Functional Magnetic Resonance Imaging of Facial Affect Recognition in Children and Adolescents

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ABSTRACT

Objective: To examine further the role of the amygdala in the recognition of facial expression in adolescents. **Method:** Twelve healthy adolescents were studied using functional magnetic resonance imaging technology during a task of facial affect recognition and a visual control task. **Results:** All subjects demonstrated a significant increase in signal intensity in the amygdala for the facial expression recognition task. **Conclusions:** The data are consistent with previous work in healthy adult subjects implicating the amygdala as essential for the recognition of fearful facial expression. *J. Am. Acad. Child Adolesc. Psychiatry,* 1999, 38(2):195–199. **Key Words:** functional magnetic resonance imaging, affect, amygdala, adolescents, facial expression.

The ability to correctly discriminate emotion in facial expression is an essential component of successful social behavior. The amygdala has been consistently identified as a structure paramount not only in emotional learning generally, but specifically in the evaluation of emotional content of facial expression. Investigations by LeDoux (1994) have stressed the importance of the amygdala in fear detection and conditioning, describing it as a neural system that evolved to detect danger and produce rapid protective responses without conscious participation. The central nucleus of the amygdala has been described as essential for the expression of autonomic and somatic fear responses elicited by both learned and unlearned threats. These responses are controlled through efferent connections from the central amygdala to brainstem nuclei (Rogan and LeDoux, 1996). The amygdala has also been characterized as a higher-order "convergence zone" for the social homeostatic and survival-related meanings of complex stimuli (Damasio, 1994). Taken together, these lines of evidence describe the amygdala as a structure that has evolved to help the human animal recognize and learn the emotional meaning of stimuli in his/her environment and produce appropriate behavioral responses.

Specific participation of the amygdala in the decoding of facial expression has also been documented. Awake recordings in nonhuman primates have shown that neurons in the amygdala are selectively responsive to faces and their expression (Brothers et al., 1990; Ungerleider and Mishkin, 1982). In addition, Seeck and colleagues (1993) have shown differential evoked responses in humans, using depth electrodes placed in the amygdala, to familiar versus novel faces. These reports are in accordance with human clinical neuropsychological evidence which has shown that damage to the medial temporal lobe, specifically the amygdala, produces impairment of facial affect recognition. This reported impairment, however, seems to be strongly associated with the recognition of fearful facial expression (Adolphs et al., 1994, 1995; Hamann et al., 1996).

The amygdala and its connections have additionally been implicated (along with a number of other medial temporal lobe structures) in the neuropathology of

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schizophrenia. Swayze et al. (1992) have proposed that abnormalities in "synaptic pruning" during development may play a role in medial temporal lobe pathology. Bauman (1991) has reported limbic (including amygdalar) neuropathological abnormalities in autistic children. Hendren et al. (1995) have described children who showed symptoms of schizophrenia spectrum disorder. The symptoms included social impairment, attention deficit, constricted or inappropriate affect, and hypersensitivity to criticism. Structural magnetic resonance imaging (MRI) findings revealed a significant decrease in amygdala volume as well as temporal lobe volume in these children compared with nonpsychiatric controls.

Recent investigations have applied positron emission tomography to examine amygdala activity in healthy adults. Kilts et al. (1996) found that the recognition of anger in facial expressions involves the activation of a rostral limbic system that includes the amygdala, anterior cingulate cortex, insula, and dorsolateral prefrontal cortex. Recently, Breiter and Rauch (1996), using functional MRI (fMRI), reported preferential amygdala activation in response to fearful faces; this activation was noted to be of a greater magnitude in the left compared with the right amygdala. Furthermore, Morris et al. (1996) suggested that the left amygdala may also be responsive to the intensity of fearful facial affect, based on fMRI data.

Hamann et al. (1996), using a facial affect recognition task (Ekman and Friesen, 1976), examined adults who had sustained bilateral amygdala damage either in childhood or as adults. It was found that individuals who showed impairment on tasks of affect recognition had sustained amygdala damage early in development. Studies of nonhuman primates support the idea that early damage to the amygdala has a deleterious effect on later social and emotional learning and behavior, while lesions of the amygdala in mature nonhuman primates do not produce the same types of behavioral impairments (Bachevalier, 1991).

