonance imaging (fMRI): Use of a cluster-size threshold. *Magn Reson Med* 33:636–647.

George MS, Ketter TA, Parekh PI, Herscovitch P, Post RM (1996): Gender differences in regional cerebral blood flow during transient self-induced sadness or happiness. *Biol Psychiatry* 40:859–871.

Hamann SB, Stefanacci L, Squire LR, Adolphs R, Tranel D, Damasio H, et al (1996): Recognizing facial emotion. *Nature* 379:497.

Hariri AR, Bookheimer SY, Mazziotta JC (2000): Modulating emotional responses: Effects of a neocortical network on the limbic system. *Neuroreport* 11:43–48.

Hart AJ, Whalen PJ, Shin LM, McInerney SC, Fischer A, Rauch SL (2000): Differential response in the human amygdala to racial outgroup vs ingroup face stimuli. *Neuroreport* 11: 2351–2355.

Irwin W, Davidson RJ, Lowe MJ, Mock BJ, Sorenson JA, Turski PA (1996): Human amygdala activation detected with echoplanar functional magnetic resonance imaging. *Neuroreport* 7:1765–1769.

Ishai A, Ungerleider LG, Martin A, Schouten JL, Haxby JV (1999): Distributed representation of objects in the human ventral visual pathway. *Proc Natl Acad Sci U S A* 96:9379–9384.

Kapp BS, Whalen PJ, Supple WF, Pascoe JP (1992): Amygdaloid contributions to conditioned arousal and sensory information processing. In: Aggleton JP, editor. *The Amygdala: Neurobiological Aspects of Emotion, Memory and Mental Dysfunction.* New York: Wiley-Liss, pp 229–254.

Killcross S, Robbins TW, Everitt BJ (1997): Different types of fear-conditioned behavior mediated by separate nuclei within amygdala. *Nature* 388:377–380.

Kolb B, Wilson B, Taylor L (1992): Developmental changes in the recognition and comprehension of facial expression: Implications for frontal lobe function. *Brain Cogn* 20:74–84.

LaBar KS, Gatenby JC, Gore JC, LeDoux JE, Phelps EA (1998): Human amygdala activation during conditioned fear acquisition and extinction: A mixed-trial fMRI study. *Neuron* 20:937–945.

LaBar KS, LeDoux JE (1996): Partial disruption of fear conditioning in rats with unilateral amygdala damage: Correspondence with unilateral temporal lobectomy in humans. *Behav Neurosci* 110:991–997.

Lane RD, Reiman EM, Bradley MM, Lang PJ, Ahern GL, Davidson RJ, et al (1997): Neuroanatomical correlates of pleasant and unpleasant emotion. *Neuropsychologia* 35:1437–1444.

LeDoux JE (1994): Emotion, memory and the brain. *Sci Am* 270:32–39.

LeDoux JE (1996): *The Emotional Brain.* New York: Simon & Schuster.

Morris JS, Friston KJ, Büchel C, Young AW, Calder AJ, Dolan RJ (1998a): A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain* 121:47–57.

Morris JS, Frith CD, Perrett DI, Rowland D, Young AW, Calder AJ, et al (1996): A differential neural response in the human amygdala to fearful and happy facial expressions. *Nature* 383:812–815.

Morris JS, Öhman A, Dolan RJ (1998b): Conscious and unconscious emotional learning in the human amygdala. *Nature* 393:467–470.

Morris JS, Öhman A, Dolan RJ (1999): A subcortical pathway to the right amygdala mediating "unseen" fear. *Proc Natl Acad Sci U S A* 96:1680–1685.

Nelson CA (1987): The recognition of facial expressions in the first 2 years of life: Mechanisms of development. *Child Dev* 57:889–909.

Orozco S, Ehlers CL (1998): Gender differences in electrophysiological response to facial stimuli. *Biol Psychiatry* 44:281–289.

Rauch SL, van der Kolk BA, Fisler RE, Alpert NM, Orr SP, Savage CR, et al (1996): A symptom provocation study of posttraumatic stress disorder using positron emission tomography and script-driven imagery. *Arch Gen Psychiatry* 53: 380–387.

Reiman EM, Lane RD, Ahern GL, Schwartz GE, Davidson RJ, Friston KJ, et al (1997): Neuroanatomical correlates of externally and internally generated human emotion. *Am J Psychiatry* 54:918–925.

Schwarzer G (2000): Development of face processing: The effect of face inversion. *Child Dev* 71:391–401.

Shin LM, Kosslyn SM, McNally RJ, Alpert NM, Thompson WL, Rauch SL, et al (1997): Visual imagery and perception in posttraumatic stress disorder: A positron emission tomographic investigation. *Arch Gen Psychiatry* 54:233–241.

Talairach J, Tournoux P (1988): *Co-Planar Stereotaxic Atlas of the Human Brain.* New York: Thieme.

Tanner JM (1986): Normal growth and techniques of growth assessment. *Clin Endocrinol Metab* 15:411–451.

Whalen PJ (1998): Fear, vigilance and ambiguity: Initial neuroimaging studies of the human amygdala. *Curr Dir Psychol Sci* 7(6):177–188.

Whalen PJ, Rauch SL, Etcoff NL, McInerney SC, Lee MB, Jenike MA (1998): Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *J Neurosci* 18:411–418.

Woods RP, Cherry SR, Mazziotta JC (1992): Rapid automated algorithm for aligning and reslicing PET images. *J Comput Assist Tomogr* 16:620–633.