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FOCAL ELECTRICAL INTRACEREBRAL STIMULATION OF A FACE-SENSITIVE AREA CAUSES TRANSIENT PROSOPAGNOSIA

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Abstract—Face perception is subtended by a large set of areas in the human ventral occipito-temporal cortex. However, the role of these areas and their importance for face recognition remain largely unclear. Here we report a case of transient selective impairment in face recognition (prosopagnosia) induced by focal electrical intracerebral stimulation of the right inferior occipital gyrus. This area presents with typical face-sensitivity as evidenced by functional neuroimaging right occipital face area (OFA). A face-sensitive intracerebral N170 was also recorded in this area, supporting its contribution as a source of the well-known N170 component typically recorded on the scalp. Altogether, these observations indicate that face recognition can be selectively impaired by local disruption of a single face-sensitive area of the network subtending this function, the right OFA.

Key words: face perception, OFA, electrical stimulation, prosopagnosia, N170.

INTRODUCTION

Face perception is an extremely important social function that is subtended by a set of widely distributed brain areas in human (Sergent et al., 1992; Allison et al., 1994, 1999; Kanwisher et al., 1997; Haxby et al., 2000; Ishai, 2008; Rossion et al., 2012) and non-human primates (Tsao et al., 2008), with a right hemisphere advantage. Despite intense research, important debates remain about the degree of face-specificity, and the functional organization of the areas of the ventral occipito-temporal cortex that are preferentially activated when perceiving faces as compared to other object categories (Wiggett and Downing, 2008; Weiner and Grill-Spector, 2010; Rossion et al., 2012). In particular, whether all of the right hemisphere face-sensitive occipito-temporal areas are necessary for normal face recognition remain unknown. In humans, the localization of lesions causing prosopagnosia – classically the impairment of face recognition following brain damage (Bodamer, 1947) – can potentially provide information about the necessity of occipito-temporal areas and their putative connections for face recognition (Hécaen and Angelergues, 1962; Damasio et al., 1982; Barton et al., 2002; Thomas et al., 2008). However, while there is a much higher prevalence of lesions in the right than the left hemisphere causing prosopagnosia, these patients usually have large and variable lesions that can encompass the lingual, fusiform, and parahippocampal gyri, and even the anterior part of the inferior temporal cortex (Barton et al., 2002; Bouvier and Engel, 2006; Bukach et al., 2006; Sorger et al., 2007), preventing to draw firm conclusions about the necessity of a given area for face recognition. Moreover, brain areas that may appear structurally intact and thus not considered to be critically associated with face recognition in a patient with prosopagnosia may in fact be functionally depressed because they do not receive normal inputs from lesioned areas ('diaschisis', see Price and Friston, 2002; see also Thomas et al., 2008). Another issue related to the functional organization of the cortical face network concerns the relative time-course of these areas: when and along

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Abbreviations: ERP, evoked related potential; FFA, fusiform face area; SEEG, stereo-electroencephalographic; TMS, transcranial magnetic stimulation; MRI, magnetic resonance imaging; CT, computed tomography; TE, echo time; TR, repetition time.

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which time-course do they show face-sensitive responses (e.g., Jiang et al., 2011; Sadeh et al., 2010) and contribute to the face-sensitive N170 response recorded on the human scalp (Bentin et al., 1996; for reviews see Eimer, 2011; Rossion and Jacques, 2011).

In the present study we had a unique opportunity to test the role and time-course of the most posterior face-sensitive area that has been consistently reported, namely the right occipital face area ('rOFA', e.g., Gauthier et al., 2000; for a recent review see Pitcher et al., 2011). This opportunity was offered to us in the clinical context of a young human patient with a rare medically intractable right occipital epilepsy related to a focal cortical dysplasia involving the right inferior occipital gyrus. The patient had normal familiar face recognition and face perception outside of the epileptic seizures, as assessed by behavioral tests. Intra-cerebral electrodes were stereotactically implanted in the patients' occipito-temporal region in order to localize the zone of seizure onset, and to determine the post-surgical neuropsychological outcome. As part of her pre-surgical investigation, focal intracerebral electrical stimulations were performed to directly test the role of this region in face recognition, and the patient underwent a functional magnetic resonance examination contrasting the presentation of faces and objects. We also had the unique opportunity of recording intracerebral potentials to visual stimulation of faces and non-face objects in this cortical region, allowing testing for the time-course of its contribution to face recognition.

