Neuropsychologia 50 (2012) 44–54

Contents lists available at SciVerse ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Fear and happiness in the eyes: An intra-cerebral event-related potential study from the human amygdala

Stefano Meletti[a,*], Gaetano Cantalupo[c], Francesca Benuzzi[a], Roberto Mai[b], Laura Tassi[b], Elisa Gasparini[a], Carlo Alberto Tassinari[c], Paolo Nichelli[a]

[a] Dept. Neuroscience, University of Modena and Reggio Emilia, Nuovo Ospedale Civile Sant'Agostino Estense, Via Giardini 41100 Modena, Italy
[b] Epilepsy Surgery Centre "C.Munari", Ospedale Niguarda, Viale Ca' Granda Milano, Italy
[c] Neuroscience Department, University of Parma, Italy

ARTICLE INFO

Article history:
Received 11 March 2011
Received in revised form 15 October 2011
Accepted 20 October 2011
Available online 25 October 2011

Keywords:
Amygdala
Eyes
Facial expression
Fear
Theta frequency

ABSTRACT

We present the response pattern of intracranial event-related potentials (ERPs) recorded from depth-electrodes in the human amygdala (four patients) to faces or face parts encoding fearful, happy or neutral expressions. The amygdala showed increased amplitude ERPs (from 200 to 400 ms post-stimulus) in response to the eye region of the face compared to whole faces and to the mouth region. In particular, a strong emotional valence effect was observed, both at group and at single-subject level, with a preferential response to fearful eyes respect to every other stimulus category from 200 to 400 ms after stimulus presentation. A preferential response to smiling eyes compared to happy faces and smiling mouths was also observed at group level from 300 to 400 ms post-stimulus presentation. A complementary time–frequency analysis was performed showing that an increase in the theta frequency band (4–7 Hz) accounted for the main event-related band power (ERBP) change during the 200–500 ms post stimulus interval. The analysis of the ERBPs changes according to their emotional valence showed a strong increase in theta ERBP to fearful eyes, which was higher respect to any other facial stimulus. Moreover, theta ERBP increase to "smiling eyes" was larger respect with that evoked by smiling mouths and whole happy faces. Minimal post-stimulus ERBPs changes were evoked by neutral stimuli. These data are consistent with a special role of the amygdala in processing facial signals, both with negative and positive valence, conveyed by the eye region of the face.

1. Introduction

In the last decade a number of studies have highlighted the role of the amygdala in processing emotional signals and different lines of evidences indicate that the amygdala is critically involved in processing facial expressions. In particular, it has been shown that human amygdala lesions produce recognition deficits both for 'basic' facial emotions, such as sadness and fear (Adolphs & Tranel, 2004; Adolphs, Tranel, Damasio, & Damasio, 1994; Young, Hellawell, Van De Wal, & Johnson, 1996), and for more complex facial expressions that signal social or cognitive emotions (Adolphs, Baron-Cohen, & Tranel, 2002; Shaw et al., 2005). Consistent with these data, functional neuroimaging experiments in healthy subjects and intracranial event-related potentials (ERPs) recorded in epileptic patients demonstrated that the view of faces depicting a wide range of facial emotions, and especially frightened ones, elicits neural activity in the amygdala (Breiter et al., 1996; Krolak-Salmon, Henaff, Vighetto, Bertrand, & Mauguiere, 2004; Morris et al., 1996). However, the relative contribution of the amygdala in facial expression processing is not completely clear. Lesion studies and data from high-functioning autistic subjects suggest that the human amygdala is especially involved in decoding features of the eye region (Adolphs et al., 2005; Baron-Cohen et al., 1999). Accordingly, recent PET and fMRI studies showed that the amygdala responds to direct gaze (Kawashima et al., 1999) and to the "wide-eyed" expression that signal fear (Morris, deBonis, & Dolan, 2002; Whalen et al., 2004). Furthermore, Adolphs et al. (2005) proposed that an impairment in fear recognition can arise from the inability to process information from the eye region that is normally essential for recognizing this emotion: the failure could be related to the lack of spontaneous fixation on the eye region and implicates that the amygdala damage would impair the use of visual information from the eye region for decoding different facial expressions. In other words, the amygdala might be involved in detecting salient facial features and in reflexively triggering fixation changes toward them rather than being involved in emotion discrimination per se (Adolphs & Spezio, 2006; Spezio, Adolphs, Hurley, & Piven, 2007; Spezio, Huang, Castelli, & Adolphs, 2007). This support the idea that

* Corresponding author.
E-mail address: Stefano.meletti@unimore.it (S. Meletti).

