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Visual Field Influences Functional Connectivity Pattern in a Face Affect Recognition Task

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Abstract. We studied MEG responses in humans to centrally and peripherally presented face stimuli to test the hypothesis that different visual field locations may be associated with different types of processing, possibly utilizing different white matter pathways between striate and extrastriate areas. Functional and structural connectivity between V1/V2 and the fusiform area specializing for faces were examined using mutual information and diffusion tensor imaging. We observed distinct connectivity patterns when facial images were presented at the fovea or one of the quadrants and demonstrated early extrastriate activation leading striate activation for upper visual field stimulation.

Keywords: MEG; Connectivity; Face Processing; Fusiform; V1/V2; Mutual Information; Diffusion Tensor Imaging

1. Introduction

It is well established that visual stimuli presented in one part of the visual field are projected to the contralateral part of the visual cortex such that images presented in the right visual field are projected to the left visual cortex. It is however unclear whether stimuli presented in different parts of the visual field are processed differently in extrastriate areas and whether different white matter pathways between striate and extrastriate areas are involved when stimuli are presented to different quadrants. Here we studied MEG responses in humans to centrally and peripherally presented face stimuli to contrast the processing of faces when the images are presented at the center and periphery of the visual field.

2. Material and Methods

Seven healthy right-handed male subjects (mean age 32) participated in a face-affect recognition experiment in which they viewed stimuli of happy, fearful and neutral faces selected from Ekman and Friesen's Pictures of Facial Affect. We used a block design for presenting the images in different parts of the visual field: the images appeared at one of the five positions (center or quadrants) on the screen, fixed for each run. Each run consisted of 30 images. Each image was shown for 500 ms and one second later an option list of the emotions was shown for three seconds. Subjects named the emotion verbally as soon as the list appeared. Three runs for each of the five image positions were recorded. The run order was randomized and counter-balanced across subjects. Two baseline runs were also recorded for each subject, one before and one after the task runs. In these two control runs, subjects were in place with the same luminosity and fixation cross on the screen as in the task runs.

We recorded MEG signals using the CTF/VMS whole head 151-channel system. The MEG signal was recorded in epoch mode as a 5-second segment beginning from 500 ms before to 4.5 sec after each image onset. The recording was made with a low-pass filtering at 200 Hz and sampling at 625 Hz.

The MEG signal was filtered in the 3-200 Hz band. To capture early fast responses, we used a 200 Hz upper bound, considerably higher than that in most MEG and EEG studies of face processing. We used magnetic field tomography (MFT) [Ioannides et al., 1990], a non-linear distributed source method, to extract tomographic estimates of brain activity millisecond by millisecond from the MEG signal. We then used statistical parametric mapping (SPM) to identify brain areas and latencies when the activity was significantly different between task and control conditions. Finally, we examined functional and anatomic connectivity between brain regions using mutual information [Ioannides et al.,

2000] and white matter fiber tractography based on turboprop diffusion tensor imaging (DTI) [Arfanakis et al., 2005].

3. Results

Two brain areas showed most robust responses to face stimuli, namely, around the calcarine sulcus (V1/V2) and posterior fusiform gyri (FG). Fig. 1 compares these two regional activation time courses (ACVs) for images presented to the five positions. Each curve was computed from single trial ACVs along the main direction of the current density (J_1) and then averaged across trials and subjects. In agreement with our early results from averaged MEG signals [Liu and Ioannides, 2006], we found that both the V1/V2 and fusiform areas activated earlier (i.e. first peak latency) for peripheral than for central presentation. V1/V2 activity was significantly stronger for lower than central and upper visual field presentation. Fusiform activity, however, was significantly stronger for central than for peripheral presentation.

