A recent case study found that bilateral damage to the amygdala impairs the normal appraisal of vocal expressions of fear. However, the single source of evidence for this auditory emotion-processing impairment is from a patient with extra-amygdaloid damage that may include the basal ganglia, which have been shown to be important for prosody evaluation. In this study we provide evidence of preserved evaluation of vocal expressions of fear in a female patient (S.P.) with bilateral damage to the amygdala but with intact basal ganglia. This same patient has previously been shown to be impaired in the evaluation of facial expressions, including fear. These results indicate that the analysis of nonverbal signals of fear from different input channels are dissociable, being at least partially dependent on different brain structures. We suggest that the amygdala, in conjunction with the basal ganglia, may support the normal appraisal of auditory signals of danger. NeuroReport 9: 3607–3613 © 1998 Lippincott Williams & Wilkins.

Key words: Amygdala; Auditory; Emotion; Prosody; Speech; Voice

Introduction

Research in animals suggests that the amygdala represents an important neural substrate for emotion and social behavior. In humans, a growing body of research suggests that the amygdala is important for the social communication of emotion. The majority of evidence from case studies of patients with bilateral amygdaloid damage and neuroimaging studies with intact subjects suggests that the amygdala supports the normal evaluation of facial expressions of fear. Given that the amygdala is a region of multimodal convergence, we might expect it to support the modality-independent analysis of fear-related signals. The amygdala may then serve as a more global danger appraisal module. Consistent with this view, lesions of the human amygdala have been found to impair the analysis of fear from the voice as well as the face. However, the only evidence for this assertion is from a case study of a patient with partial bilateral lesions of the amygdala, who in addition has indications of partial damage to the basal ganglia. Given the basal ganglia have been shown to make significant contributions to the analysis of both emotional and propositional prosody, this additional damage complicates our understanding of the amygdala’s independent role in the evaluation of fearful vocalizations.

In order to assess amygdaloid contributions to the evaluation of vocal expressions of emotion, independent of the basal ganglia, we administered various measures of complex auditory processing of an emotional and non-emotional nature to a patient (S.P.), who has sustained bilateral amygdaloid damage without basal ganglia insult. Consistent with her amygdaloid damage, S.P. has previously been described as unable to acquire conditioned-fear responses, and exhibits impairments in the evaluation of facial expressions, including fear. Accordingly, if the amygdala supports the multi-modal analysis of expressions of fear, we expect that S.P.’s amygdaloid damage should be sufficient to reveal impairments in the evaluation of fear in the auditory domain.

Materials and Methods

Subjects: S.P. is a 54 year-old, right-handed, female whose seizures began at ~3–4 years of age. When her condition worsened in adulthood, at the age of 48, S.P. underwent en bloc temporal lobe resection for her medically intractable complex partial seizures of right medial temporal lobe origin. The surgical procedure involved an ~3.5 cm resection of the anterior middle and inferior temporal gyri. This was followed by a severing of the occipito-temporal fasciculus and subsequent near-complete removal of the amygdala and all of the hippocampus, parahippocampus, and projection fibers to their posterior...
Prior to her right temporal lobe resection, S.P. was diagnosed as having a lesion in her left amygdala. Two separate biopsies in independent locations indicated reactive gliosis extending through a significant portion of her left amygdala. Consistent with gliosis, post-surgery T2-weighted MR (magnetic resonance) images revealed abnormal signal throughout the rostral-caudal extent of the left amygdala. These images also revealed two-three small foci of signal hyperintensity in the periventricular and subcortical white matter. These are commonly seen in many patients of this age, and are probably due to a combination of blood flow and other age-related changes in the white matter. No other abnormalities were observed on either T1 and T2-weighted MR images. Examples of her left and right medial temporal lobe damage can be seen in the MR images presented in Fig. 1.

S.P. received a High School diploma and matriculated in college for 2 years. Her neuropsychological profile suggests she is within the normal range on measures of general intelligence (WAIS-R, 100 V, 92 P, 97 FS). S.P. performs normally on measures of face identity, age, and gender discrimination, but has difficulty in interpreting facial expressions of emotion, including severe impairments in evaluating expressions of fear, disgust and sadness.18,19

S.P’s performance on a range of auditory processing tasks was compared with that of 12 non-epileptic healthy subjects (10 female, 2 male) of similar age (42.5 ± 4.9) and education (14.75 ± 2.5) to S.P. All participants gave their informed consent and were paid for their participation.