Taken together, these findings suggest that amygdala function is critical for the development of affect/emotional recognition. This study examined this hypothesis by studying a group of healthy adolescents while applying fMRI during a test of fearful facial affect recognition known to produce amygdalar activation. Fearful faces were chosen for this study because of the existing literature supporting a robust physiological response in the adult amygdala to fearful facial affect, as well as affectively negative pictures (Breiter et al., 1996; Fein et al., 1997; Irwin et al., 1996). The application of fMRI techniques provides an important new methodology for the study of cerebral activation during cognitive and emotional processing. fMRI had a clear advantage over other imaging techniques given the age of the study subjects; specifically, fMRI is a completely noninvasive procedure that is well tolerated by children and adolescents. In addition, in studies of children and adolescents, fMRI is not restricted by the same ethical constraints as other types of invasive neuroimaging procedures. We collected fMRI data and conventional MR images to measure changes in regional cerebral activation during paradigms requiring recognition of facial expression. On the basis of the findings reviewed above, it was hypothesized that the left and right amygdala would show significant activation during recognition of fearful facial affect. Thus, clearly defined regions of interest (ROIs) were selected a priori to measure cortical and subcortical changes in activation of focal brain regions.

METHOD

Subjects

Subjects included 12 healthy volunteers who were part of an ongoing study at our center (5 males, 3 right-handed; 7 females, 6 right-handed; aged 12–17 years [mean age = 13.9]). Each subject received a structured clinical interview (Schedule for Affective Disorders and Schizophrenia for School-Age Children) (Puig-Antich et al., 1980). Subjects with a history of organic brain syndrome, head injury, substance abuse, or any Axis I psychiatric disorder were excluded. Subjects who wore any type of corrective lenses were also excluded. Subjects with any family history of psychiatric disorders were also excluded. Family history was based on self-report from subjects' parent/guardian(s); subjects were excluded if they had any first-degree relative(s) with an Axis I disorder or if they had any history of seizure disorder. All subjects and their parent/guardian(s) gave written informed consent for the procedure.

Imaging Procedure

Scanning was performed on a 1.5-T General Electric Signa MR scanner (General Electric Systems, Milwaukee, WI) retrofit with a whole-body echo-planar (EP) gradient set (Advanced NMR, Inc., Wilmington, MA) using a quadrature head coil. A T_1-weighted sagittal image was used to localize a slice plane that included both the right and left amygdala. Six high-resolution oblique images (FOV = 40 × 20, TE = 15 msec, TR = 5,000 msec, matrix = 256 × 160, nex = 2) were acquired in this plane to facilitate anatomic correlation with the functional imaging data.

Functional images were collected every 3 seconds using an EP gradient echo pulse sequence (TE = 40 msec, flip angle = 75°). An image matrix of 128 × 64 was used with a 3-mm × 3-mm in-plane resolution and a 7-mm slice thickness. During each cognitive task condition, a series of 50 sequential images were obtained.

Materials

Stimuli were generated by a Macintosh computer and were projected with a magnetically shielded LCD video projector onto a translucent screen placed at the feet of the subject. The subject was able to see the screen by the use of a mirror placed above his/her head in the scanner.

Two sequences were presented during EP imaging. Each scan sequence or epoch was divided into 5 alternating 30-second segments of rest and activation that lasted for a total of 150 seconds (Fig. 1). The segments consisted of a 30-second baseline period, followed by a 30-second stimulus period "on," a 30-second period without any stimulus "off," a second 30-second stimulus period "on," and finally a 30-second "off" period (Yurgelun-Todd et al., 1996). During baseline and "off" periods, subjects were asked to visually fixate on a white fixation point in the middle of the screen. In the first condition, each "on" stimulus was composed of 3 unique nonsense gray-scale figures displayed for 10 seconds each. The nonsense figures were randomly generated gray-scale pixels, randomly arranged. Subjects were asked to passively view these stimuli. In the second condition, subjects viewed 3 faces (again for 10 seconds each). Subjects were asked to discriminate and label the expression on the faces. All 6 faces presented were different individuals showing expressions of fear. Fearful expressions were chosen on the basis of previous work that showed an amygdala-related response to fearful faces (Adolphs et al., 1994, 1995). Stimulus presentation was not randomized. Because of possible carryover from the affect recognition task and the way that this might vary across individuals, the affect recognition task was always presented after the pixel condition. The faces used were black-and-white photographs taken from Ekman and Friesen (1976). The faces and nonsense stimuli were matched for size and intensity.

