Mirror of the soul: a cortical stimulation study on recognition of facial emotions

Clinical article

CARLO GIUSSANI, M.D.,1,2 DAVID PIRILLO, M.D.,1,2 AND FRANCK-EMMANUEL ROUX, M.D., PH.D.1,3

1Institute National de la Santé et de la Recherche Médicale Unité 825 and L’Institut Fédératif de Recherche 96, Hôpital Purpan; 2Pôle Neurosciences, Centre Hospitalier Universitaire, Hôpital Purpan; and 3Université Paul-Sabatier, Toulouse, France

Object. The capability of recognizing the expressions of facial emotions has been hypothesized to depend on a right hemispheric cortical-subcortical network. Its impairment deeply disturbs social relationships. To spare right hemispheric cortical areas involved in recognizing facial emotion, the authors used intraoperative cortical stimulation and the awake surgery technique in a consecutive series of patients. The feasibility and the interest to map them during brain mapping for neurosurgical procedures are discussed.

Methods. After a preoperative neuropsychological evaluation, 18 consecutive patients with right hemispheric lesions (5 metastases, 6 high-grade gliomas, 4 low-grade gliomas, 2 arteriovenous malformations, and 1 malignant meningioma) were tested by intraoperative cortical stimulation while performing a facial emotion recognition task along with sensorimotor and visuospatial tasks.

Results. Three hundred eighty-six cortical sites were studied. Five (1.30%) reproducible interference sites for facial emotion recognition were identified in 5 patients: 1 site in the medial segment of T1; 1 site in the posterior segment of T1; 1 site in the posterior segment of T2; and 2 sites in the supramarginal gyrus. No selective impairment was found regarding the emotion category. All facial emotion recognition sites were spared during surgery, and none of the patients experienced postoperative deficits in recognition of facial emotions.

Conclusions. The finding of interference sites in facial emotion recognition in the right posterior perisylvian area, independent to sensorimotor or visuospatial orientation processes, reinforces the theory about the role of anatomically and functionally segregated right hemisphere structures in this cognitive process. The authors advocate offering a brain mapping of facial emotion recognition to patients with right posterior perisylvian tumors.

(Key words: • brain tumor • cortical mapping • facial emotion recognition

The English philosopher and physician Thomas Browne (1605–1682) wrote in his work the Religio Medici “… there are mystically in our faces certain Characters which carry in them the motto of our Souls….” This basic communicative importance of faces is manifested from the beginning of our lives as revealed in infants who begin to look at faces at a very early age.32 Faces provide a wealth of information that uniquely helps social communication. Even though the perception of identity is important for social communication, the perception of the variable aspects of the face as emotional expressions plays a greater role in facilitating social communication.

Selective impairments in recognizing facial emotions without a deficit in facial identity,29 and conversely (that is, selective impairments in recognizing facial identity without a deficit in recognizing facial emotions),12 have been reported in the neurocognitive literature, suggesting that different aspects of faces are processed in separate neural subsystems. Contemporary models of perception of facial emotions assume that emotional information is processed by a network involving both cortical and subcortical structures.14,17,24,26,27,45,47 This network comprises the amygdala, basal ganglia, and geniculate bodies; hippocampal and insular formations; right orbitofrontal cortex; right superior temporal gyrus and sulcus; right supramarginal gyrus; and right somatosensory-related cortices.1 According to this model, a direct cortical stimulation study was published about facial emotion recognition.20 The authors found in some patients that the right hemisphere, particularly the posterior lateral temporal cortex, could be involved in emotion recognition in neurosurgical patients. However, the literature describing the face expression recognition mechanisms is not conclu-
Recognition of facial emotions

...and the role of the right perisylvian and periorbital cortices has to be better described and validated.15,36,23

Our team routinely uses direct electrocortical brain mapping in patients with brain tumors to avoid damage to different cognitive functions.9,18,30,31,33,35,36,42,43 To spare right hemispheric cortical areas theoretically related to the recognition of facial emotion expressions and to gain a better understanding of this process, we studied a consecutive series of 18 patients harboring brain tumors and vascular lesions. Among other sensorimotor and spatial recognition tasks selected for the right hemisphere, we used a facial expression recognition task based on the 6 primal facial expressions.19 The functional-anatomical organization of facial emotion recognition is analyzed in relation to these surgical data. We also discussed the feasibility and the interest to map facial emotion recognition.