EXPERIMENTAL PROCEDURES

Case description

The patient is a 32-year-old right-handed woman (K.V.) who has rare medically intractable right occipital epilepsy related to a focal cortical dysplasia involving the right inferior occipital gyrus. She has never complained of difficulties in face recognition, even during seizures. Neuropsychological evaluations performed before the intracerebral exploration revealed a normal performance on intellect, memory, visual perception, and most importantly face and object perception (Table 1). She also has a normal pattern of performance in paradigms measuring integration of local facial features into a global ('holistic/configural') representation (face inversion effect, Fig. 1 and composite face effect, Fig. 2), as tested 6 months after the intracerebral exploration. She gave written consent to participate in these procedures, monitored by the appropriate ethics committee.

Stereo-electroencephalographic (SEEG) placement of intracerebral electrodes

SEEG recording was performed in order to define the epileptogenic zone (Talairach and Bancaud, 1973). The electrode implantation sites were chosen according to non-invasive data collected during the earlier phase of the investigation in order to localize and delineate the zone of epileptic seizure onset and early propagation (Maillard et al., 2009). Stereotactic placement of the intracerebral electrodes (Dixi Medical, Besançon, France), consisting of 5–18 contiguous contacts of 2-mm long separated by 1.5 mm, was performed as follows: after induction of general anesthesia, the Leksell G-frame (Elekta S.A., Stockholm, Sweden) was positioned on the patient's head and a stereotactic MRI (3D SPGR T1 weighted-sequence, TR: 20 ms, TE: 6 ms; matrix 512×512, with double injection of gadolinium, Signa 1.5 Tesla; General Electric Medical System, Milwaukee, United States) was carried out. MRI was imported into a computer-assisted stereotactic module (Leksell Surgiplan; Elekta S.A., Stockholm, Sweden), and electrode trajectories were calculated according to pre-operative planning, with careful avoidance of vascular structures. A post-operative stereotactic CT-scan was then carried out and fused with pre-operative MRI to determine the exact position of each electrode according to the Talairach and Tournoux coordinates. The signal was recorded at a 512-kHz sampling rate on a 128-channels amplifier (2 SD LTM 64 Headbox; Micromed, Italy). The reference electrode was a prefrontal–central surface electrode (FPz).

Eight electrodes were placed in the right hemisphere targeting the calcarine fissure (electrode Ca, containing 12 contacts), ventral-occipital cortex (electrode O, containing 10 contacts), middle ventral temporal cortex (electrode F containing 15 contacts), occipito-parietal junction (electrode S, containing 18 contacts), collateral fissure and the middle temporal gyrus (electrode TM, containing 15 contacts), entorhinal cortex and inferior temporal gyrus (electrode TB, containing 15 contacts), superior temporal gyrus (electrode T, containing 5 contacts) and hippocampus (electrode B, containing 12 contacts). Four electrodes were placed in the left hemisphere, exploring the ventral occipital cortex (electrode O′, containing 12 contacts), the middle ventral temporal cortex (electrode F′, containing 15 contacts), occipito-parietal junction (electrode S′, containing 18 contacts) and hippocampus (electrode B′, containing 15 contacts).

Cortical stimulations

Bipolar electrical intracerebral stimulations were applied between two contiguous contacts along one common electrode and performed at 50 Hz during 5 s at intensities ranging from 1 to 1.8 mA (usual stimulation settings in SEEG). Impulsion was diphasic and 1050 µs width. Trains of stimulation of electrodes targeting the right occipital lobe and the ventral-temporal cortex bilaterally (electrodes Ca, O, O′, F, F′) were carried out during naming photographs of famous faces, objects, and famous visual scenes that she has correctly named before the procedure. For a given category, the patient had to name a set of 3 stimuli, one before, one during and one after the stimulation (Fig. 3). Using this procedure we performed 33 stimulations (19 sets of famous faces, 10 sets of objects and 4 sets of famous scenes) at 12 different sites (Table 2). We used 10 different famous faces, 10 different objects and 10 different famous scenes. The patient never had to name the exact same set of 3 stimuli for 2 given stimulations. She was not aware of the stimulation onset and termination, the stimulation site and the potential evoked perceptual changes.

To ensure that the face task does not differ in difficulty from the non-face task, the patient was tested at the face and non-face (objects and famous scenes) recognition tasks the day before the stimulations. She named easily all famous faces, objects and famous scenes that were presented.

Functional mapping

Brain regions of interest for face perception were mapped using fMRI and intracerebral evoked related potentials (intracerebral ERPs) by contrasting responses to pictures of faces and objects (Allison et al., 1994; Bentin et al., 1996; Kanwisher et al., 1997). fMRI was performed 1 month after the SEEG exploration. No seizure occurred in 24 h before ERP recordings and fMRI procedure.

Intracerebral event-related potentials. The material consisted of 60 grayscale pictures of unknown faces and of 45 grayscale pictures of non-living objects extracted from the oral naming