Image Analysis

All conventional MR images were interpreted by a neuroradiologist, and no clinical abnormalities were detected for any study subject. All images were corrected for in-plane as well as rotational motion using the DART image registration technique (Maas et al., 1997). Data for which motion exceeded 1 mm in any direction or 1° of rotation were not considered. Measures of signal intensity were derived by averaging the signal measured in all pixels in each ROI for each time point during the task activation period. This included a 30-second baseline condition, 2 activation segments of 30 seconds' duration, and two 30-second resting segments. ROIs included the right and left amygdala, as well as a region in the left superior parietal lobule. Each ROI was composed of 4 pixels (6 mm × 6 mm). This region was placed within the medial aspects of the amygdala for all subjects. Normalization of signal at baseline was completed for each study epoch for every individual.

Activation was measured using neuroanatomically defined ROIs in both the right and left amygdala and right and left parietal cortex; these ROIs were selected with reference to an anatomic atlas (Schnitzlein and Murtagh, 1990), and placements were made on the basis of structural landmarks visible on both high-resolution MR and EP MR images.

RESULTS

There was no significant difference between left and right amygdala activation; therefore, data from the left and right amygdala were combined for statistical analysis. As hypothesized, a significant increase in activation in the amygdala was found in response to recognition of facial expression compared with viewing the fixation point ($t = 3.70$, $p < .01$) (Fig. 1). This effect was not seen during the presentation of nonsense visual stimuli ($t = -0.437$, $p = .665$) (Fig. 1). As seen in Figure 1, there was a 0.7% (±0.006%) increase in signal intensity in response to faces across subjects, compared with a 0.2% (±0.005%) decrease in response to nonsense patterns. Furthermore, higher activation was evident in the amygdala for the facial expression stimuli compared with the random pixel stimuli ($t = 4.63$, $p < .01$). The data were

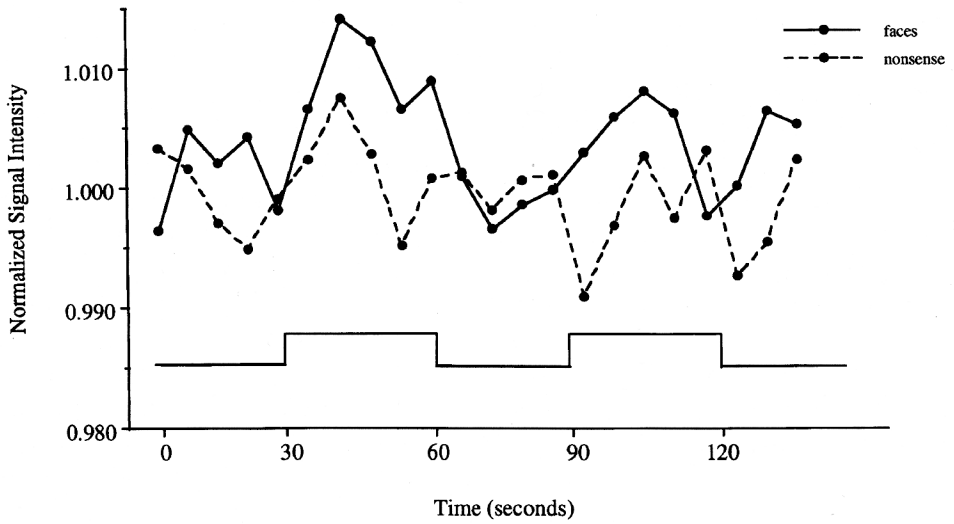

Fig. 1 Activation in the amygdala in response to a facial affect recognition task.

analyzed using parametric and nonparametric statistical procedures. These procedures were concordant for significance.

A second analysis was completed to control for the effect of the passive viewing of stimuli in which the data from the nonsense visual stimuli were subtracted from the faces condition; this difference was also highly significant ($t = 3.31$, $p < .01$). No significant effects based on age, gender, or handedness were observed.

