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# **A tight relationship between BOLD fMRI activation/deactivation and increase/decrease in single neuron responses in human association cortex**

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# 1 **Abstract**

2 The relationship between Blood-Oxygen-Level-Dependent (BOLD) responses in  
3 functional magnetic resonance imaging (fMRI) and increases or decreases in neural  
4 firing rate across human brain regions, especially the association cortex, remains  
5 largely unknown. Here, we contrast direct measures of neuronal activity in two  
6 adjacent brain regions of the fusiform gyrus (FG) associated with fMRI increases  
7 (lateral FG portion) or decreases (medial FG portion) of the same category-selective  
8 neural activity. In both individual brains tested across multiple recording sessions, a  
9 frequency-tagging stimulation objectively identified a substantial proportion (about  
10 70%) of face-selective neurons. While single-units recorded in the lateral FG showed  
11 a selective increase to faces, neurons localized in the medial FG decreased spiking  
12 activity selectively to faces. Beyond a relative reduction to faces compared to non-  
13 face objects, about a third of single neurons found in the medial FG showed genuine  
14 suppression of baseline spiking activity upon presentation of a face. These  
15 observations clarify the nature of face-selective neural activity in the human brain,  
16 which can be expressed both as increases and active suppressions of spiking  
17 activity, and, more generally, shed light on the physiological basis of the fMRI signal.

## 18 Introduction

19 Functional magnetic resonance imaging (fMRI) has revolutionized our  
20 understanding of human brain function. While animal studies have characterized  
21 Blood-Oxygenation-Level-Dependent (BOLD) fMRI activation as a correlate of local  
22 synaptic activity (Logothetis et al., 2001; Bartolo et al., 2011), the cellular  
23 mechanisms of deactivation (negative BOLD signals) remain unknown. Since BOLD  
24 activity relies on contrasts between (two) conditions of interest, fMRI deactivations  
25 have been attributed to various causes, i.e., (relative) decreases in neuronal activity  
26 (Shmuel et al., 2006; Devor et al., 2008; Boorman et al., 2010), (relative) increases  
27 in neural activity (without concomitant compensation by cerebral blood flow (CBF)  
28 increase) (Schridde et al., 2008), or hemodynamic contributions (“blood stealing”;  
29 Harel et al., 2002). However, notwithstanding recent evidence of fMRI deactivation  
30 associated with electrocorticographic alpha power decrease in the human visual  
31 cortex (Fracasso et al., 2021), most studies have been carried out in animal models  
32 and primary sensory or motor regions. Therefore, the relationship between BOLD  
33 responses and increases or decreases in neuronal firing rate across human brain  
34 regions, especially the association cortex, remains unknown.

35 Here, thanks to a unique opportunity to record fMRI and spiking activity in  
36 neighboring populations of neurons of the same region of the association cortex, we  
37 shed light on the nature of the relationship between category-selective activity  
38 recorded at macroscopic and cellular scales. Specifically, two patients with refractory  
39 epilepsy (P1, P2) were implanted with hybrid macro-microelectrodes in their fusiform  
40 gyrus, a hominoid-specific cortical structure (Weiner and Zilles, 2016) that is critically  
41 involved in face recognition (Cohen et al., 2019). While microelectrodes recording  
42 single-unit activity located in the lateral portion of P1’s middle fusiform gyrus (MidFG)  
43 (i.e., in cytoarchitectonic area FG4; Lorenz et al., 2017), a region known to elicit  
44 larger BOLD activity to faces than non-face objects (‘Fusiform Face Area’, FFA;  
45 Kanwisher et al., 1997), in P2 they fell in the medial MidFG portion (FG3), in which  
46 lower BOLD responses to faces than objects are typically observed (Pelphrey et al.,  
47 2003; Kanwisher, 2017; Gao et al., 2018). By recording face-selective neural  
48 responses both in spiking activity and fMRI signals (independent sessions) in two  
49 neighboring regions of the same brains, we tested the hypothesis of a systematic  
50 relationship between the two types of signals. In particular, we hypothesized that

51 fMRI deactivations to faces were associated with a majority of face-selective  
52 decreases in spiking activity.