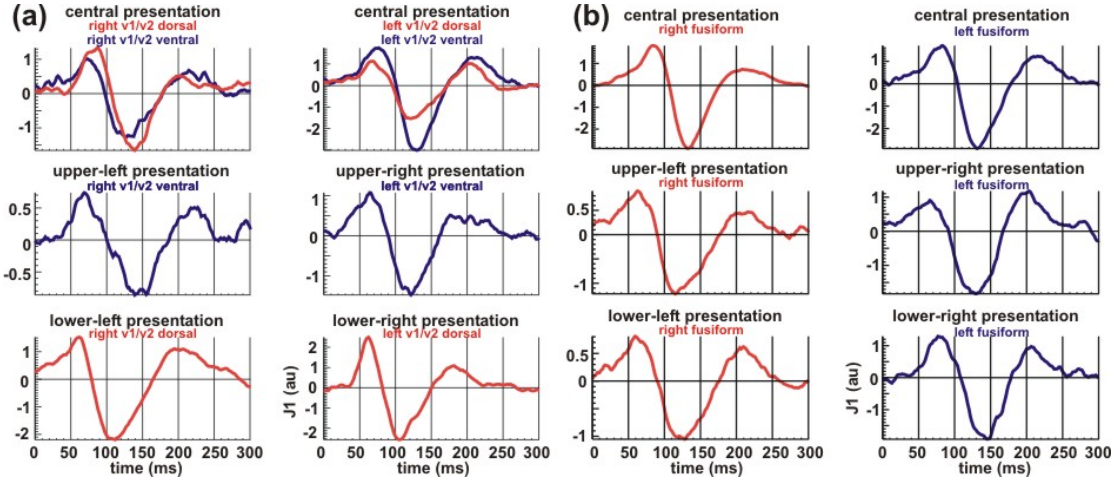

Figure 1. *Regional activation time courses obtained from the grand average of single trial time courses for (a) V1/V2 and (b) fusiform areas when images presented to the center (top rows), upper-left or –right (middle) and lower-left or –right (bottom). For central presentation, time courses for bi-hemishperic activations were shown, while for qudrant presentions, only activations in the hemisphere contralateral to the stimulation are displayed. Note the vertical scale is different for each figurine.*

Mutual information analysis further showed how activity between the two areas is linked (Fig. 2). The figure demonstrated linked activity from bilateral V1/V2 to fusiform for central presentation and from contralateral V1/V2 to fusiform for lower visual field presentation. In the upper visual field, the linkage was from fusiform to V1/V2 [Liu and Ioannides, 2006]. DTI analysis (for three subjects) identified putative connections between V1/V2 and fusiform areas (Fig. 3).

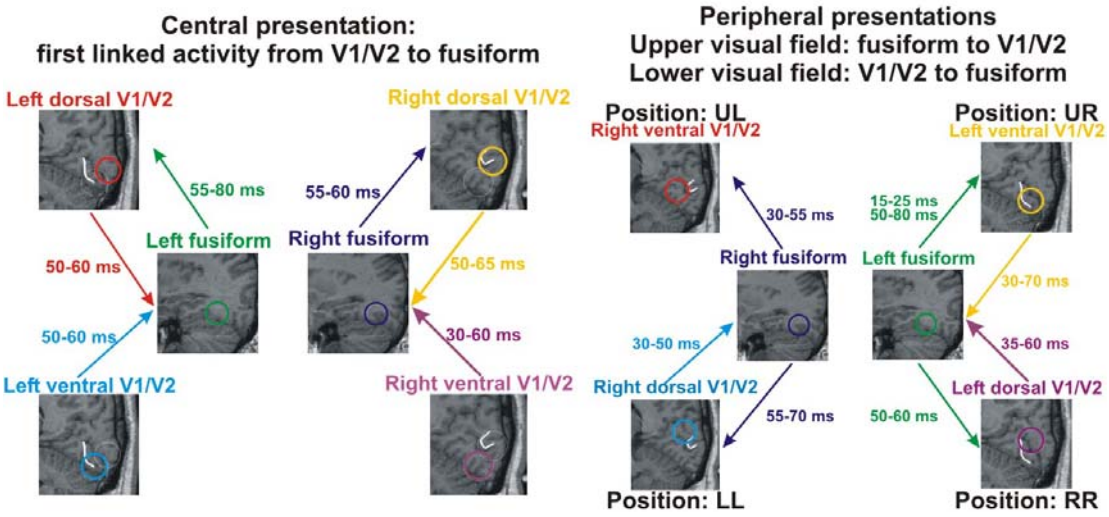

Figure 2. *Connectivity patterns between V1/V2 and fusiform areas for centrally and peripherally presented images obtained from seven subjects. Color circles indicate the areas and white outlines denote the V1/V2 border, with both supperimposed on one of the subjects' MRIs. For each link activity at each printed time range, an arrow points from the first to the second activated area.*

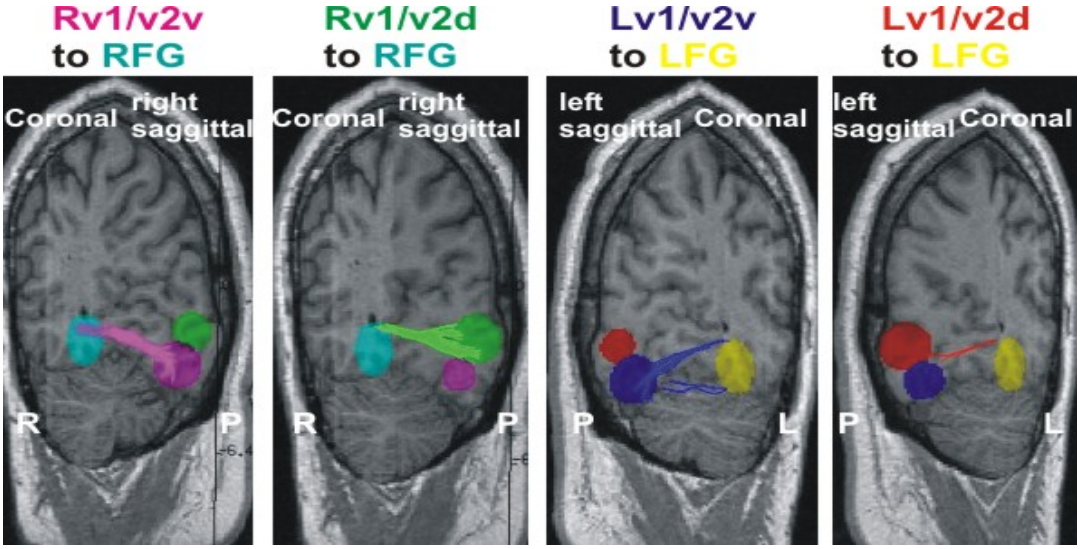

Figure 3. *DTI images showing connnection tracts from V1/V2 to fusiform area for centrally presented images for one of the subjects. Each figurine comprises a saggittal cut through the V1/V2 area and a coronal cut through the fusiform area. Color text and circles indicate the area, while color lines denote tracts.*

