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Electrocorticographic language mapping with a listening task consisting of alternating speech and music phrases

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HIGHLIGHTS

- A short listening task consisting of alternating speech and music phrases induces high gamma activity in classical language areas.
- ECoG language mapping using the discrimination between the speech and music phrases had a sensitivity of 0.32 and a specificity of 0.95 when compared to electrocortical stimulation mapping (ESM).
- This non-demanding listening task can therefore give a quick and reliable indication where to find critical language areas.

ABSTRACT

Objective: Electrocorticographic (ECoG) mapping of high gamma activity induced by language tasks has been proposed as a more patient friendly alternative for electrocortical stimulation mapping (ESM), the gold standard in pre-surgical language mapping of epilepsy patients. However, ECoG mapping often reveals more language areas than considered critical with ESM. We investigated if critical language areas can be identified with a listening task consisting of speech and music phrases.
Methods: Nine patients with implanted subdural grid electrodes listened to an audio fragment in which music and speech alternated. We analysed ECoG power in the 65–95 Hz band and obtained task-related activity patterns in electrodes over language areas. We compared the spatial distribution of sites that discriminated between listening to speech and music to ESM results using sensitivity and specificity calculations.
Results: Our listening task of alternating speech and music phrases had a low sensitivity (0.32) but a high specificity (0.95).
Conclusions: The high specificity indicates that this test does indeed point to areas that are critical to language processing.
Significance: Our test cannot replace ESM, but this short and simple task can give a reliable indication where to find critical language areas, better than ECoG mapping using language tasks alone.

1. Introduction

The goal in epilepsy surgery is to remove enough epileptogenic tissue to achieve seizure freedom without damaging important functional areas, such as language areas. The current gold standard for localizing critical language areas is electrocortical stimulation mapping (ESM). In ESM, the function in small patches of cortex is determined by running short trains of electrical pulses to temporarily impair execution of an appropriate task. The electrical currents are delivered directly to the cortex, either intraoperatively or

Abbreviations: ECoG, electrocorticography; ESM, electrocortical stimulation mapping; IFG, inferior frontal gyrus; MEG, magneto-encephalography; PCA, principal component analysis; STG, superior temporal gyrus.

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through implanted subdural grid- or depth electrodes in pre-surgical monitoring (Hamberger, 2007).

A disadvantage of ESM is that the electrical currents can induce seizures or afterdischarges, which often hinder further functional mapping. Moreover, ESM mapping of language is a time consuming (usually over one hour) and demanding procedure that requires good patient cooperation (Hamberger, 2007; Wu et al., 2010; Kojima et al., 2012).

It is therefore important to seek an alternative for ESM. Several studies investigated if recording language task related activity changes with electrocorticography (ECoG) is useful for localizing language areas. Different frequency bands have been explored, but most studies have focussed on high gamma activity between 50 and 200 Hz (Sinai et al., 2005; Brown et al., 2008; Towle et al., 2008; Wu et al., 2010; Miller et al., 2011; Kojima et al., 2012; Bauer et al., 2013; Arya et al., 2015). Activity in this frequency band appears to be the best indicator of task-related cortical activation, (Crone et al., 2001, 2006; Sinai et al., 2005; Wu et al., 2010; Miller et al., 2011; Kojima et al., 2012) because timing and spatial localization of high gamma seem more specific to timing and localization of functional brain activation than task related alpha and beta activity (Crone et al., 2006).

So far, ECoG high gamma analyses were not good enough to replace ESM, because they often reveal more language sites than found with ESM (Sinai et al., 2005; Brown et al., 2008; Towle et al., 2008; Wu et al., 2010; Kojima et al., 2012; Bauer et al., 2013; Arya et al., 2015). A suggested explanation for the observed mismatch is that ECoG measures of high gamma localize regions that are involved in language processing, whereas ESM is thought to only localize critical language areas (Towle et al., 2008; Wu et al., 2010; Arya et al., 2015).