Materials, design and procedure: A female actor from the Yale University undergraduate drama program was recorded vocalizing a variety of speech and nonlinguistic utterances for the purposes of the experiments described below. All stimuli were recorded digitally at 22 kHz and edited using SoundEdit Pro software. All stimuli were presented and all responses were collected via a personal computer. All auditory stimuli were presented to participants through high quality headphones.

For emotional prosody identification, six given names (James, Jeffrey, John, Jason, Jeremy and Joseph) ranging from 1 to 3 syllables, were intoned in seven different manners intended to convey different emotional states (anger, disgust, fear, happiness, sadness, surprise, and neutral). Given names were chosen for their emotionally neutral lexical content and as a plausible stimulus for emotional prosody. Through a series of pilot experiments, reliably categorized exemplars were generated for each emotion type. One exemplar of each name for each emotion type was chosen, yielding 42 separate stimuli. Six Yale University undergraduate judges categorized the final versions with relatively high success (mean percent correct: anger = 95%, disgust = 97%, fear = 90%, happy = 83%, sad = 100%, surprise = 97%; chance = 16.7%).

The emotionally intoned names were presented to subjects for identification. Subjects were presented with each of the seven exemplars for each emotion type (anger, disgust, fear, happiness, sadness, surprise and neutral). Upon presentation, subjects picked the emotion term that best matched the tone of voice (angry, disgust, fear, happy, sad and surprise).

Our procedure for rating emotional prosody was adapted from Adolphs et al.6 for use with the auditory stimuli presented in the prosody identification task. Participants were asked to rate how appropriate
a verbal emotion term matched a presented auditory stimulus. For example, subjects were presented with an auditory exemplar accompanied by an emotion term (e.g., happy) and asked to indicate ‘How happy does this person sound?’ on a scale from 1 to 6 (1 being not at all and 6 being very much). Subjects were encouraged to use the complete scale to indicate how they perceived each auditory stimulus.

On each trial, the rating scale was presented during the presentation of the auditory stimulus. Six emotion terms were used in the experiment (afraid, angry, disgusted, happy, sad, and surprised) and seven different categories of auditory stimuli were employed, including prototypical exemplars for each emotion term, plus neutral expressions. Each emotion category contained six independent exemplars of that emotion, for a total of 42 auditory stimuli. All stimuli were presented once with each emotion term. Emotion terms were blocked such that a subject rated all 42 stimuli before switching to a new emotion term. The order of emotion term blocks was randomized across subjects, and stimuli were randomized within a block.

Emotional vocalization identification: The actor was asked to vocalize non-linguistic sounds which were characteristic of six different basic emotional states (anger = growls, disgust = retching, fear = screams, happiness = laughter, sadness = crying, and surprise = gasping). Seven exemplars of differing vocal qualities were recorded for each emotion type. Six Yale University undergraduate judges categorized the final versions with high success (mean percentage correct: anger = 100%, disgust = 91%, fear = 95%, happy = 100%, sad = 100%, and surprise = 100%; chance = 16.7%). Subjects were presented with each sound and asked to indicate which it best matched from the list of seven emotional terms.

Word identification: The recorded emotionally intoned stimuli from the emotional prosody identification task were presented to subjects for word identification. Subjects were asked to ignore the emotional meaning of the voice and to simply indicate which word was spoken, from a list of six alternatives.

To study propositional prosody, the actor was asked to intone six proper name stimuli (James, Jeffrey, John, Jason, Jeremy and Joseph) in three different manners intended to convey different propositional contexts (command [1], question [7], statement of fact [1]). Single names rather than carrier sentences were chosen in order to equate task difficulty with the emotional prosody task. Upon presentation of the intoned name, subjects were to indicate which of the three propositional contexts the tone of voice best matched. Six Yale University undergraduate judges categorized the final versions with high success (mean percentage correct: command = 96%, question = 100%, and statement = 94%; chance = 33.3%).