## 53 **Materials and Methods**

54 **Participants.** The study included two right-handed participants (aged 23 and  
55 46) who were patients undergoing clinical intracerebral evaluation with depth  
56 electrodes (SEEG; Talairach and Bancaud, 1973) for refractory partial epilepsy in the  
57 Epilepsy Unit of the University Hospital of Nancy, France in 2019 (P1) and 2023  
58 (P2). The participants gave written informed consent to participate to the study  
59 (REUNIE, 2015-A01951-48), which was approved by a national ethical committee  
60 (CPP Est III, N°16.02.01).

61 **Intracerebral recordings acquisition.** Electrophysiological data were  
62 recorded from Behnke-Fried hybrid micro-macro electrodes (Ad-Tech Medical  
63 Instrument). Intracerebral depth electrodes were stereotactically implanted within the  
64 participant's brains to delineate their seizure onset zone for clinical purposes.  
65 Electrode implantation sites were determined based on non-invasive data collected  
66 during the early stages of the investigation and were verified by CT-scan fused with  
67 a pre-operative T1-weighted MRI. The present report focuses on recordings from the  
68 macro-microelectrodes, i.e., electrodes with macro-contacts modified to include 8  
69 recording microwires and one reference, protruding about 3 to 4 mm beyond the tip  
70 of the macro-electrode (Ad-Tech Medical; see Salado et al., 2018 for details about  
71 the macroelectrode implantation procedure). The macro-microelectrodes targeted  
72 the right (P1) and the left (P2) MidFG. Although differential recordings in the same  
73 hemisphere(s) and individual brains would have been optimal, our results are  
74 unlikely to be due to differences between the two individuals or hemispheres  
75 reported, for two reasons. First, notwithstanding the right hemisphere's dominance in  
76 human face recognition (Jonas et al., 2016; Kanwisher, 2017; Gao et al., 2018), the  
77 same contrasted pattern of BOLD activation/deactivation for faces in the  
78 lateral/medial portions of the fusiform gyrus, respectively, has been systematically  
79 observed across hemispheres (Pelphrey et al., 2003; **Fig. 2**). Second, while a larger  
80 number of single-units were found for P1 than P2 recordings, the proportions of face-  
81 selective units did not differ between the two individuals.

82 The microwires signal was recorded at a 30 kHz sampling rate, using a 256-  
83 channel amplifier (BlackRock Microsystems), and recording activity was band-pass  
84 filtered (0.3-7500 Hz). Here we report microelectrode data recorded during 3 days (8  
85 sequences performed in P1) and 11 days (14 sequences performed in P2). These  
86 differences across participants were due to the clinical context in which the  
87 experiment took place. Participants were tested individually and seated at 80 cm  
88 from the computer screen.

89 **Microwires localization in the individual anatomy.** The exact position of  
90 each contact from the micro-macro electrode relative to the individual brain anatomy  
91 was determined in each participant's brain by coregistrating the post-operative CT-  
92 scan with a T1-weighted MRI of the patient. The microwires coordinates were  
93 estimated at approximately 4 mm from the tip of the macroelectrode. In addition, the  
94 location of microwires relative to fMRI-defined face-selective regions was determined  
95 by having all participants perform an fMRI face localizer a few months after the  
96 SEEG procedure, using an fMRI version of the frequency-tagging paradigm  
97 providing high SNR and reliability (Gao et al., 2018). After fMRI scanning, estimated  
98 microelectrode coordinates were rendered into the T1-weighted MRI co-registered  
99 and normalized to ACPC space with the functional Z-score map, using *MRicroGL* for  
100 visualization. The location of the microelectrodes was also defined in relation to the  
101 boundaries of the cytoarchitectonic areas FG2/FG4 and FG1/FG3 (Rosenke et al.,  
102 2017).

103 **Stimuli.** Stimuli were selected from a large pool of 200 to 218 non-face object  
104 images and 45 to 48 face images (as in e.g., Jonas et al., 2016), presented in  
105 grayscale or color sequences. Each image contained an unsegmented object or face  
106 near the center, varying significantly in size, viewpoint, lighting conditions, and  
107 background (**Fig. 1**). Images were equalized for mean pixel luminance and contrast,  
108 but low-level visual cues associated with the two categories (faces and objects)  
109 remained highly variable, naturally minimizing the contribution of low-level visual  
110 cues to the face-selective neural responses (Rossion et al., 2015).