The aim or our study was to improve the localization of critical language areas with ECoG measures of high gamma by contrasting language with music. Music and speech are both universal and we can all recognize the many similarities between music and speech. They are streams of sound with a rule-based structure, consisting of basic elements (tones and phonemes) that are built in higher hierarchical structures (melodies and songs, words and sentences) (Besson and Schön, 2001; Zatorre et al., 2002). But despite the many similarities, there are also obvious differences between speech and music. The contrast between these similar, but at the same time different stimuli might help to 'downsize' the ECoG language sites. This idea resembles the recommendation by Wu et al. who suggest that to discriminate between critical and non-critical language areas, patients need to perform multiple tasks and be presented with stimuli of different modalities (Wu et al., 2010).

In this study we addressed the following research question: can the accuracy of localizing critical language areas with ECoG measures of high gamma compared to ESM be improved by looking at differences in activity patterns induced by listening to speech and music?

To answer this question, we analysed the magnitude of high gamma (65–95 Hz) activity as recorded with implanted subdural grid electrodes while patients listened to an audio fragment in which speech and music phrases alternated. We determined the spatial distribution of the activity patterns in perisylvian electrodes and compared ECoG to ESM by calculating sensitivity and specificity.

2. Methods

2.1. Participants

We retrospectively included nine patients from a consecutive series who fulfilled the following inclusion criteria: (1) patients had medically refractory epilepsy and underwent subdural grid implantation in the University Medical Center in Utrecht for pre-surgical evaluation. Subdural grid electrodes covered completely or partly our region of interest (see Section 2.4); (2) patients had undergone ESM language mapping and had listened to the audio fragment during their stay at the intensive epilepsy monitoring unit; (3) patients had confirmed left sided or bilateral language localization with fMRI and/or Wada test. There were no in- or exclusion criteria regarding type of lesion or epilepsy. Approval of the institutional ethical committee was not indicated because of the retrospective character of this study, provided that data were coded and handled anonymously. All patients gave written, informed consent for analysing and publishing the data.

2.2. Listening task

The audio fragment consisted of a story about the life and work of the composer Joseph Haydn (1732–1809). Phrases of speech (male storytelling voice) and music (four different versions of Haydn's 'Die sieben letzten Worte unseres Erlösers am Kreuze') alternated four times. Duration of the speech phrases was 8–43.5–19–29 s (total: 99.5 s), duration of music phrases 27–27.5–28–29 (total: 111.5 s, orchestral, string quartet, piano and choir respectively). The task was presented using regular PC speakers adjusted to a comfortable hearing level. Patients were relaxed, and were not in an ictal or post-ictal state. They were only asked to listen; the clinical neurophysiologist who performed the test checked that they had paid attention to the test by asking some general questions afterwards.

2.3. Data acquisition and pre-processing

ECoG was performed using silastic grids and strips consisting of several rows of eight platinum electrodes, with 2.3 mm exposed diameter per electrode and an inter-electrode distance of 1 cm centre to centre (Ad-Tech, Racine, USA). Location of electrodes was determined using photographs taken during the implantation and with a post-implantation CT-scan. This CT was co-registered to a pre-implantation 3D MRI. Electrode artefacts were visualized on a rendering of the cortical surface using dedicated software (Noordmans et al., 2001).

Simultaneous ECoG and audio/video was recorded with a 128 channel video-EEG system (Micromed, Treviso, Italy) at a sampling frequency of 512 Hz using a hardware band pass filter of 0.15–134.4 Hz. Unipolar data were recorded using an extracranial reference electrode (G2) placed on the mastoid contralateral to the implantation. If common artefacts were present, the data were re-referenced to a relatively silent intracranial electrode overlying another silastic grid, remote from the region that was analysed. In case of remaining artefacts we chose an average reference.

The sound of the audio fragment was extracted from the audio of the video-EEG and added as an additional EEG channel for synchronization of the music and speech onsets. Given the video frame rate of 25 frames/s, this resulted in a synchronization accuracy of at best 40 ms. An example of the synchronized audio and ECoG channels is given in Supplementary Fig. S1.

2.4. Data analysis

For the purpose of our analysis we defined a region of interest in the perisylvian area where language function is expected: the superior temporal gyrus, the frontal operculum, the lower pre- and postcentral gyri and the supramarginal gyrus. Grid placement was guided by clinical information; not every patient had complete electrode coverage of this region of interest.