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Gamma activity modulated by naming of ambiguous and unambiguous images: Intracranial recording

Yoshimi Cho-Hisamoto [a,b,1], Katsuaki Kojima [a,1], Erik C. Brown [c], Naoyuki Matsuzaki [a], Eishi Asano [a,b,*]

[a] Department of Pediatrics, Children's Hospital of Michigan, Wayne State University, Detroit, MI 48201, USA
[b] Department of Neurology, Children's Hospital of Michigan, Wayne State University, Detroit, MI 48201, USA
[c] MD–PhD Program, Wayne State University, School of Medicine, Detroit, MI 48201, USA

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HIGHLIGHTS

- Ambiguous and unambiguous images differentially elicited cortical gamma-augmentation.
- Ambiguous image-specific activation involved frontal and parietal areas at >400 ms.
- We failed to replicate rapid top-down guess processing exerted by the orbitofrontal cortex.

ABSTRACT

Objective: Humans sometimes need to recognize objects based on vague and ambiguous silhouettes. Recognition of such images may require an intuitive guess. We determined the spatial–temporal characteristics of intracranially-recorded gamma activity (at 50–120 Hz) augmented differentially by naming of ambiguous and unambiguous images.
Methods: We studied 10 patients who underwent epilepsy surgery. Ambiguous and unambiguous images were presented during extraoperative electrocorticography recording, and patients were instructed to overtly name the object as it is first perceived.
Results: Both naming tasks were commonly associated with gamma-augmentation sequentially involving the occipital and occipital-temporal regions, bilaterally, within 200 ms after the onset of image presentation. Naming of ambiguous images elicited gamma-augmentation specifically involving portions of the inferior-frontal, orbitofrontal, and inferior-parietal regions at 400 ms and after. Unambiguous images were associated with more intense gamma-augmentation in portions of the occipital and occipital-temporal regions.
Conclusions: Frontal–parietal gamma-augmentation specific to ambiguous images may reflect the additional cortical processing involved in exerting intuitive guess. Occipital gamma-augmentation enhanced during naming of unambiguous images can be explained by visual processing of stimuli with richer detail.
Significance: Our results support the theoretical model that guessing processes in visual domain occur following the accumulation of sensory evidence resulting from the bottom-up processing in the occipital-temporal visual pathways.

1. Introduction

The ability to recognize a visually-presented object is included in the important brain functions to be preserved in epilepsy surgery. Previous studies of patients with epilepsy using electrocorticography (ECoG) showed that naming of 'realistically-drawn or photographic objects' elicited augmentation of gamma activity at >50 Hz, sequentially involving bilateral occipital, bilateral occipital-temporal, left inferior-frontal and bilateral Rolandic regions (Cervenka et al., 2013; Kojima et al., 2013a). A number of studies using functional MRI (fMRI) have demonstrated hemodynamic activation in the aforementioned regions during naming of such unambiguous images (Graves et al., 2007; Garn et al., 2009;

* Corresponding author. Address: Division of Pediatric Neurology, Children's Hospital of Michigan, Wayne State University, 3901 Beaubien St., Detroit, MI 48201, USA. Tel.: +1 313 745 5547; fax: +1 313 745 0955.
E-mail address: eishi@pet.wayne.edu (E. Asano).
[1] Y.C.H. and K.K. equally contributed to the study.

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Liljeström et al., 2009). Electrophysiological and hemodynamic activation in the occipital and occipital-temporal regions is likely to reflect cortical processing involved in perception and attentive analysis of visual stimuli (Mishkin and Ungerleider, 1982; Goodale and Milner, 1992), while that in the left inferior-frontal and bilateral Rolandic regions involved in semantic generation of relevant answers and overt articulation (Cervenka et al., 2013; Kojima et al., 2013a).

The first question to be addressed in this ECoG study regards *what cortical regions* would be activated commonly and differentially during naming of 'unambiguous' and 'ambiguous' images. In our daily life, we sometimes need to judge what an object really is based on a vague and ambiguous silhouette. Recognition of such an image may require an intuitive guess rather than a meticulous analysis of the visual stimuli. Previous fMRI studies suggested that cortical processing for such a guess may be mediated at least partially by frontal or parietal lobes, based on the observations that tasks involving recognition of ambiguous images elicited greater hemodynamic activation in the orbitofrontal, inferior-frontal and inferior-parietal regions (Bar et al., 2006; Eger et al., 2007). Taking into account that hemodynamic activation on fMRI is tightly correlated with augmentation of gamma-band activity but not slower activities (Niessing et al., 2005), we hypothesize that naming of 'ambiguous' images, compared to that of 'unambiguous' ones, would elicit more intense gamma-augmentation in these frontal and parietal regions in the present study.