111 **Face localizer paradigms.** A well-validated Fast Periodic Visual Stimulation  
112 (FPVS) face localizer paradigm was performed to define face-selective neural  
113 activity. Highly variable natural images of faces were embedded periodically within a

114 rapid 6 Hz stream of object images. In the fMRI version (from Gao et al., 2018; also,  
115 Laurent et al., 2023), mini-face blocks (“bursts”) were presented for 2.167 s every 9 s  
116 to account for the sluggishness of the BOLD response (i.e.,  $F = 1/9 = 0.111$  Hz).  
117 Each mini-block consisted of a set of seven face images alternated with six non-face  
118 object images to avoid category adaptation and maximize the contrast between  
119 faces and objects (**Fig. 1A**). Each fMRI sequence lasted 405 s and contained 44  
120 cycles of face bursts (including a 4.5 s baseline at both the beginning and end of  
121 each sequence, respectively). During intracerebral recordings, highly variable natural  
122 images of faces were inserted periodically every fifth image (i.e., face-selective  
123 frequency at  $1.2$  Hz =  $6/5$  Hz) as usually performed (**Fig. 1B**; Rossion et al., 2015;  
124 Jonas et al., 2016). A stimulation sequence lasted 70 s, including 66 s of stimulation  
125 at full contrast flanked by 2 s of fade-in and fade-out, with gradual increases and  
126 decreases in contrast, respectively. All images were presented with a sinusoidal  
127 stimulation contrast to provide a smooth transition between successive images.  
128 Participants were unaware of the periodicity of the faces. During both fMRI and  
129 intracerebral recordings, participants stared at a small black cross presented at the  
130 center of the stimuli and detected rare brief nonperiodic color changes (70-10 times  
131 per sequence for fMRI/iEEG respectively, for 500 ms) of the fixation cross (black to  
132 red). The experiments were conducted using Matlab for P1 and Java 8 for P2.

133 **Spike sorting.** Spike detection and clustering were carried out using an  
134 automatic algorithm, based on a Bayesian approach (Le Cam et al., 2023). The  
135 clusters were visually reviewed and classified into single-units (SU) and multi-units  
136 (MU) based on their spike shape, variance, inter-spike interval distribution, and the  
137 presence of a refractory period. Of all the sessions held by the two participants, 299  
138 SU and 62 MU were identified. Across all independent sessions (i.e., recorded on  
139 different half-days), 206 SU and 39 MU were retained for analyses. Signal  
140 processing and frequency-domain analyses were similar to previous SEEG studies  
141 (Jonas et al., 2016; Hagen et al., 2020). An average of 2 units per contact were  
142 isolated.

143 **Intracerebral recordings analyses.** Analyses were performed using the free  
144 software *Letswave 6*, running on MATLAB R2022a. A Fast Fourier Transform (FFT)  
145 was applied to the iEEG recordings, and the amplitude spectrum was cut into 1 Hz