To control for nonspecific cortical arousal, a ROI was also sampled in the superior parietal lobule. No significant effects for faces ($t = 0.997$, $p = .326$), nonsense stimuli ($t = -0.157$, $p = .876$), or the subtraction of the nonsense stimuli from the facial expression ($t = 0.872$, $p = .389$) were found in this region.

At the conclusion of the scanning session, subjects were interviewed regarding the expressions they identified. Seventy-four percent of the responses given by the subjects correctly identified the type of affect being presented. While some subjects correctly categorized the faces as being fearful, other faces were incorrectly categorized as angry, confused, surprised, or even happy. In short, although only one type of facial expression was presented, the adolescents frequently interpreted the faces as displaying more than one category of affect.

DISCUSSION

These preliminary data indicate that fMRI has the sensitivity to detect activation in the amygdala during a facial affect recognition task in adolescent subjects. These results are in agreement with previous evoked potential and neuroimaging studies that have reported an increase in amygdala activation during tasks requiring recognition of facial expression in adults (Breiter and Rauch, 1996; Morris et al., 1996; Seeck et al., 1993). More specifically, these results further complement previous studies (Adolphs et al., 1995; Damasio, 1994; Hamann et al., 1996) that have implicated the amygdala as a structure essential to affect recognition.

The findings from this study are particularly significant as they demonstrate limbic system activation using fMRI in adolescents, thereby showing that the amygdala is involved in affect recognition prior to adulthood. The finding that adolescents showed significant amygdala activation in response to a task that required the judgment of fearful facial affect is consistent with the speculated role of the amygdala in both fear detection and social learning. Results from the investigations described above have shown that developmental perturbation of the amygdala and its connections can result in profound behavioral disturbances (Bachevalier, 1991; Hamann et al., 1996). These disturbances are not as pronounced when damage occurs during adulthood. Adults who have lesions of the amygdala suffer from various affect recognition deficits, but they do not manifest the myriad of social and emotional disturbances consistent with limbic developmental abnormalities (Adolphs et al., 1994, 1995).

Of particular note is that the subjects were not able to identify consistently the correct facial expression, despite their significant activation. These findings extend our understanding of amygdala function and suggest that one role of the amygdala during development may be to recognize facial expression and, through experience, learn to assign a label to facial expression. LeDoux (1992, 1994) has argued that the amygdala is one of the structures essential in attaching emotional significance to stimuli, a process essential for successful development.

There are several limitations to this study. First, only fearful facial affect was examined. Fearful faces were used because of the amygdala's consistent responsivity to fearful stimuli, as previously described. Although neutral faces have served as a control stimulus in many studies of affect recognition (Irwin et al., 1996), some investigators have expressed concern that adolescent subjects may make affective attributions to neutral faces, therefore confounding their validity as a control stimulus. Future investigations should address this issue by including neutral faces as well as additional categories of emotional expression (i.e., happiness, sadness etc.). A second limitation is that our sample was small and contained a skewed distribution of age, with more older than younger adolescents. To properly address developmental changes, a broader range of ages with a larger sample of subjects at each age will be required. Third, to interpret more clearly the significance of changes in signal intensity, morphometric measures including relative volume of gray and white matter should be completed for study subjects. These measures would allow correctional analyses to be carried out which would aid in the understanding of the relationship between neuroanatomical and neurophysiological maturation. Future studies should better address more general confounds such as anxiety and general arousal.

Although the interpretation of these results must remain preliminary, this study is significant because it

demonstrates the feasibility of using fMRI to measure subcortical activation in adolescent subjects. Moreover, we have confirmed that in an adolescent population, the amygdala activates in response to fearful faces. Furthermore, we have shown that amygdala activation in an adolescent population resembles amygdala activation reported previously in adult subjects.

Clinical Implications

These preliminary results have important clinical implications. The characterization of age-associated changes in limbic function in healthy children and adolescents is necessary to identify neurobiological anomalies associated with behavioral pathology. Without a clear delineation of normal changes found during subcortical development, it would be impossible to determine whether abnormalities in affective processing skills are associated with neuropathological variations or normal maturational changes. The capacity for social interaction is highly dependent on the ability to recognize and appropriately respond to affective stimuli. This ability has been consistently identified as an important premorbid factor in many psychiatric disorders. Therefore, the understanding of neural mechanisms underlying affective processing may provide new insights into the early diagnosis and treatment of psychiatric illness.

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