To study voice discrimination, five different native English speaking females, ranging in age from 20–29, were recorded speaking five given names (Robert, Timothy, Arthur, Franklin, and Marvin). An effort was made to equate all speakers’ speech rate and volume. On a given trial, subjects were presented with two voice exemplars, one 0.5 s following the other. Subjects were asked to listen carefully to the voice quality of the speakers, and to indicate whether the first and second names were spoken by the same person or different people. Half of the time the speakers were the same, the other half they differed. The names spoken on a given trial were always different.

Results

S.P.’s performance relative to controls on both non-emotional and emotional auditory processing tasks is presented in Table 1 and Table 2, respectively. We first asked S.P. to make auditory judgments of a non-emotional nature, in order to establish her baseline ability to process complex auditory stimuli. On the voice discrimination task, S.P. discriminated between various unfamiliar female voices of similar age as well as controls (83% vs 75 ± 9.1%, for controls). This suggests that S.P. possesses an intact ability to process differences in vocal quality that are needed to discriminate unfamiliar speaker identity. We next examined her capacity for evaluating the suprasegmental aspects of speech stimuli (i.e. aspects of the speech stimulus not related to phonemic or lexical content), as indexed by her performance on the propositional prosody task. S.P. was intact on the propositional

<table>
<thead>
<tr>
<th>Table 1. Percentage correct performance of S.P. and controls (mean ± s.d.) on non-emotional auditory processing control tasks.</th>
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<tbody>
<tr>
<td>Voice discrimination</td>
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<tr>
<td>Propositional prosody identification</td>
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<tr>
<td>Word identification</td>
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</tbody>
</table>

In the voice discrimination task, S.P. and controls were asked to indicate whether the same or different person spoke two sequentially presented words (chance performance = 50% correct). S.P. discriminated between various unfamiliar female voices as well as controls. In the propositional prosody identification task, S.P. and controls were asked to match single spoken words with their appropriate propositional contexts. S.P. reveals intact recognition of propositional prosody.

In the word identification task, S.P. and controls were asked to identify the linguistic content of emotionally voiced names.
Table 2. Percentage correct performance of S.P. and controls (mean ± s.d.) on emotional auditory processing tasks.

<table>
<thead>
<tr>
<th>Emotion</th>
<th>S.P.</th>
<th>Controls</th>
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<tbody>
<tr>
<td><strong>Emotional prosody identification</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anger</td>
<td>84.7</td>
<td>87.5 ± 14.4</td>
</tr>
<tr>
<td>Disgust</td>
<td>16.7*</td>
<td>93.8 ± 14.2</td>
</tr>
<tr>
<td>Fear</td>
<td>81.7</td>
<td>89.8 ± 19.2</td>
</tr>
<tr>
<td>Happy</td>
<td>62.6</td>
<td>58.3 ± 35.5</td>
</tr>
<tr>
<td>Sad</td>
<td>87.5</td>
<td>97.2 ± 6.4</td>
</tr>
<tr>
<td>Surprise</td>
<td>91.7</td>
<td>95.1 ± 2.9</td>
</tr>
<tr>
<td><strong>Emotional vocalization identification</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anger</td>
<td>100.0</td>
<td>88.0 ± 18.9</td>
</tr>
<tr>
<td>Disgust</td>
<td>100.0</td>
<td>92.9 ± 10.6</td>
</tr>
<tr>
<td>Fear</td>
<td>78.6</td>
<td>86.9 ± 28.1</td>
</tr>
<tr>
<td>Happy</td>
<td>100.0</td>
<td>89.2 ± 28.3</td>
</tr>
<tr>
<td>Sad</td>
<td>100.0</td>
<td>100 ± 0.0</td>
</tr>
<tr>
<td>Surprise</td>
<td>85.7</td>
<td>87.5 ± 26.2</td>
</tr>
</tbody>
</table>

In the emotional prosody task (chance performance = 14.3%), subjects were asked to indicate what emotion term best matched an emotionally intoned word. S.P. shows no difficulty in categorizing intonational patterns associated with fear. S.P. is largely able to judge emotional meaning from prosody, with the exception of expressions of disgust (z = 5.15, *p < 0.001), where she was at chance level performance. In the emotional vocalization task, subjects were asked to identify the meaning of non-linguistic vocalizations of emotions (anger = growls, disgust = retching, fear = screams, happy = laughter, sad = sobbing, surprise = gasps; chance performance = 14.3% correct). S.P. is unimpaired in interpreting the meaning of non-linguistic vocalizations of emotion, including fear and disgust.