Methods

Patient Population

Between August 2006 and February 2008, 18 patients without language deficit (11 men and 7 women; 25–70 years old, mean 47 years) among those who had undergone surgery for brain tumors or other lesions at our institution were prospectively studied using cortical brain mapping. The patients harbored different brain lesions in different right hemispheric areas (F1/F2, 8 patients; paracentral, 2 patients; parietal lobe, 4 patients; and T1/T2, 4 patients). Five patients had metastatic lesions, 6 had high-grade gliomas, 4 had low-grade gliomas, 2 had arteriovenous malformations, and 1 patient had a malignant meningioma. The degree of patient handedness was assessed using the Edinburgh Handedness Inventory test.34 In this study, 15 patients were right-handed, 2 patients were left-handed, and 1 patient demonstrated a bilateral handedness. In brain tumor surgery, we routinely perform surgery using an “awake surgery” technique if mapping can be useful to the surgical procedure and if the case is appropriate for such a procedure. Accordingly, tumor removal was expected to be delicate in some patients with right hemispheric tumors for various reasons (proximity of the Rolandic area or of dedicated areas, or suspected bilateral language representation). All patients and their families gave informed consent to have their language areas studied by direct brain mapping.

Preoperative and Postoperative Assessment

All patients had neuropsychological examinations to assess their ability to perform the required tasks. This testing included evaluation of written and oral understanding as well as naming, language fluency, and object handling. Visual field testing was performed to rule out visual field defects and/or neglect. No patient with significant visual field defect or neglect was included in this study. The ability of the patients to identify and name facial emotion expressions was specifically tested. Patients were asked to name 1 of the 6 primal facial expressions: anger, happiness, fear, surprise, disgust, and sadness.19 Only patients showing no errors in these tests were included in the study.

Awake Surgery and Direct Brain Mapping Technique

All patients underwent our routine “awake surgery” procedure.40 The brain was exposed in a standard fashion. Anatomical relationships among gyri were defined using neuronavigation (StealthStation, Sofamor Danek). Once the patient was completely awake and collaborating, an intraoperative cortical stimulation technique was used to localize the eloquent cortex after the afterdischarge threshold was determined using electrocorticography. The cortex was stimulated by a bipolar electrode of a cortical stimulator with 1-mm electrodes separated by 5 mm (Nimbus Newmedic International s.a.s.). The current amplitude was progressively increased by 1-mA increments starting at 2 mA. We used a procedure of stimulation that included biphasic square wave pulses of 1 msec at 60 Hz, with a maximum train duration of 4 seconds. The stimulation amplitude ranged between 4.4 and 5.9 mA. Cortical sites exposed by the craniotomy were randomly tested under direct stimulation during the different tasks. When a functional site was located, it was marked with a 0.25-cm² sterile label, and another area was tested.

Brain Mapping Tasks

Our routine brain mapping procedure in the left hemisphere uses 2 different kinds of tasks: a naming task (using a data set of uncolored objects) to search for standard anomia, and reading-aloud tasks with various sentences and numbers. In this series of awake procedures in the right hemispheres, we used different tasks. We used a spatial orientation task asking the patient to bisect a horizontal line while electrostimulation was applied to search for neglect,48 and an object naming task and sensorimotor tasks to map Rolandic area when appropriate. In this series, we concluded the brain mapping procedure by adding a facial emotion recognition task. We used photos of individuals (varying for age, sex, and race) exhibiting 1 of the 6 primal facial emotions: anger, happiness, fear, surprise, disgust, and sadness.19 These photos were presented randomly to the patient, and a cortical mapping for facial emotion recognition was performed while the patient was asked to name the facial expression. Facial emotion recognition mapping did not extend the global brain mapping procedure, which was usually completed in < 30 minutes. Our strategy was to spare neglect and facial emotion recognition task areas found in the right hemisphere during the tumor removal by resecting tumor to no more than 1 cm from eloquent cortex (distance of the resection margin from the nearest functional site). Naming and reading tasks were also used when a bilateral language representation was suspected or when a patient was left-handed.