146 segments centered on the face-selective frequency and its three additional  
147 harmonics (i.e., 1.2 Hz, 2.4 Hz, 3.6 Hz, and 4.8 Hz), as well as on the base  
148 stimulation frequency and its harmonics (i.e., 6 Hz, 12 Hz, and 24 Hz). The  
149 amplitude of these FFT segments was summed and transformed into a Z-score. Z-  
150 scores were computed as the difference between the amplitude at the target  
151 frequency bin and the mean amplitude of 20 surrounding bins (10 on each side)  
152 divided by the standard deviation of amplitudes in the corresponding 20 bins. SNR  
153 spectra were also calculated as the ratio between the amplitude at each frequency  
154 bin and the average of the corresponding 20 surrounding bins (11 on each side,  
155 excluding the 2 bins directly adjacent to the bin of interest). A cluster (SU or MU) was  
156 considered as showing a significant response for faces and classified as “face-  
157 selective” if the Z-score at the target frequency bin exceeded 1.64 (i.e.,  $p < 0.05$  one-  
158 tailed). In addition, face-selectivity was characterized at a more conservative  
159 threshold (i.e.,  $Z > 2.32$ ,  $p < 0.01$ ). To isolate face-selective responses from  
160 responses to non-face objects in the time domain (as in **Fig. 2C, F**), an FFT notch  
161 filter (filter width = 0.05 Hz) was then applied on the 70 s single or multi-units time-  
162 series to remove the general visual response at 6 Hz and two additional harmonics  
163 (i.e., 12 and 18 Hz). To account for the sinusoidal modulation of contrast, the face  
164 onset time was shifted forward by 33 ms ( $\sim 1/5$  of a 6 Hz cycle duration). This delay  
165 was estimated by comparing SEEG responses to sequences presented with  
166 sinewave or squarewave (i.e., abrupt) contrast modulation of visual stimulation. The  
167 onset of face-selective response was delayed by 30-35 ms for sinusoidal visual  
168 stimulation, which corresponds to 4 screen refresh frames (33 ms) and 35% of the  
169 full contrast. The spike trains of each identified cluster were then segmented into 1-s  
170 segments around face onset, and the resulting epochs were temporally smoothed  
171 (20 ms time-window) and averaged. The net average spike rate was calculated by  
172 subtracting each sequence's mean baseline spike rate in a [-0.166–0 s] time-window  
173 relative to face onset. Finally, the latency was computed as the time point at which  
174 net firing crossed the baseline  $\pm 2.58$  s.d. value (i.e.,  $p < 0.01$ , two-tailed percentile  
175 bootstrap) for at least 30 ms. as described in Jacques et al., 2022.

176 **FMRI acquisition.** The two participants were scanned at the CHRU-Nancy,  
177 with a 3T Siemens Magnetom Prisma system (Siemens Medical System, Erlangen,  
178 Germany) with a 64-channel head-neck coil. Anatomical images were collected



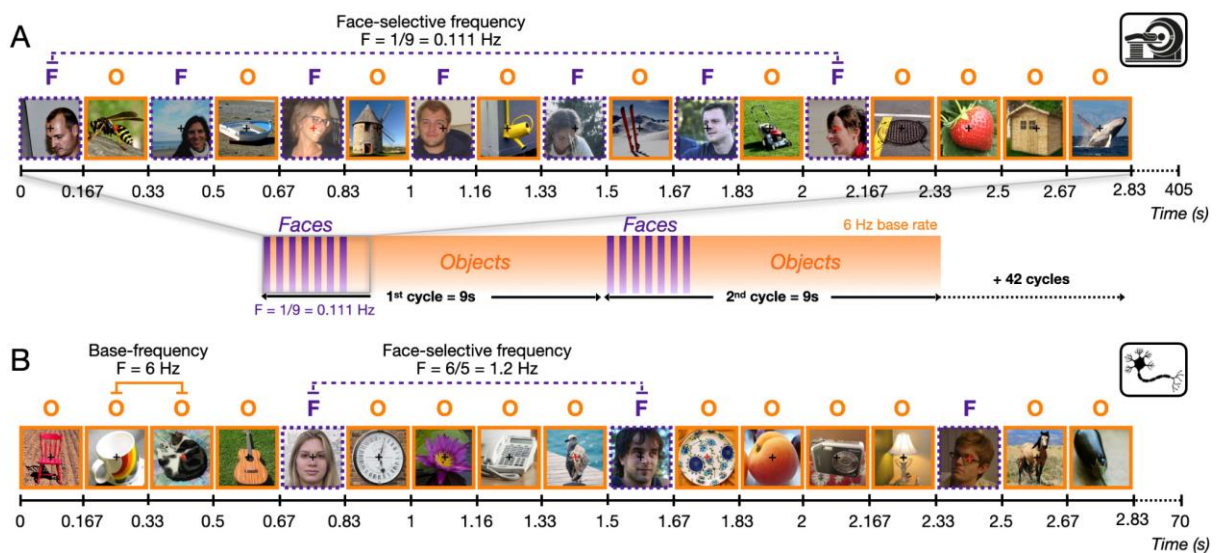
179 using a high-resolution T1-weighted magnetization-prepared gradient-echo image  
180 (MP-RAGE) sequence (192 sagittal slices, TR = 2300 ms, TE = 2.6 ms; flip angle  
181 (FA) = 9°, field of view (FOV) = 256 × 256). Functional images were collected with a  
182 T2\*-weighted simultaneous multi-slice echo planar imaging (SMS EPI) sequence  
183 (TR = 1500 ms, TE = 30 ms, FA = 72°, FOV= 240×240 mm<sup>2</sup>, voxel size = 2.5 mm  
184 isotropic, matrix size = 96×96 for sequences done in 2019 or matrix size = 80×80 for  
185 sequences done in 2022, interleaved), which acquired 44 oblique-axial slices  
186 covering the entire temporal and occipital lobes. The total duration of each sequence  
187 (run) for P1 (tested in 2019) was 333 s including 9 s of dummy scans (222 TRs). The  
188 total duration of each run for P2 (tested in 2022) was 405 s including 9 s of dummy  
189 scans (270 TRs). Images were back-projected onto a projection screen by an MRI-  
190 compatible LCD projector. The participants observed the sequences through a mirror  
191 placed within the FR head coil. The images subtended a viewing angle of 8° × 8°  
192 (33.4 cm × 33.4 cm) at a viewing distance of 240 cm. Three fMRI sequences were  
193 performed for each patient, who were scanned 6-8 weeks after the microelectrode  
194 recordings.