The second question regards *when* gamma-augmentation specific to the naming of 'ambiguous' images would take place. Analysis of averaged signals on magnetoencephalography (MEG) suggested that 'a task required to recognize ambiguous images' elicited cortical activation (presumably reflected by current dipole sources) in the occipital poles at 100 ms, in the left orbitofrontal region at 130 ms, and in the ventral occipital-temporal regions at 180 ms; thus, inferring that 'top-down' initial guess is exerted by the orbitofrontal region 50 ms earlier than 'bottom-up' systematic visual analysis in the occipital-temporal region (Bar et al., 2006). Taken together with the observations in the aforementioned neuroimaging and neurophysiology studies, we tested the hypothesis that gamma-augmentation specific to 'ambiguous' images would involve the frontal-parietal regions (including the orbitofrontal cortex) earlier than the occipital-temporal regions, bilaterally.

Measurement of ECoG signals provides a unique opportunity to externally validate previous observations in non-invasive neurophysiology studies. ECoG signals are directly recorded from the ventral and medial surfaces of cerebral cortex with a spatial resolution of 1 cm (Nagasawa et al., 2011; Uematsu et al., 2013). The signal-to-noise ratio is 20 to >100 times better on ECoG compared to scalp EEG recording (Ball et al., 2009). Conversely, it remains unclear if MEG truly detects discernible activities generated by deeply located cortices (Wennberg et al., 2011). Magnetic fields produced by cerebral cortex generally decrease as a function of $1/\text{distance}^2$ from the MEG sensors. The orbitofrontal gyrus is inherently >3 cm away from all MEG sensors. Furthermore, the risk of inaccurate estimation of deep sources in noninvasive recording has been suggested (Wang and Gotman, 2001), whereas ECoG studies do not require an additional analytic process to estimate the source of cortical activation. We determined whether our ECoG analysis can provide the data concordant with a theoretical model that rapid top-down guess selection in the orbitofrontal cortex precedes the bottom-up processing in the occipital-temporal visual pathway (Bar et al., 2006). Such rapid orbitofrontal activation justifying their top-down facilitation theory, to our best knowledge, has not been rigorously investigated for replication by other investigators.

2. Methods

2.1. Patients

This study has been approved by the Institutional Review Board at Wayne State University. The inclusion criteria consisted of (i) patients with focal epilepsy who underwent extraoperative subdural ECoG recording as a part of presurgical evaluation in Children's Hospital of Michigan or Harper University Hospital in Detroit between December 2008 and November 2012; (ii) language mapping using measurement of gamma-augmentation elicited by naming of 'unambiguous' and 'ambiguous' images (Fig. 1); and (iii) written informed consent obtained by adult patients or the guardians of pediatric patients. The exclusion criterion consisted of structural lesion or seizure onset zone involving the occipital lobe. A total of 10 right-handed English-speaking patients satisfied the aforementioned criteria and were included in the present study (Table 1).

2.2. ECoG recording

Platinum macro-electrodes were surgically placed in the subdural space over the left, right, or bilateral cortical regions (intercontact distance: 10 mm; diameter: 4 mm; median: 112 electrode sites per patient [standard deviation: 23]). Placement of intracranial electrodes was clinically guided by the results of Phase-I presurgical evaluation, including scalp video-EEG recording, MRI, and 2-deoxy-2-[^{18}F]fluoro-D-glucose (FDG) positron emission tomography (PET) (Asano et al., 2009). All electrode plates were stitched to adjacent plates or the edge of dura mater, to avoid movement of subdural electrodes after intracranial implantation. In all patients, intraoperative photographs were taken with a digital camera before dural closure as well as after re-opening during the second stage of surgery. All electrodes were displayed on the three-dimensional brain surface reconstructed from high-resolution MRI, as previously described in detail (Alkonyi et al., 2009; Wu et al., 2011). We confirmed the spatial accuracy of electrode display on the three-dimensional brain surface by using intraoperative digital photographs (Wellmer et al., 2002; Dalal et al., 2008).

ECoG signals were recorded for 3–5 days with a sampling rate of 1000 Hz, using a 192-channel Nihon Kohden Neurofax 1100A Digital System (Nihon Kohden America Inc, Foothill Ranch, CA, USA). The averaged voltage of ECoG signals derived from the fifth and sixth intracranial electrodes on the amplifier was used as the original reference; ECoG signals were then re-montaged to a common average reference (Korzeniewska et al., 2011). Channels contaminated with large interictal epileptiform discharges or artifacts were visually identified and excluded from the average, in order to minimize their contamination on ECoG traces. Usage of a common average reference is a widely-accepted practice in assessment of event-related gamma-augmentation recorded on subdural grid electrodes; its advantages and limitations were previously discussed (Crone et al., 2001; Nagasawa et al., 2011). Electrooculography (EOG) electrodes were placed 2.5 cm below and 2.5 cm lateral to the left and right outer canthi. ECoG traces were visually inspected with a band-pass filter with low-frequency cut-off at 53 Hz and sensitivity of 20 μV/mm; thereby, irregular broadband signals synchronized with facial and ocular muscle activities seen on EOG electrodes were treated as artifacts (Otsubo et al., 2008; Jerbi et al., 2009; Kovach et al., 2011; Kojima et al., 2013a). Seizure onset was defined as a sustained rhythmic change on ECoG accompanied by subsequent clinically typical seizure activity, not explained by state changes, and clearly distinguished from background ECoG and interictal activity (Asano et al., 2009). Electrode