Cortical Mapping Procedures

All patients underwent the awake surgery technique that was previously described by our team.40 Intraoperative direct cortical stimulation was used to localize areas of functional cortex after determination of the afterdischarge threshold by electrocorticography. All patients were tested at the same site for spatial orientation and facial expression recognition. Subcortical mapping was...
Performed only for the spatial orientation task. When necessary, the rolandic area was also mapped. In patients with suspected right hemispheric representation, naming and reading tasks were added. When we started a direct cortical stimulation procedure, we chose a substantial number of sites on the brain surface. Except in the preand postcentral gyri, we stimulated the same areas during the entire procedure to test for all tasks. The number of sites studied was variable and depended on the size of the craniotomy. The cortex was directly stimulated using a bipolar electrode consisting of 1-mm contacts separated by 6 mm (Nimbus cortical stimulator, Newmedic). The cortical mapping procedures and the patients’ answers were video recorded. Intraoperative photographs of the brain were taken with sites of positive or negative responses to cortical stimulation.

**Postoperative Neuropsychological Tests**

Postoperatively, patients underwent the same tests they had undergone preoperatively to detect any language, visuospatial orientation, or facial expression recognition difficulties. The results were compared with the intraoperative findings. These postoperative tests can be considered important in determining either the degree of recovery or surgery-related deficits. As previously reported by our team, difficulties can be encountered in the analysis of surgery-related deficits given that these deficits were sometimes related to the patient’s surgical stress and fatigue. Analysis of postoperative testing can further be complicated by limited long-term follow-up of patients with high-grade gliomas.

**Conditions of Validation of the Study**

Strict validation conditions of language interference sites were applied and can be summarized in 4 points. 1) To be accepted as a facial emotion recognition area, the sites were tested ≥ 3 times. The sites that did not present reproducible interferences were not included in the final analysis. 2) The cortical mapping procedures were recorded on video. Each patient’s spoken answers were recorded using a microphone placed near his or her mouth so that the responses could be further analyzed in team meetings. 3) Because they can be considered nonspecific, the facial emotion recognition interferences found in the pre- and postcentral gyri (considered as emotion interferences due to blockage of articulatory mechanisms) were not included in the final analysis. 4) Finally, it must be emphasized that we qualified a site as “facial emotion recognition–specific” when no other language interference was found at that site during object naming. However, we cannot completely exclude the possibility that other functions not tested in this study could be revealed by stimulation in a specific site of facial emotion recognition. In fact, the amount of time to perform the brain mapping during an awake craniotomy can be limited due to patient fatigue. Therefore, the task specificity of an interference site is inversely related to the number of tasks administered. Nevertheless, the cognitive functions that we chose to map in a specific cortical region case by case depend on the previous different information coming from brain lesions and functional imaging studies that those specific cognitive functions are processed in that cortical region. This means that an interference site can be reasonably defined specific for a cognitive function when ≥ 2 cognitive functions, which have been shown to be related to the brain area mapped, are simultaneously tested. For these reasons, a visuospatial orientation task was administered along with a facial emotion recognition task in this right hemisphere cortical study. Moreover, in patients with suspected right hemisphere language representation, an object-naming and a reading task were used. In this way a specific interference site for facial emotion recognition would have been reliably differentiated from a language interference site.