0028-3932/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2011.10.020

the amygdala's role is much broader than the older view, and seems unlikely to be restricted to processing only stimuli related to threat or danger. The amygdala is rather important to detect salience and biological relevance of environmental stimuli and to resolve ambiguity. In this line the amygdala could process information about the eye region of faces to obtain cues for rapid decoding of facial expressions.

To our knowledge, direct electrophysiological evidence of a differential or preferential response of the human amygdala to the eye region compared to the whole face or to the lower part of the face, is lacking. In this study, we tested the response pattern of intracranial event-related potentials (ERPs) recorded from the human amygdala to static faces and face parts (eyes and mouth region) encoding fear, happy and neutral expressions. We hypothesize that, if the amygdala is especially sensitive to the expressive features of the eye region of conspecifics, brain potentials directly recorded from it would show a different response to the eye and to the mouth region of the face. In particular, we expect that viewing isolated fearful eyes should be sufficient to evoke the ERP response observed to fearful faces (a broad negative potential between 200 and 800 ms post-stimulus) (Krolak-Salmon et al., 2004). Moreover, we expect that even if the "smiling mouth" is the face-feature we use to decode happiness in explicit recognition tasks (Adolphs et al., 2005; Smith, Cottrell, Gosselin, & Schyns, 2005), the amygdala should respond preferentially to the "smiling eyes" rather than to the "smiling mouth". In contrast with fear, joy is mostly characterized by the inferior part of the face, especially by the mouth (smile) which is the diagnostic element enabling the recognition of this emotion (Schyns, Bonnar, & Gosselin, 2002). However, a fake smile will be betrayed by the absence of expressive cues in the eye region, such as the wrinkles around the eye corners (the so-called "Duchenne smile") (Ekman, Davidson, & Friesen, 1990).

To test these hypotheses intracranial ERPs were recorded in four drug-resistant epileptic patients implanted with depth-electrodes according to stereo-EEG (SEEG) methodology as part of their pre-surgical evaluation. Data were first analyzed in the domain of time (ERPs), and then a time–frequency analysis (event-related band power, ERBP) was carried out to investigate the role of different frequency changes over time after the stimulus presentation. This last analysis has the aim to explore the relative contributions of theta and gamma oscillations to the processing of emotional signals, and in particular to the processing of facial signals of threat and joy. Recently, the contribution of gamma frequency (around 40 Hz) has been demonstrated within the human amygdala in response to complex emotional visual scenes (Oya, Kawasaki, Howard, & Adolphs, 2002) and to fearful facial expressions (Luo, Holroyd, Jones, Hendler, & Blair, 2007; Sato et al., 2011). However, other studies underlined the importance of frequencies oscillations in the theta range during emotional processing (Knyazev, 2007; Paré, Collins, & Pelletier, 2002; Maratos, Mogg, Bradley, Rippon, & Senior, 2009). In particular it has been proposed that theta band activity plays an important role in integrating and synchronizing neural responses to emotional stimuli across sub-cortical (amygdala) and cortical structures, such as frontal and visual cortices (Lewis, 2005).

2. Material and methods

2.1. Patients

Four patients suffering from drug-resistant focal epilepsy were stereotactically implanted with intracerebral electrodes as part of their pre-surgical evaluation. The structures to be explored were defined on the basis of ictal manifestations, electroencephalography (EEG), and neuroimaging studies. Event-related potentials (ERPs) recordings were performed as part of the cortical functional mapping at the end of the stereotactic-EEG (SEEG) monitoring, once relevant seizures had been recorded. No seizures were recorded the day of the ERPs experiment, nor during the 24 h prior to it. According to a direct individual benefit, patients were fully informed of the electrode implantation, SEEG, and ERPs recordings, and they gave their consent. The subjects' consent was obtained according to the declaration of Helsinki and the local Ethical Committee approved the study. Table 1 (online supplementary material) reports the clinical and neuroradiological features and the implantation sites of each subject. All subjects were right-handed as determined by the Edinburgh Inventory (Oldfield, 1971). Patients 1 and 2 were diagnosed with left occipito-temporal lobe epilepsy. Patient 3 was diagnosed with a right occipito-temporal lobe epilepsy. Patient 4 was diagnosed with a right frontal-lobe epilepsy. A total of four amygdale were implanted, two from the right hemisphere (Pt. 3 and 4) and two from the left hemisphere (Pt. 1 and 2).

