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Intracerebral electrical stimulation of a face-selective area in the right inferior occipital cortex impairs individual face discrimination

Jacques Jonas [a,b,c,d,e,*], Bruno Rossion [e], Julien Krieg [b,c], Laurent Koessler [b,c], Sophie Colnat-Coulbois [d,f], Hervé Vespignani [a,b,c,d], Corentin Jacques [e], Jean-Pierre Vignal [a,b,c], Hélène Brissart [a], Louis Maillard [a,b,c,d]

[a] Service de Neurologie, Centre Hospitalier Universitaire de Nancy, 29 Avenue du Maréchal de Lattre de Tassigny, 54000 Nancy, France
[b] Université de Lorraine, CRAN, UMR 7039, Campus Sciences, Boulevard des Aiguillettes, 54500 Vandœuvre-lès-Nancy, France
[c] CNRS, CRAN, UMR 7039, Campus Sciences, Boulevard des Aiguillettes, 54500 Vandœuvre-lès-Nancy, France
[d] Faculté de Médecine de Nancy, Université de Lorraine, 9 Avenue de la Forêt de Haye, 54500 Vandœuvre-lès-Nancy, France
[e] Université Catholique de Louvain, 10 Place du Cardinal Mercier, 1348 Louvain-La-Neuve, Belgium
[f] Service de Neurochirurgie, Centre Hospitalier Universitaire de Nancy, 29 Avenue du Maréchal de Lattre de Tassigny, 54000 Nancy, France

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ABSTRACT

During intracerebral stimulation of the right inferior occipital cortex, a patient with refractory epilepsy was transiently impaired at discriminating two simultaneously presented photographs of unfamiliar faces. The critical electrode contact was located in the most posterior face-selective brain area of the human brain (right "occipital face area", rOFA) as shown both by low- (ERP) and high-frequency (gamma) electrophysiological responses as well as a face localizer in fMRI. At this electrode contact, periodic visual presentation of 6 different faces by second evoked a larger electrophysiological periodic response at 6 Hz than when the same face identity was repeated at the same rate. This intracerebral EEG repetition suppression effect was markedly reduced when face stimuli were presented upside-down, a manipulation that impairs individual face discrimination. These findings provide original evidence for a causal relationship between the face-selective right inferior occipital cortex and individual face discrimination, independently of long-term memory representations. More generally, they support the functional value of electrophysiological repetition suppression effects, indicating that these effects can be used as an index of a necessary neural representation of the changing stimulus property.

Introduction

One of the most impressive functions of the human brain is its ability to differentiate complex visual forms (DiCarlo and Cox, 2007). The human face constitutes the most familiar, socially relevant, and complex visual form, so that discriminating individual faces requires elaborate and refined perceptual skills called for by few other categories of objects. Despite the high similarity among faces and their complex configuration of several parts (eyes, nose, mouth, etc.), adults attain a high degree of proficiency with these skills. Yet, to date, the neural basis of individual face discrimination in the human brain remains by and large a mystery.

In humans, there is a large bilateral network of occipito-temporal areas responding preferentially to faces (i.e., face-selective areas), with right hemispheric dominance (e.g., Allison et al., 1994; Calder and Young, 2005; Haxby et al., 2000; Rossion et al., 2012a; Sergent et al., 1992; Weiner and Grill-Spector, 2010). To investigate sensitivity to individual faces of these areas, functional magnetic resonance imaging (fMRI) studies have taken advantage of the reduction of neural activity following repetition of the same stimulus (repetition suppression, also referred to fMR-adaptation or habituation; Grill-Spector and Malach, 2001; Grill-Spector et al., 2006). The rationale of this approach is that populations of neurons sensitive to differences between individual faces show a smaller response when the same face identity is repeated compared to the presentation of different face identities. Many fMRI studies have reported such decreases to individual face repetition in face-selective areas of the ventral occipito-temporal cortex (e.g., Gauthier et al., 2000; Grill-Spector and Malach, 2001; Andrews and Ewbank, 2004; Schiltz et al., 2006; Gilaie-Dotan and Malach, 2007; Davies-Thompson et al., 2009; Xu and Biederman, 2010; Ewbank et al., 2013). Multivariate pattern analyses of fMRI data have also identified various clusters of voxels in the ventral occipito-temporal cortex that are sensitive to individual faces (Goesaert and Op de Beeck, 2013; Kriegeskorte et al., 2007; Nestor et al., 2011). Taken together, the observations of these studies point to a distributed representation of individual face information in the ventral occipito-temporal cortex, with a right hemispheric advantage. However, the relationship between these effects – in particular the face identity repetition suppression effects in neuroimaging – and behavioral performance at individual face