**Data Analysis**

During this study, all data regarding brain mapping results were integrated into an Excel database (Microsoft Corp.). In presenting our data, we chose to define regions by using the gyral/sulcal anatomy. For instance, the supramarginal gyrus was considered a region, as well as the angular gyrus. Large gyri, such as the temporal gyrus, for example, were arbitrarily divided into 3 segments by drawing an imaginary line extending to the pre- and postcentral sulci. Fifteen regions were defined for the right hemisphere. We analyzed brain mapping data by separating facial emotion recognition interference sites from other interference sites. To avoid confusion in the presentation of the results, we localized all facial emotion recognition sites found in the right hemisphere in a figure using a standard brain according to operative anatomical data. The type of responses and the size of facial emotion recognition areas are presented elsewhere in the text.

Due to the limited number of emotion recognition interference sites, it was not possible to conduct a statistical analysis of the collected data.

**Results**

In this study, cortical mapping of facial emotion recognition areas was performed in all 18 patients without problems. Some cortical regions were not studied such as the occipital lobe, the basal temporal cortex (lingual and fusiform gyri), and the interhemispheric regions. Other cortical regions were studied at least once including the F1, F2, and F3; pre- and postcentral gyri; parietal lobe; and T1, T2, and T3 areas.

Prefrontal and postcentral interference sites, considered as implicated in sensorimotor pathways, were excluded from the final analysis. Overall, 386 cortical sites (mean 21 sites per patient; range 8–39 sites) were studied. Five (1.30%) reproducible interference sites for facial emotion recognition were found in 5 patients. No patient experienced generalized seizures intraoperatively. The maximal current that did not evoke afterdischarges ranged from 4 to 5.4 mA. Interferences in horizontal line bisection were found in 8 patients.

**Location of Facial Emotion Recognition Task Interferences**

Facial emotion recognition sites appeared to be local-
ized. All 5 facial emotion recognition sites found were localized in the posterior perisylvian region: 1 site in the medial segment of T1; 1 in the posterior segment of T1; 1 in the posterior segment of T2; and 2 sites in the supramarginal gyrus (Fig. 1) for a total of 121 sites studied in these specific regions. The posterior sylvian fissure was studied in 10 patients; among them, 5 had facial emotion recognition areas. No facial emotion was found elsewhere, that is, in the frontal regions, the upper parietal region, or the anterior or inferior temporal region (Fig. 2).

What is important to underline is the absence of overlapping interference sites between all facial emotion recognition sites, the bisecting horizontal line sites, or language sites found in left-handed patients. This means that the disruption of the recognition of facial emotions was not related or influenced by the presence of a neglect phenomenon or language interferences induced by electrostimulation. All facial emotion recognition sites were spared during surgery.

Size of Interference Area

Facial emotion interferences were localized in small parts of cortical areas. Among the 5 emotion recognition interference areas found, all were single sites measuring < 1 cm² (the stimulation of the areas located in the immediate vicinity did not show any emotion recognition interference).

Type of Interference

Face recognition interferences were clear and reproducible. Different types were noted. Emotion mismatching (the patient named an incorrect emotion in response to the presented one) was noted in 3 cases. Repeated hesitation for naming (patient said, “This is…I know…let me think…yes I know—sad?” “Correct…” ) was detected in 2 other cases. No speech arrest or true anomia was detected. No selective impairment was found regarding the emotion category.

Single Facial Emotion Recognition

Four single (not reproducible) facial emotion recognition interferences were detected. These interferences were excluded from the analysis because of the impossibility of knowing whether these interferences were provoked by electrostimulation or by single patient hesitation for different reasons (for example, stress).

Other Findings

Interference cortical or subcortical sites in line bisection were detected in 8 patients, all in different areas from face recognition sites. In total, 14 line bisection sites were found: 1 site each in the F1, F3, and T1 areas; 2 in the T2 area; 1 in intraparietal area; 5 in the anterior supramarginal gyrus; 2 in the posterior supramarginal gyrus; and 1 site in the angular gyrus. No language-related areas were found in our 3 patients with suspected bilateral language representation.

