Epilepsy & Behavior 18 (2010) 254–261

Contents lists available at ScienceDirect

Epilepsy & Behavior

journal homepage: www.elsevier.com/locate/yebeh

Cortical gamma-oscillations modulated by visuomotor tasks: Intracranial recording in patients with epilepsy

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ARTICLE INFO

Article history:
Received 15 January 2010
Received in revised form 21 February 2010
Accepted 24 February 2010
Available online 23 May 2010

Keywords:
Video-EEG monitoring
Subdural ECoG recording
Pediatric epilepsy surgery
Event-related synchronization
Cross-modal spatial attention
Visual evoked potentials
Primary visual cortex
Primary motor cortex
Primary somatosensory cortex
Electrical stimulation

ABSTRACT

We determined how visuomotor tasks modulated gamma-oscillations on electrocorticography in epileptic patients who underwent epilepsy surgery. Each visual-cue consisted of either a sentence or hand gesture instructing the subject to press or not to press the button. Regardless of the recorded hemisphere, viewing sentence and gesture cues elicited gamma-augmentation sequentially in the lateral-polar occipital and inferior occipital-temporal areas; subsequently, button-press movement elicited gamma-augmentation in the Rolandic area. The magnitudes of gamma-augmentation in the Rolandic and inferior occipital-temporal areas were larger when the hand contralateral to the recorded hemisphere was used for motor responses. A double dissociation was found in the left inferior occipital-temporal cortex in one subject; the lateral portion had greater gamma-augmentation elicited by a sentence-cue, whereas the medial portion had greater gamma-augmentation elicited by a gesture-cue. The present study has increased our understanding of the physiology of the human visuomotor system.

1. Introduction

Movements of humans are frequently triggered by visual cues. A typical example of visually-cued movement is a driver's response according to a traffic signal or policeman's gesture. Visually-cued movement tasks have been used to localize the primary motor cortex in presurgical evaluation for patients with drug-resistant epilepsy. Previous studies using intracranial electrocorticography (ECoG) have shown that visually-cued motor tasks elicited augmentation of gamma-oscillations in the Rolandic area [1–5], and that the area showing such movement-related gamma-augmentation was highly concordant with the primary motor area proven by electrical neurostimulation [6]. It has been generally accepted that event-related gamma-oscillations can be treated as quantitative measures of cortical activation [7]. In short, augmentation of gamma-oscillations is considered to represent cortical activation [8–12], whereas attenuation of gamma-oscillations is considered to represent cortical deactivation [13–15]. The benefits of ECoG recording include: (i) minimal artifacts from cranial muscles [1], (ii) a better signal-to-noise ratio compared to scalp electroencephalography (EEG) and magnetoencephalography (MEG), which record cortical signals from outside of the scalp [16–18] and (iii) better temporal resolution compared to functional MRI (fMRI) [19].

Some ECoG studies showed that centrally-presented picture stimuli elicited gamma-augmentation sequentially in the lateral-polar occipital region and the inferior occipital-temporal region [15,20], but no motor task was simultaneously employed in these studies. It still remains uncertain how gamma-oscillations are modulated in the occipital and posterior temporal regions during '*visuomotor*' tasks. In the present study of patients whose ECoG sampling involved both the occipital, posterior temporal and Rolandic areas, we addressed three questions described below. (i) We first determined whether visuomotor tasks elicit gamma-augmentation sequentially in the lateral-polar occipital region (defined as the lateral-to-polar surface of Brodmann Area 17/18 [15]), the inferior occipital-temporal region (defined as the inferior surface of Brodmann Area 19/37) and the Rolandic area (i.e. the pre- and post-central gyri). (ii) We subsequently determined whether sentence- and gesture-cues differentially modulate gamma-oscillations in the occipital and posterior temporal regions during visuomotor tasks, and determined whether there was a *double dissociation* between the type of tasks and the location of gamma-modulation. (iii)

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1525-5050/$ – see front matter
doi:10.1016/j.yebeh.2010.02.015

Furthermore, we determined whether the laterality of motor responses affects gamma-modulation in the occipital and posterior temporal regions during a visuomotor task. Our recent study of auditory-motor tasks [21] demonstrated that the magnitude of gamma-augmentation in the superior temporal gyrus was larger when the hand contralateral to the recorded hemisphere needs to be used for motor responses, compared to when the ipsilateral hand does, and we hypothesize that a similar phenomenon can be seen during visuomotor tasks, too.

2. Methods

2.1. Patients

The inclusion criteria of the present study consisted of: (i) patients with focal epilepsy undergoing extraoperative subdural ECoG recording as a part of presurgical evaluation in Children's Hospital of Michigan, Detroit, between April 2007 and March 2009, (ii) completion of visuomotor tasks described below, and (iii) subdural electrodes chronically implanted on both pre- and post-central gyri at least 4 cm above the Sylvian fissure as well as at least on a portion of the lateral-polar occipital region (defined as the lateral-to-polar surface of Brodmann Area 17/18) or the inferior occipital-temporal region (defined as the inferior surface of Brodmann Area 19/37) [15]. The exclusion criteria consisted of: (i) the presence of massive brain malformations (such as large porencephaly, perisylvian polymicrogyria or hemimegalencephaly) which are known to confound the anatomical landmarks for the central sulcus or calcarine sulcus, (ii) history of previous epilepsy surgery, and (iii) the presence of epilepsia partialis continua. The study was approved by the Institutional Review Board at Wayne State University, and written informed consent was obtained from the parents or guardians of all subjects.