195 **fMRI analyses.** As in Laurent et al. (2023), the volumes of each run were first  
196 rigidly realigned with each other, and a mean functional image of the runs was  
197 computed for co-registration with the anatomical image, using *SPM12*. The volumes  
198 were also spatially smoothed with a Gaussian kernel of 2 mm (FWHM; i.e., full width  
199 at half maximum). The functional runs were averaged across runs in the volumetric  
200 space. Then, a Fourier analysis was performed using the FFT function in Matlab  
201 without windowing. The FFT was applied on the entire BOLD response time-course  
202 and the amplitude spectrum was directly derived from the Fourier transform  
203 coefficients. Amplitudes at the face stimulation frequency (i.e., at F = 0.111 Hz) were  
204 converted into Z-scores, using the mean and standard deviation of the amplitude at  
205 neighboring frequencies (see Gao et al., 2018 for details). The relative activations  
206 and deactivations of the neural responses at the face stimulation frequency were  
207 defined by the phase of the BOLD response. For each individual, the histogram (20  
208 bins) of phase values of all the voxels with a Z-score > 3.1 and with a positive phase  
209 value was calculated. The phase value of the histogram bin that has the largest  
210 number was used as the center phase ( $\varphi$ ) to define all the voxels with their phase  
211 values within  $\varphi \pm \pi/2$  as activations (+ sign) and voxels with their phase values

212 outside of this window as deactivations (– sign). These signs were then applied to Z-  
 213 score maps to obtain the final response map.

## 214 Results

215 In both MidFG regions sampled, robust differential activity to natural images of  
 216 faces vs. non-face categories was objectively recorded with a similar well-validated  
 217 frequency-tagging paradigm in fMRI (**Fig. 1A**) and microelectrode  
 218 electrophysiological recordings (**Fig. 1B**).