As a more sensitive test of S.P.'s perception of auditory expressions of emotion, we examined her subjective ratings of emotional salience for different emotion types with the emotional prosody ratings task. As illustrated in Fig. 2, when S.P. rated the degree to which different prototypical exemplars of each emotion sounded like various emotion terms, her ratings were generally lower than that of control subjects. However, her ratings of fearful prosody were similar to those of controls (5.17 vs 5.69 ± 0.44 for controls). This suggests that S.P. not only can categorize examples of fearful prosody appropriately, but she perceives them as intensely as controls. Whereas, she rated disgust (mean rating = 1.25, z = 3.05, p < 0.001) and surprise (mean rating = 2.83, z = 2.20, p < 0.05) as significantly less salient than controls (Fig. 2). We further assessed how well her ratings discriminated fear from other emotion types. Figure 3 illustrates S.P. and control ratings of fearful content across all emotion types. S.P. shows a normal discrimination of auditory expressions of fear from other emotions.

In addition to assessing S.P.'s evaluation of emotion-modulated speech, we examined her evaluation of non-linguistic emotional sounds associated with different emotional states (e.g., screams, laughter, etc.) using the emotional vocalizations task. As shown in Table 2, S.P.'s evaluation of fear was lower than that of other emotions, but nonetheless was within the normal range for controls (78.6% vs 86.9 ± 28.1% for controls). She was unimpaired in

![Fig. 2](image_url)  
**Fig. 2.** S.P. and control ratings of the degree to which different prototypical exemplars of each emotion type sounded like its matching emotion term on a scale of 1-6 (1, not at all; 6, very much). S.P. = ▲; Controls = □. Control mean = bars. Her ratings of fear are similar to that of controls; whereas, her ratings of disgust and surprise are significantly diminished relative to controls.

prosody task (91.6% vs 85.7 ± 12.9% for controls), suggesting that she was able to interpret correctly linguistic meaning from the prosodic features of speech. We also examined S.P.'s identification of the linguistic content of these same utterances in the word identification task and showed that she can judge correctly the segmental/phonemic composition of all stimuli (100% vs 99.8 ± 0.7% for controls). Thus, S.P. exhibits an intact ability to evaluate complex nonemotional auditory stimuli.

S.P. was then asked to judge the emotional tone of voice present in single name utterances using the emotional prosody identification task. As illustrated in Table 2, S.P. had no difficulty in categorizing intonational patterns associated with fear (91.7% vs 89.6 ± 19.2% for controls). It is unlikely that S.P.'s preserved evaluation of fear is the result of the insensitivity of this task to the presence of impairment, due to possible ceiling effects. This is evidenced in the substantial variability found in the control subjects' performance in identifying fear. These results suggest that S.P. was largely able to interpret all of the tested varieties of emotional prosody, with the exception of expressions of disgust (16.7% vs 93.8% for controls, z = 5.15, p < 0.001), where she was at chance level performance. S.P. considered most expressions of disgust to be neutral in content.
her appraisal of vocalizations of all emotional states, including vocalizations of disgust (100% vs 92.9 ±
10.6% for controls).

**Discussion**

S.P.'s intact performance on various non-emotional auditory control tasks provides evidence that she can adequately interpret various suprasegmental features of speech stimuli, such as fundamental frequency (pitch), intonation (pitch contour), intensity (loudness), speech rate, and vocal quality, that are important determinants of the communication of emotional prosody. When asked to interpret a speaker's emotional state from various utterances, her performance across tasks reveals evaluations of emotion that were largely intact, including her appraisal of auditory expressions of fear. S.P. was able to appropriately label fearful vocalizations and her ratings of perceived emotional salience suggest that her auditory perception of fear is qualitatively similar to control subjects. In addition, S.P. was able to interpret non-linguistic expressions of fear. Thus, S.P.'s performance profile suggests that she is largely able to process complex auditory stimuli of both a non-emotional and emotional nature.