2.2. Stereotactic implantation

Cerebral angiography was first performed in stereotactic conditions. In order to reach the clinically relevant targets, the stereotactic coordinates of each electrode were calculated preoperatively on the individual cerebral MRI previously enlarged at the angiography scale. The electrodes were implanted perpendicularly to the mid-sagittal plane using Talairach's stereotactic method (Talairach & Bancaud, 1973). Depth electrodes (DIXI, Besancon, France) were 0.8 mm in diameter and had 5, 10, or 15 recording contacts. Contacts were 2.0 mm long, and successive contacts were separated by 1.5 mm. Since the voltage field related to amygdala activity has the properties of a "closed" field, particular attention was paid to ensure that the recording was from within the amygdala structures (Hudry, Ryvlin, Royet, & Mauguiere, 2001; Lorente de Nò, 1947). Therefore, at first we identified the cerebral structures explored by each stereo-EEG electrode through their entry point and target point as defined in the three-dimensional proportional grid system devised by Talairach and Tournoux (1988). Talairach coordinates of the electrode contacts of interest for this study were calculated, by superposing the X-ray of the skull of the patient with the electrodes implanted on the Talairach proportional grid system with a grid scale of 1 mm. Then, to visualize with higher accuracy the exact locations of the electrode contacts, we reconstructed the trajectories of the stereo-EEG electrodes on the post-implantation MRI images in each patient. A probabilistic cytoarchitectonic map of the amygdala (Eickhoff et al., 2005) was also referenced to validate contacts positions.

2.3. Facial emotion recognition (FER) assessment

Since previous research demonstrated that drug-resistant medial temporal lobe epilepsy can impair explicit recognition of facial emotions (Benuzzi et al., 2004; Meletti et al., 2003) patients' facial emotion recognition ability was tested according to a previously published protocol before performing the ERPs paradigm (Meletti et al., 2009). Pictures of facial affect, taken from the Ekman and Friesen series (1976), were used to prepare a task requiring subjects to match a facial expression with the appropriate verbal label, choosing among the following five basic emotions: happiness, sadness, fear, disgust, and anger. Ten pictures (facial stimuli) were used for each emotion giving a total of 50 trials. Normative data (for the pictures of facial affect series) report the following mean percentages of correct recognition for the selected items: happiness = 99.2%; sadness = 95.6%; fear = 88.4%; disgust = 95.6%; anger = 94.4%.

Testing procedure: pictures (10 cm × 13 cm) were presented, one by one, on a sheet of paper. The verbal labels for the five facial expressions were printed under each picture and the subjects were asked to select the word that best described the emotion shown in each photograph. The participants were instructed to consider all five alternatives carefully before responding. There was no time limit and the patients were given no feedback on their performances. All the subjects completed the test without difficulty in a single session that typically lasted from 10 to 20 min.

Fifty right-handed (Oldfield, 1971) healthy volunteers with no history of neurological or psychiatric illness participated as controls.

2.4. Stimuli and ERP paradigm

To test the effects of the different facial emotions and the role of the upper and lower face part on amygdala ERPs, subjects were presented with the following stimulus categories: whole face, eyes, and mouth, showing either fearful, happy or neutral expressions.

Whole face stimuli were 33 static gray-scale images of emotionally expressive faces (six women and five men depicting three different emotional expressions, i.e., fear, happiness, and neutral) taken from the Ekman's set of pictures of facial affect (Ekman & Friesen, 1976). The pictures used are referred as EM, JJ, MF, MO, PE, PF, SW, WF, NR, GS and C in the Ekman's data set. An elliptic mask was fitted to solely reveal the face itself while hiding hair and ears. Stimuli showing only the eye or the mouth region were created from whole face stimuli (Fig. 1). We therefore obtained 99 stimuli: (a) 33 fear encoding stimuli (11 fearful faces; 11 fearful eyes; 11 fearful mouths); (b) 33 happiness-encoding stimuli (11 happy faces; 11 happy eyes; 11 happy mouths); (c) 33 neutral stimuli (11 neutral faces; 11 neutral eyes; 11 neutral mouths). A luminance meter was used to adjust the images: average luminance was 30–35 cd/m^2. Uniform figure/background was ensured by using the same mid-gray background. Luminance and contrast were equated for whole face stimuli, eyes-stimuli and mouth-stimuli.

Each trial started with a fixation cross (2 s) followed by the presentation of a stimulus (500 ms). Size-, brightness-, and contrast-adjusted images were presented