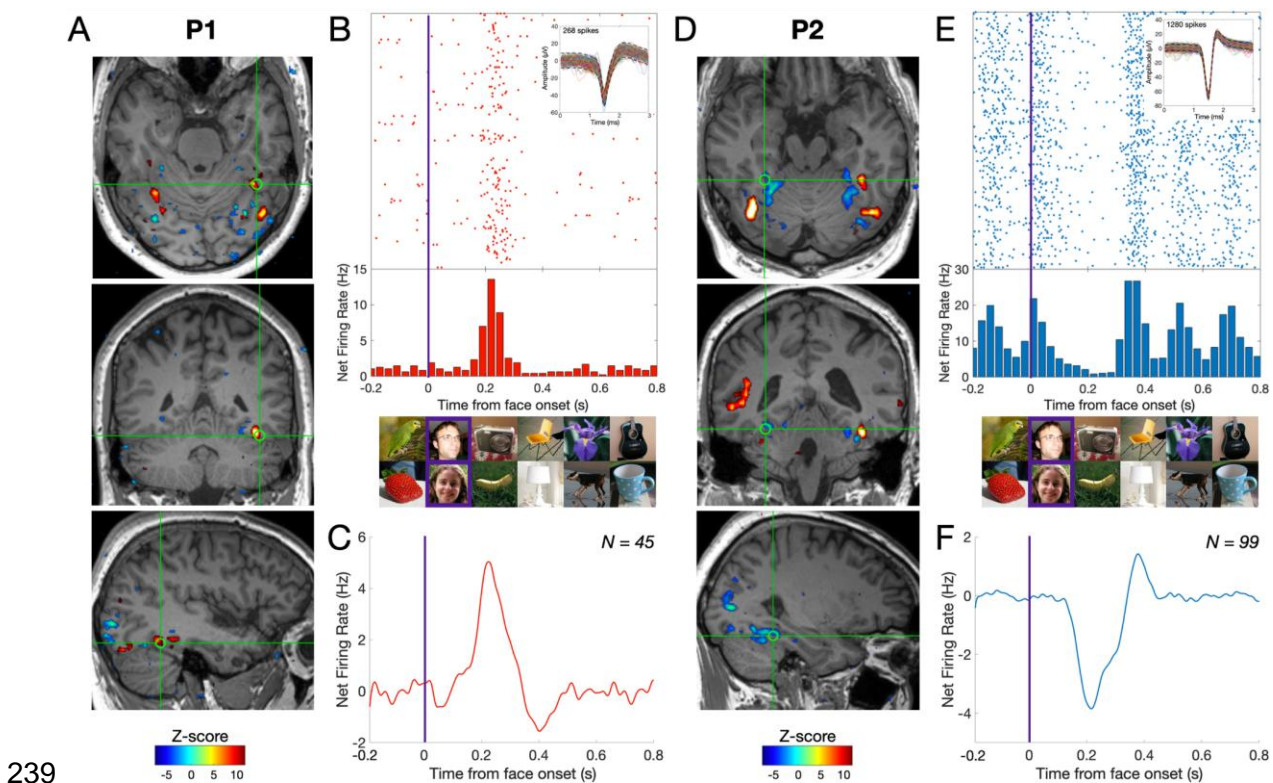


219

220 **Fig. 1. The frequency-tagging Face Localizer paradigm in fMRI (Gao et al., 2018) and**  
 221 **intracerebral electrophysiological recordings (Jonas et al., 2016).** In both cases, the same  
 222 variable natural non-face images alternate at a 6 Hz rate (1 fixation/image). **(A)** During a 405 s fMRI  
 223 run, a “mini-burst” of 7 images of variable faces (purple: “F”) alternating with 6 non-face object images  
 224 (orange: “O”) is presented every 9 s (0.111 Hz). A full run is composed of 44 cycles (3 s shown here).  
 225 **(B)** During intracerebral recordings, variable face images are inserted periodically every fifth image  
 226 (1.2 Hz). Each recording includes two 70-s stimulation sequences (3 s shown here). With both  
 227 recording methods (and EEG; Rossion et al., 2015), this paradigm provides robust population-level  
 228 face-selective activity devoid of low-level sensory confounds at the tagged frequencies. Here it is  
 229 applied to single and multi-unit recording activity in the human fusiform gyrus.

230 **FMRI category-selective responses**

231 **Fig. 2A and D** illustrate the category-selective regions identified with fMRI, on  
 232 axial, coronal, and sagittal slices in both participants ( $Z > 3.1$ ;  $p < 0.001$ ), relative to  
 233 the microelectrodes location. Fast Fourier Transform (FFT) of the BOLD response  
 234 time-courses is used to define face-selective voxels in the frequency-domain (0.111  
 235 Hz; Gao et al., 2018). BOLD frequency spectra at each voxel are transformed into Z-  
 236 scores, which can either be positive (higher response to face than non-face stimuli,  
 237 i.e., BOLD signal increase) or negative (lower response to faces than non-faces, i.e.,  
 238 BOLD signal decrease).