There were two exceptions, however, to this general pattern of intact vocal emotion identification. S.P.'s performance indicated she had some difficulty in evaluating expressions of surprise and disgust, although she exhibited only a partial impairment in

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**FIG. 3.** S.P. and control ratings of fearful content across all emotional expressions. When presented with names intoned in a fearful manner, S.P. and control were asked to indicate how fearful sad, happy, etc., each stimulus sounded by rating their salience on a scale of 1-6 (1, not at all; 6, very much). We found that S.P. discriminates auditory expressions of fear from other emotions.
bilateral lesions of the amygdala.\textsuperscript{10} Those results suggest that amygdaloid lesions result in impairments in the auditory analysis of fear and anger. This discrepancy is unlikely due to differences in the extent of amygdaloid lesions in patients D.R. and S.P., considering that S.P.’s bilateral amygdaloid lesions appear to be larger in extent than that of D.R.\textsuperscript{4,10} This is particularly true of the right amygdala, where in contrast to S.P.’s near complete removal of the amygdala, D.R. has marginal loss of amygdala volume. We propose that our results differ from this previous report in two other significant respects. First, D.R. exhibits significant impairments in non-emotional speech perception, which included deficits in unfamiliar voice matching, voice recognition, and the comprehension of propositional prosody. This pattern of results suggests the presence of a more global dysfunction that is not specific to the auditory processing of emotion. In particular, D.R.’s significant difficulty in interpreting propositional prosody indicates her deficit in prosody evaluation extends to the evaluation of linguistic meaning in addition to emotional tone of voice. In contrast, our study of S.P. reveals intact performance on non-emotional measures of auditory processing, including propositional prosody. Therefore, impairments in the auditory evaluation of fear may only be revealed when accompanied by additional deficits in the processing of speech quality.

Second, evidence of D.R.’s more pervasive auditory processing deficits may indicate the presence of damage in addition to the amygdala. An inspection of other reports of D.R.\textsuperscript{4} suggests that she may have sustained partial damage to the right globus pallidus and caudate nucleus as well as the left putamen. S.P. does not show any indication of damage to these regions. This is of particular significance given that a substantial body of evidence has emerged suggesting that insult to the basal ganglia results in perceptual deficits for both emotional and propositional prosody.\textsuperscript{11-16} However, the majority of studies assessing auditory processing deficits associated with basal ganglia lesions are not consistent with a relatively circumscribed deficit in processing fear. A recent study suggests that basal ganglia damage disproportionately compromises the recognition of expressions of disgust,\textsuperscript{21} although, the majority of studies report more global processing deficits.\textsuperscript{11-16} Therefore, basal ganglia damage alone is unlikely to account for severe deficits in the auditory evaluation of fear. We propose that basal ganglia damage in addition to lesions of the amygdala may be important for such evidenced impairments. Thus, substantial amygdala damage may be necessary but insufficient to produce deficits in evaluating auditory expressions of fear.

This dissociation between the evaluation of non-verbal expressions of fear from the face and the voice is not surprising if one considers the neuroanatomical segregation of sensory inputs to the amygdala. Anatomical studies of the primate amygdala reveal that it is much more extensively connected with primary and secondary visual than auditory cortices.\textsuperscript{8} In fact, there is little evidence of significant connectivity between the amygdala and traditional higher-order auditory areas.\textsuperscript{22} This source of evidence suggests that the amygdala has limited access to cortical areas that support complex auditory information processing. However, this inequity in auditory and visual inputs to the amygdala does not extend to subcortical brain regions. In contrast to the relative sparseness of primate amygdaloid connectivity with auditory cortices, one of the most substantial amygdaloid subcortical pathways lies between the amygdala and the basal ganglia.\textsuperscript{1,12-13} Such evidence implies that in humans the basal ganglia may be a primary source of complex auditory information processing en route to the amygdala, further suggesting that evaluating the emotional significance of auditory stimuli may rely on amygdalo-striatal interactions.

This study provides evidence that damage to the amygdala does not result in an obligatory impairment in the appraisal of auditory expressions of fear. Although there is substantial evidence to suggest that the amygdala supports the evaluation of facial expressions of emotion,\textsuperscript{1-7} the cross-modal appraisal of fear may depend on structures other than, or in addition to, the amygdala.

References
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