* Corresponding author at: Service de Neurologie, Hôpital Central, Centre Hospitalier Universitaire de Nancy, 29 Avenue du Maréchal de Lattre de Tassigny, 54000 Nancy, France.
E-mail address: j.jonas@chu-nancy.fr (J. Jonas).

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discrimination remains unknown. Moreover, these neuroimaging studies are not in a position to clarify the extent to which these identified brain regions encode *critical* information for individual face discrimination behavior.

This question can be tackled with other approaches. For instance, studies of neuropsychological patients with prosopagnosia – typically impairment in face recognition following brain damage – suggest that multiple regions of the right ventral occipito-temporal cortex play an important role in individual face discrimination (e.g., Barton, 2008; Bouvier and Engel, 2006; Rossion et al., 2003; Sergent and Signoret, 1992). However, patients with acquired prosopagnosia usually have large cortical lesions (e.g., Barton, 2008; Busigny et al., 2010a) preventing firm conclusions to be drawn about the critical role of a given cortical area in this process. Transcranial magnetic stimulation (TMS) on the scalp above a right face-selective area of the lateral occipital cortex (right "occipital face area", "OFA") may also impair individual face discrimination (Pitcher et al., 2007). Yet, it is fair to say that the TMS disruptive effects on individual face discrimination are relatively small (e.g., Solomon-Harris et al., 2013) and not always observed (Pitcher et al., 2008). More generally, these effects are of limited localizing value because TMS cannot be applied to other face-selective areas of the ventral visual stream, and the TMS effects are not necessarily limited to the cortical area directly under the coil (Sack and Linden, 2003).

In a recent study, we reported a transient inability to recognize photographs of famous faces during intracerebral electrical stimulation of the right occipital cortex in an epileptic patient implanted with depth electrodes (Jonas et al., 2012). Since the stimulated area was located in the right OFA, this study provided evidence for a causal link between this face-selective area and face recognition (Jonas et al., 2012; see also Vignal et al., 2000 and Parvizi et al., 2012 for reports of a distortion of the physician's face following electrical stimulation of the prefrontal cortex and fusiform gyrus respectively). Here we report the results of a second intracerebral exploration performed a year later in the same patient (KV, Jonas et al., 2012). Since this second exploration also involved intracerebral electrodes in the right inferior occipital cortex, it provided a unique opportunity to test the causal link between the right OFA and behavioral individual face discrimination. To do so, we designed an experimental paradigm with unfamiliar rather than familiar faces during intracerebral stimulation, testing individual face discrimination independently from memory factors. To test the relationship between repetition suppression/adaptation effects and individual face discrimination behavior, we measured repetition suppression by means of a fast periodic visual stimulation (FPVS) paradigm with trains of either identical faces or different faces (Rossion and Boremanse, 2011; Rossion et al., 2012b). This approach has the advantage of providing high signal-to-noise ratio repetition suppression effects for face identity within a few minutes of stimulation, a factor that is particularly important in a clinical context with limited testing time.