239

240 **Fig. 2. Relationship between BOLD signal and neuronal activity in the human MidFG. (A), (D)**  
 241 Significant face-selective activations (hot colors) and deactivations (cold colors) on axial, coronal, and  
 242 sagittal slices ( $Z > 3.1$ ;  $p < 0.001$ ). The estimated location of the microelectrode (green circle) falls in  
 243 left MidFG activation in P1 and right MidFG deactivation in P2. **(B), (E)** Representative raster plots of  
 244 two face-selective single-units (SU) showing activity increase in P1 and decrease in P2 to faces,  
 245 respectively. The representative face-selective SU in panel B also exhibits a high increase in firing  
 246 rate to the general visual stimulation at 6 Hz. Each line corresponds to a 1 s epoch time-locked to the  
 247 onset of a face (at 0 s), from a 140 s of recording. SU waveforms are shown in the upper-right  
 248 corners. **(C), (F)** Average time-courses of all face-selective SU identified ( $N = 45$  across 4 sessions in

249 P1,  $N = 99$  across 7 sessions in P2;  $Z > 2.32$ ,  $p < 0.01$ ), showing response increase to faces in P1  
250 and decrease to faces in P2.

251 As expected, faces elicited larger BOLD responses than non-face objects in  
252 the lateral MidFG, but lower responses in the medial MidFG (Pelphrey et al., 2003;  
253 Gao et al., 2018). Microwires in P1 (estimated Talairach location -40, -46, -19; **Fig.**  
254 **2A**) fell in the lateral MidFG face-selective region: the Fusiform Face Area (“FFA”,  
255 peak coordinate: -35, -51, -18) (Quiroga et al., 2023), while microwires in P2 (29, -  
256 41, -12; **Fig. 2D**) located in the medial MidFG, an unprecedented sampled region  
257 with lower (deactivated) BOLD signal for faces.

### 258 **Cellular category-selective responses**

259 Recordings of category-selective spiking activity in P1 and P2 took place over  
260 up to 11 days, with single-units detected on 7 microwires per session. Across all  
261 independent sessions (i.e., on different half-days), we recorded 245 units ( $N = 206$   
262 single-units, SU and  $N = 39$  multi-units, MU; pooled over 4 sessions for P1 and 7  
263 sessions for P2) firing to variable pictures of faces and objects. Following FFT,  
264 common visual responses to faces and objects were identified at the base frequency  
265 rate and harmonics (6, 12, and 18 Hz) while face-selective responses were  
266 measured at the specific face-stimulation frequency and harmonics (i.e., 1.2, 2.4,  
267 3.6, and 4.8 Hz; **Fig. 1B**) (Rossion et al., 2015; Jonas et al., 2016). Despite a brief  
268 recording time for each unit (2 sequences of 70 s), only a small proportion of single  
269 neurons failed to respond (i.e., no significant base rate response:  $N = 10/62$ , 16.1%  
270 in P1;  $N = 17/144$  11.8% in P2; all  $Z < 1.64$ , all  $p_s < 0.05$ ; no difference between  
271 participants,  $p = 0.54$ , Pearson’s  $\chi^2$ ). Among all visually responsive neurons, we  
272 found a very high proportion of face-selective neurons ( $p < 0.05$ ) in both activated  
273 and deactivated MidFG regions (P1: 98.1%;  $N = 51/52$ ; P2: 86.6%;  $N = 110/127$ ).  
274 Even at a more conservative threshold ( $p < 0.01$ ), strong face-selectivity is observed  
275 (P1: 86.5%;  $N = 45/52$  ; P2: 77.9%;  $N = 99/127$ ; no difference between the two  
276 individuals,  $p = 0.27$ , Pearson’s  $\chi^2$  test).