2.2. Subdural electrode placement and video-ECoG recording

For chronic extraoperative ECoG recording and subsequent functional cortical mapping, platinum grid electrodes (10 mm inter-contact distance, 4 mm diameter; Ad-tech, Racine, WI) were surgically implanted (Fig. S1 on the website) [22,23]. MRI including a T1-weighted spoiled gradient echo image as well as fluid-attenuated inversion recovery image was preoperatively obtained [24–26]. Using planar x-ray, images (lateral and anteroposterior) were acquired with the subdural electrodes in place for electrode localization on the brain surface [27–31]. A three-dimensional surface image was created with the location of electrodes directly defined on the brain surface [27,29,31].

Extraoperative video-ECoG recordings were obtained for 3 to 10 days, using a 192-channel Nihon Kohden Neurofax 1100A Digital System (Nihon Kohden America Inc, Foothill Ranch, CA, USA), as previously described [25,26]. For evaluation of interictal and ictal activities as well as event-related gamma-oscillations, the sampling rate was set at 1,000 Hz with the amplifier band pass at 0.08 - 300 Hz. Antiepileptic medications were discontinued or reduced during ECoG monitoring until a sufficient number of habitual seizures were captured.

2.3. Visuomotor tasks

2.3.1. Sentence-cue visuomotor tasks

None of the subjects had a seizure within two hours prior to the visuomotor tasks. Each subject was awake, unsedated, and comfortably seated on the bed in a dimly lit room. Each subject was instructed to press the button using the thumb when a sentence-cue saying “Press the button” was visually presented and not to press the button when one saying “Do not press” was presented (Fig. S2 on the website).

Each subject completed two sentence-cue visuomotor tasks (one for each hand); each task contained 40 trials, following a practice session prior to each task. Thereby, 20 sentence-cues saying “Press the button” and 20 saying “Do not press” were presented in a pseudorandom sequence during each task. Sentence-cues were presented using a 17-inch LCD computer monitor placed 60 cm in front of subjects. Sentence cues were binocularly presented at the center of the monitor, in grayscale, on the black background, for 1,500 msec with an inter-stimulus interval of 2,000 msec [15]. The reaction time was defined as the period between the onset of presentation of sentence-cue saying “Press the button” and the onset of button-press. We determined whether the mean or standard deviation (SD) of reaction time differed between the right and left hands or between the contralateral and ipsilateral hands (Wilcoxon-Signed Ranks Test). We also determined whether the reaction time was correlated with the age of subjects (Spearman's Rank Test).

2.3.2. Gesture-cue visuomotor tasks

Each subject subsequently completed two gesture-cue visuomotor tasks (one for each hand) following a practice session prior to each task, which contained 40 trials (20 to press and 20 not to press the button). Subjects were instructed to press the button using the thumb when a gesture of pressing the button was visually presented and not to press the button otherwise (Fig. S3 on the website). Otherwise, the task parameters were the same as those employed in the sentence-cue visuomotor task.

2.4. Measurement of ECoG amplitude modulations elicited by visuomotor tasks

Each ECoG trial was transformed into the time-frequency domain, and we determined ‘when’ and ‘where’ gamma-oscillations were modulated. The time-frequency analysis used in the present study was previously validated [32–35]. The measures of interest in the present study included a percent change of the amplitude of gamma-oscillations relative to that during the reference period (i.e. the resting baseline) as well as statistical significance of task-related augmentation of gamma-oscillations. Specifically, a percent change of amplitudes averaged across 50- to 150-Hz frequency bands was defined as ‘gamma-range amplitude’ in the present study [15,21,33]. The methodological details are described in the supplementary document on the website (Supplementary Document S1).

2.5. Assessment of the effect of laterality of motor responses on event-related gamma-augmentation

We determined whether the magnitude of gamma-augmentation in the ‘*visual sites*’ was different between when the hand contralateral to the sampled hemisphere was used for motor-responses and when the ipsilateral hand was used; thereby, ‘*visual sites*’ were defined as those in the lateral-polar occipital and inferior occipital-temporal regions showing significant gamma-augmentation elicted by either sentence- or gesture-cue visual stimuli. Using ECoG traces time-locked to the onset of motor responses [21], the maximum ‘gamma-range amplitude’ in each ‘*visual site*’ was compared between the contralateral and ipsilateral hands as well as between the left and right hands (Wilcoxon-Signed Ranks Test).

2.6. Delineation of ECoG data on three-dimensional MRI

ECoG data for each electrode channel were exported to the given electrode site on the individual three-dimensional brain surface in two different ways. In order to delineate *‘when’*, *‘where’* and *‘at what frequency band’* significant alteration of spectral amplitude occurred, time-frequency plot matrixes created above were placed onto a three-dimensional MRI at the cortical sites corresponding to their respective