Postoperative Neuropsychological Tests

Preoperative and postoperative findings can be summarized in 2 points. 1) None of our patients had a significant postoperative facial emotion recognition deficit. Postoperative scores of facial emotion recognition were
similar to the preoperative scores in 16 patients (46–49 of 50 questions); scores were slightly lower than the preoperative score in 2 patients (42/50 in one and 41/50 in the other patient, respectively [47/50 and 48/50 preoperatively]), although this decrease in score was not considered to be significant. 2) Other postoperative defects were noted. One patient had a slight postoperative prosopagnosia, and 3 had postoperative spatial neglect. This neglect was persistent at the 3-month follow-up neuropsychological evaluation in 2 of these patients.

**Discussion**

In this series of patients, 5 interference sites related to facial emotion recognition were found in the right hemisphere. All these sites were localized in the posterior part of the perisylvian region. The involvement of the right parietal lobe cortex in facial emotion recognition seems to be in agreement with that reported in the literature. Nevertheless, even though different studies have largely implicated the right hemisphere in the elaboration and recognition of facial emotions, neither the underlying processes nor the anatomical correlates are yet totally clarified.

**Facial Emotion: Mirror of the Soul**

From the Hellenistic Philosophers, such as Aristotle, the Stoics, and the Epicureans to the modern neuropsychologists and behavior researchers, many authors pursued the description and categorization of human emotion.
Recognition of facial emotions

emotions. Feelings of a positive or negative emotion are nonverbal social communications. In fact, facial expressions are more rapid than language, constituting a dominant tool in social organization. Emotional expressions are crucial to the development and regulation of interpersonal relationships, as in the organization of attachments (in infancy as well as in courtship). Patients with congenital facial paralysis (Mobius syndrome) or a history of strokes who have lost the capability to generate the prosody that accompanies emotion expression have great interpersonal difficulties.39

Six basic facial expressions for emotions have been reported to be commonly recognized in different cultures: anger, happiness, fear, surprise, disgust, and sadness.39 An anatomical segregation in processing a specific facial expression could exist. The amygdala has been related to processing fearful or sad faces.25,42 the orbital frontal regions activated in a response to angry faces.10 the insular cortex by disgusted faces13 while the cingulated sulcus by happy faces.24

Facial emotion recognition is supposed to be a streaming process.50 initially depending on the right ventral occipitotemporal areas, known as the fusiform area, where facial features are perceived and encoded.4,23,37

Furthermore, face naming relies more particularly on the left frontal and anterior temporal areas as shown in a previous electrostimulation study.21 The amygdala may contribute to the retrieval of the conceptual knowledge about emotions triggering projections to the hippocampus, whereas the orbitofrontal cortices may direct the attention and modulate the alertness when salient stimuli such as facial expressions are encountered.7 Finally, the activation of an emotional response in the observer of facial expressions (via amygdala and orbitofrontal connections to motor structures, the hypothalamus, and brainstem nuclei) could generate knowledge about another person’s emotional state through the process of simulation.5,6

Much evidence coming from patients with brain lesions, neurophysiological studies, and functional neuroimaging studies has shown that simulation of facial emotions depends on the right hemisphere, especially the perisylvian cortex, including the superior and middle temporal gyri, the superior temporal sulcus, the anterior supramarginal gyrus, and the somatosensory cortex.2,5,6,8,11,28,50,51 In particular, a milestone contribution comes from Adolphs et al.2 who studied 108 individuals with focal brain lesions and assessed the recognition of basic emotions from facial expressions. The lesions were analyzed as a function of task performance by coregistration in a common brain space, and the statistical analyses of their joint volumetric density showed that recognizing facial emotion expressions requires right somatosensory-related cortices.

Moreover, using functional MR imaging, Vuilleumier et al.50 and Van de Riet et al.49 showed the importance of the right temporal and parietal perisylvian regions in correctly processing facial emotion expressions. Unfortunately, no functional MR imaging study has been conducted until now with the purpose of preoperatively mapping facial emotion recognition areas in cases of neurosurgical lesions in the right hemisphere.