Materials and methods

Case description

The patient is a 32-year-old right-handed female (KV) who has rare refractory right occipital epilepsy related to a focal cortical dysplasia involving the right inferior occipital gyrus. Her case was previously reported as evidence of a transient inability to recognize famous faces following intracerebral electrical stimulation of the right inferior occipital gyrus (Jonas et al., 2012). Because she was contraindicated to conventional resection based on this first stereo-electroencephalography (SEEG; Talairach and Bancaud, 1973), the patient underwent a second SEEG about a year later (December 2011) in order to perform radiofrequency-thermolesions of the epileptic focus (Catenoix et al., 2008). To date, the patient did not have surgery. All of the SEEG and behavioral data reported in the present paper study come from this second electrode implantation and have never been reported.

The patient never reported face recognition difficulties, between and during seizures and had preserved memory and preserved visual perception (including faces and objects), as shown by neuropsychological evaluations (Jonas et al., 2012). She gave written informed consent for this study, which was approved by the ethical committee of the Nancy University Hospital.

Intracerebral electrode placement and SEEG recordings

Stereotactic placement of 3 intracerebral electrodes, consisting of 8–11 contiguous contacts of 2 mm in length, separated by 1.5 mm, was performed according to a well-defined and previously described procedure (Maillard et al., 2009). Intracerebral EEG was recorded at a 512 kHz sampling rate with a 128 channel amplifier (2 SD LTM 64 Headbox; Micromed, Italy). The reference electrode was a prefrontal midline surface electrode (FPz). All three electrodes were placed in the right ventral occipito-temporal cortex (see Fig. 1). Electrodes D (8 contacts, D1 to D8) targeted the right ventral occipital cortex, from the lateral part of the inferior occipital gyrus to the posterior collateral sulcus. Electrode F (11 contacts, F1 to 11) was located more anteriorly in the ventral occipito-temporal junction, from the right inferior temporal gyrus to the lingual gyrus. Electrode L (8 contacts, L1 to L8) was located between electrodes D and F, also in the right occipital cortex but slightly above these electrodes. Note that this kind of electrode implantation is very rare in clinical practice, where most epileptic patients are implanted with more anterior electrodes to sample the temporal cortex.

Cortical stimulation: individual face discrimination task

Since typical clinical settings in SEEG do not allow performing a large number of electrical stimulations and the patient was only implanted with intracerebral electrodes during 3 days which were mainly dedicated to clinical investigations, we first identified the relevant electrode contacts for face processing, in order to test these contacts with a well-controlled individual discrimination task limited to the category of faces. Therefore, we first screened the effect of electrical stimulation on recognition of famous faces, scenes, and everyday objects, for most of the contacts (recognition task; Table 1). This allowed us to select relevant electrode contacts whose stimulation evoked perceptual or recognition disturbances specifically for faces (i.e., no recognition difficulties for visual scenes or object pictures). Then, we tested the effect of electrical stimulation on individual face discrimination only on these selected electrode contacts (individual face discrimination task; Table 1).

Stimuli

Pictures of unfamiliar faces of 48 Caucasian undergraduate students were used. Faces were cropped along the face contour, so that no hair or external cues were visible. All images were obtained under identical conditions (distance, lighting, position). Photo Morpher v3.10 (Morpheus, Santa Barbara, CA, USA) was used to create 48 morph continua by morphing each face with two other faces of the same sex. For each face, 300 points were placed on the critical features (i.e., pupils, iris, eye bulbs, eyelids, eyebrows, mouth, nose, and overall facial contour) to allow smooth transitions between the 11 stimuli defining each morph continuum (two original faces representing the extremes, with consecutive increments of 10%). For each of the continua, two stimuli that differed from each of the two original faces (0% and 100%) by 40% (i.e., 30% and 70%) were selected. We constructed pairs of stimuli that consisted of two identical faces (two 30% or two 70%) or two different faces (one 30% and one 70%) presented next to each other (Fig. 2). For each continuum, there were thus 3 kinds of trials ($3 \times 48 = 144$). Then, we constructed 28 sets of 5 pairs of photographs. Out of the 28 potential sets, the patient was eventually shown 13 sets (65 pairs) in total. In the majority of sets (11/13), there were three pairs of different faces and two pairs of identical faces. The size of the presented faces was 8 cm in height × 6 cm in width (roughly 8° × 6° at a distance of 60 cm).