4. Discussions

In this MEG study, we examined the spatiotemporal and connectivity pattern differences between centrally and peripherally presented facial images. The results revealed a rather complex and dynamic relationship between the V1/V2 and FG activity and the location of the stimuli. FG activity was significantly stronger for central than for peripheral presentation (Fig. 1b). V1/V2 activity, however, was significantly stronger for lower than central and upper visual field stimulation (Fig. 1a). This suggested that the lower visual field input may dominate in the early cortical responses to hemi-field stimuli. The weaker activity elicited by centrally presented images may be due to the spread of activity over the lips of the calcarine operculum and the presence of radial components which produce no MEG signal. Furthermore, the present MEG study provides regional activation time courses in a millisecond scale, which would not be possible with fMRI. Both the V1/V2 and FG onset latency (first peak latency) was shorter for peripheral than for central presentation (Fig. 1). The above results are obtained from single trial analysis, specifically, we applied the MFT and SPM analyses to the single trial MEG signals, calculated the single trial ACVs and then averaged these ACVs across trials and subjects. The

results are in excellent agreement with results obtained MFT analysis of averaged signals, processed as below: MEG signal was averaged over trials and MFT was applied to the average signal; the average activation curve was extracted for each subject and the grand-average computed across subjects. This demonstrates that tomographic analysis of single trials does not "introduce" ghost images by amplifying noise in the signal. The dynamic changes identified in the single trial MFT solutions provide a window into the dynamic processing and interactions much of which is eliminated by averaging the signal first. We have been championing the case for single trial data analysis in a series of publications from our laboratory [Liu and Ioannides, 1996; Ioannides, 2001; Ioannides et al., 2002; Ioannides et al. 2005].

In our earlier MEG study using an object recognition task in which we used the same face sets as in the current study together with other 5 object categories (horse faces, birds, flowers chairs and lorries), we found the fusiform gyri were activated by all complex objects at roughly similar latencies. The much discussed face specificity was recovered around 130-150 ms after stimulus onset when statistical parametric mapping was performed between faces and other objects [Liu et al., 1999; Ioannides, 2001]. We further used mutual information analysis of single trial regional activations and showed that during the first 200 ms the computational load associated with the task of identifying objects was spread across different brain regions and in time through feedforward and feedback linkages coupling activity in V1/V2 and fusiform areas on the right. Only for faces, the processing was dominated by a feedforward link from V1/V2 (around 100 ms) and fusiform gyrus (around 150 ms). For other objects this feed-forward link was absent, replaced by a feedback link from the same fusiform activation (around 150 ms) leading to a reactivation of V1/V2 some 50 to 100 ms later [Ioannides et al., 2000; Ioannides, 2001]. These results were elaborated further in the current study using smaller image sizes and presentations at different parts of the visual field to study whether regional activations and connectivity patterns change systematically in the fovea and the four quadrants (Fig. 2). For central presentation, the linkage was from V1/V2 to FG. Lower visual field presentation also showed a linkage from V1/V2 to FG, but this was soon followed by feedback connections from FG to V1/V2. In comparison, for upper visual field presentation, the linkage was from FG to V1/V2, uni-directional for upper-left and bi-directional for upper-right presentation. Preliminary DTI analysis suggested putative white matter tracts connecting these two areas (Fig. 3).

Conversely, the upper visual field and the ventral system – V2, ventral posterior cortex (VP), V4 and inferotemporal cortex (IT), are better suited to search for and recognize objects, including faces, in extra-personal space. Our results showed the linked activity from FG to V1/V2 for the upper visual field stimulation. This suggested higher-order visual areas may be the first to pool spatial information across the whole visual field in the integrated model [Bullier, 2001]. Information arriving in the cortex from the magnocellular layers of the lateral geniculate nucleus is first sent and processed in the parietal cortex and then sent back by feedback connections to areas V1 and V2 that act as 'active blackboards' for the rest of the visual cortical areas. Our results suggest that in addition to the strong magnocellular input in the dorsal system, a ventral magnocellular pathway is excited by face stimuli in the upper visual field.

In our previous studies, limitations of computing resources force us to restrict the analysis to few key areas and rather narrow range of latencies. The availability of computing power and data storage now allows single trial computations over long periods and the detailed study of connectivity patterns across different spatial and temporal scales [Ioannides, 2007]. This promises to reveal how the specific task related networks are activated in the context of larger brain-wide networks during normal processing and how each is modified in pathology.

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