Facial Emotion Recognition During Neurosurgical Procedures

The findings of the present study are in agreement with the hypothesis that interference sites during a facial emotion recognition task occur in the right perisylvian cortex. Data about facial recognition in neurosurgical procedures are scarce. Only 1 previous study has been published on this topic.20 Those authors also found facial emotion recognition sites in the right temporal lobe. Are facial emotion tasks really useful in neurosurgical patients who need brain mapping in the right hemisphere? Emotion recognition is an important human function, although it may be slightly less essential than language or sensorimotor functions. Facial emotion deficits are probably underestimated in neurological patients because they are not routinely tested after surgery. In this series we cannot demonstrate that these cortical areas are essential because all were spared, and none of our patients had a facial emotion recognition deficit. According to the literature, when facial emotion recognition deficits arise, patients are extremely impaired.19,22,31,38,39,41,46 Thus, sparing cortical areas related to facial emotion recognition when possible could be important to ensure a good quality of life in patients whose extent of life is frequently negatively affected by brain tumors. Based on this series of 18 patients, we advocate the use of these tasks only in the posterior sylvian region.

Limits of the Study

Of course the results of the present study have some limits. This is a limited series of patients who underwent right hemispheric awake craniotomy. Second, due to the need to perform a less time-consuming procedure to avoid patient fatigue and to keep them continuously focused, in the facial emotion recognition task we mapped only the surface of the brain. Current models of emotion perception have shown that emotional information is processed by a network involving cortical and subcortical structures through pathways involving the superior colliculus and the pulvinar nucleus of the thalamus.17 Due to the complexity of the facial emotion recognition process as well as the number of reverberating anatomical structures that it involves (convexity and basal cortex, basal ganglia, and limbic system) it was technically possible to map only the final step involving cortical areas. Nevertheless, the findings of different cortical sites of interference to facial emotion recognition in the right hemisphere permits the inference that facial emotion recognition could be a neuropsychological process separated from other cognitive processes.

Conclusions

The capability of recognizing facial emotion is fundamental in establishing and maintaining interpersonal relationships, and it seems to depend on an articulated right hemispheric cortical and subcortical network. This prospective direct cortical stimulation study added weight to the theory that facial emotion recognition hinges on the right middle and posterior segments of T1 and T2 and in-
ferior parietal cortex. Moreover, the recognition process interferences were independent from the visuospatial orienta-
tion process, suggesting that facial emotion recognition is a functionally and anatomically segregated cogni-
tive process.

As stated in other studies,21,40 we think that there is a need to adapt brain mapping tasks in neurosurgical pa-
patients not only to the patient biography and features (for example, multilingualism) but also to the brain region studied. Further studies will be needed to establish the role of subcortical right hemisphere structures in the dif-
ferent phases of facial emotion recognition. Therefore, when awake surgery and brain mapping are appropriate, we would suggest to map cortically and subcortically facial emotion recognition during right hemispheric sur-
gery for brain tumors located around the posterior end of the sylvian fissure.

Disclaimer
The authors report no conflict of interest concerning the mate-
rials or methods used in this study or the findings specified in this paper.

References
11. Bowers D, Bauer RM, Coslett HB, Heilman KM: Processing of faces by patients with unilateral hemisphere lesions. I. Disso-
ciation between judgments of facial affect and facial identity. Brain Cogn 4:258–272, 1985
12. Bruyer R, Laterre C, Seron X, Feyereisen P, Strypstein E, Pierard E: A case of prosopagnosia with some preserved co-
18. Duffau H, Lopes M, Arthuis F, Bitar A, Sichel JP, Van Effe-
26. Klüver H, Bucy PC: An analysis of certain effects of bilateral temporal lobectomy in the rhesus monkey, with special refer-
cence to “psychic blindness.” J Psychol 53:33–54, 1938
33. Ojemann G, Ojemann J, Lettich E, Berger M: Cortical lan-
Recognition of facial emotions


Manuscript submitted November 17, 2008.

Address correspondence to: Franck-Emmanuel Roux, M.D., Ph.D., INSERM 825 et Neurochirurgie, Hôpital Purpan, Place du Docteur Baylac, F-31059 Toulouse, France. email: franck.roux@club-internet.fr.