277 We then determined whether face-selective single neurons ( $p < 0.01$ )  
278 recorded in activated or deactivated face-selective regions exhibited different types  
279 of responses to faces relative to non-face objects. While a large majority of face-  
280 selective neurons in the lateral MidFG (P1) showed a significant relative increase in

281 spike rate to faces (88.9%;  $N = 40/45$ ; **Fig. 2B, C**), most neurons in the medial  
282 MidFG (P2) showed significant relative spike rate decrease to faces (95.9%;  $N =$   
283 95/99; **Fig. 2E, F**). While the mean onset response latency did not differ between  
284 increases and decreases (118.2 ms vs. 127.3 ms, respectively;  $p > 0.05$ , two-tailed  
285 percentile bootstrap; **Fig. 2C, F**), a significantly lower response (i.e., absolute  
286 average firing rate) was found for decreases than increases ([130-300 ms]; 3.69  
287 spikes/sec for increases, ranging from 0.99 to 7.42 spikes/sec; -2.73 spikes/sec for  
288 decreases, ranging from -0.44 to -9.67 spikes/sec;  $t$ -test  $p < 0.01$ ). A final noteworthy  
289 observation is that, among the 95 single-units showing a reduced firing rate to faces  
290 (P2), 34 lacked a significant general visual response (at 6 Hz; i.e., 34,3%;  $p < 0.05$ ).  
291 Beyond a mere relative reduction to faces compared to non-face objects, responses  
292 of such “face-exclusive” single neurons therefore appear to reflect genuine  
293 suppression of baseline spiking activity upon presentation of a face.

## 294 **Discussion**

295           Although BOLD signals correlate better with local field potentials (LFP) than  
296 spikes on a trial-by-trial basis (Logothetis et al., 2001), positive correlations have  
297 been observed between SU and BOLD in human (Mukamel et al., 2005; Nir et al.,  
298 2007) and non-human primates (Goense and Logothetis, 2008). Here thanks to a  
299 unique combination of fMRI and microelectrode recordings in the same individual  
300 human brains, we report a striking correspondence between increases/decreases in  
301 BOLD activity and (SU) neuronal firing, in two neighboring areas of the human  
302 association cortex. By showing that the sign of the BOLD signal fluctuation during  
303 visual stimulation matches the sign of SU activity, our findings shed light on the  
304 physiology of BOLD signals, revealing in particular that BOLD decreases can be due  
305 to relative, but also absolute, spike suppression in the human brain. Such transient  
306 spikes suppression could be due to suppression/reduction of synaptic inputs to the  
307 recorded neuron(s) or to inhibitory inputs to the neuron(s).

308           Up to now, the cellular basis of the relative BOLD decrease to faces in the  
309 medial portion of the fusiform gyrus, attributed to a smaller increase to faces relative  
310 to non-face objects or an absence of response to faces (Kanwisher, 2017), has  
311 remained somewhat of a mystery. Importantly, due to both the lack of a fusiform  
312 gyrus in non-hominoid primates (Weiner and Zilles, 2016) and of reported BOLD  
313 deactivation to faces in the monkey brain, single-unit recordings in macaque  
314 monkeys' face-selective cortical regions (Tsao et al., 2006; Bell et al., 2011) could  
315 not address this issue. Here, our neurophysiological recordings in humans suggest  
316 that faces do not only elicit a strong decrease of neuronal activity relative to non-face  
317 objects in the medial MidFG, but a genuine suppression of baseline spiking activity in  
318 a substantial proportion of the units recorded. Thus, beyond contributing to clarify the  
319 physiological basis of the fMRI signal, our study shed light on the nature of face-  
320 selective neural activity in the human brain, which can be expressed both as  
321 increase and active suppression of spiking activity. Inhibitory cellular activity is  
322 thought to play an important balancing role to maintain stable function of cortical  
323 circuits (Vogels et al., 2011), and has been shown to play a key role in cortical  
324 category-selectivity (Wang et al., 2000). Further direct recordings in the human

325 association cortex will be necessary to determine the functional relevance (i.e.,  
326 relationship to visual recognition behavior) and the cellular mechanisms (linked to  
327 cyto- and myelo-architecture; Lorenz et al., 2017) underlying these category-  
328 selective (excitatory and) inhibitory neuronal activities.

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