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Whole network, temporal and parietal lobe contributions to the earliest phases of language production

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We investigated whether it is possible to study the network dynamics and the anatomical regions involved in the earliest moments of picture naming by using invasive electroencephalogram (EEG) traces to predict naming errors. Four right-handed participants with focal epilepsy explored with extensive stereotactic implant montages that recorded temporal, parietal and occipital regions -in two patients of both hemispheres-named a total of 228 black and white pictures in three different sessions recorded in different days.

The subjects made errors that involved anomia and semantic dysphasia, which related to word frequency and not to visual complexity. Using different modalities of spectrum analysis and classification with a support vector machine (SVM) we could predict errors with rates that ranged from slightly above chance level to 100%, even in the preconscious phase, i.e., 100 msec after stimulus presentation. The highest rates were obtained using the gamma bands of all contact spectra without averaging, which implies a fine modulation of the neuronal activity at a network level. Despite no subset of nodes could match the whole set, rates close to the best prediction scores were obtained through the spectra of the temporal-parietal and temporal-occipital junction along with the temporal pole and hippocampus. When both hemispheres were explored nodes from the left side dominated in the best subsets. We argue that posterior temporal regions, especially of the dominant side, are involved very early, even in the preconscious phase (100 msec), in language production.

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1. Introduction

Information about how the speech production system works comes from many different sources—from the study of aphasic patients to brain imaging techniques (e.g., DeLeon et al., 2007; Dell, 1990; Fromkin, 1971; Garrett, 1980; Graves, Grabowski, Mehta, & Gordon, 2007; Hickok & Poeppel, 2007; Munding, Dubarry, & Alario, 2016; Wilson, Isenberg, & Hickok, 2009). This information has helped to delineate the spatiotemporal brain dynamics of how people produce language. (e.g., Blackford, Holcomb, Grainger, & Kuperberg, 2012; Costa, Strijkers, Martin, & Thierry, 2009; Laganaro and Perret, 2011; Strijkers & Costa, 2016). However, we are still far from having a complete understanding of the brain dynamics behind this unique human ability.

Here we explore the brain dynamics during speech production using invasive EEG (iEEG). Despite the advantages that this technique offers in terms of temporal and spatial resolution, few studies have made use of it to explore the brain dynamics involved in speech production (e.g., Cho-Hisamoto, Kojima, Brown, Matsuzaki, & Asano, 2015; Edwards et al., 2010; Hamamé, Alario, Llorens, Liégeois-Chauvel, & Trébuchon-Da Fonseca, 2014; Llorens, Trébuchon, Liégeois-Chauvel, & Alario, 2011; Martin, Millán, Knight, & Pasley, 2016; Tanji, Suzuki, Delorme, Shamoto, Nakasato, 2005). In particular, we study the neuroanatomical involvement of parietal, occipital and temporal structures during speech production by means of a picture naming task. We assess the iEEG of four patients implanted because of their intractable epilepsy. We focus on the brain indexes associated with failures to correctly name the pictures. That is, we compare the brain activity elicited by correct versus incorrect naming instances as a proxy for speech production processes. Hence, we assess when and where iEEG activity allows classifying correct versus incorrect responses, an approach so far not described in literature.

It is important to mention that instead of using grid electrodes, we explore patients with stereotactically implanted electrodes, which allows displaying the electrophysiological activity in a volumetric fashion. Moreover, Instead of relying on averaging repetitions like in ERPs studies, we decided to tap the differences between stereotactic-EEG (SEEG) traces before and after the stimulus presentation for predicting an event like in a brain-computer-interface approach.

To advance our results, we are able to distinguish between correct versus incorrect naming instances just a few milliseconds after the picture presentation and more than half a second before the actual patients' responses. This classification was achieved by assessing the activity of the gamma and beta bands. Furthermore, we were able to track which anatomical hubs are more sensitive to this classification—different sections of the temporal lobe at different times.

2. Patients and methods

This study was approved by The Clinical Research Ethical Committee of the Municipal Institute of Health Care (CEIC-IMAS). Patients were informed about the procedure and gave written consent before the experiment. For this study we selected four right-handed subjects with drug-resistant focal epilepsy who presented automotor seizures and an alteration of the language domain at the neuropsychological examination that spanned from none to moderate. All patients were Spaniards and fluent in Spanish. Two of them presented a right temporal lobe epilepsy (R1 and R2), the other two a left temporal lobe epilepsy (L1 and L2). In two cases, L2 and R1, there was an involvement of the mesial structures, while in the other two the seizure onset zone was located in the temporal posterior and basal regions (see Table 1 for more information). Patients were selected because of the extensive electrode coverage of the parietal, temporal and occipital regions. Two of the four subjects (L1 and R1) were explored in both hemispheres (see Fig. S1 of Section 9 for more information about the electrode position).

All recordings were performed using a standard clinical EEG system (XLTEK, subsidiary of Natus Medical) with a 500 Hz sampling rate. A uni- or bilateral implantation was performed using 12–16 intracerebral electrodes (Dixi Médical, Besançon, France; diameter: .8 mm; 5–15 contacts, 2 mm long, 1.5 mm apart) that were stereotactically inserted (thence the name stereotactic-EEG or SEEG) using robotic guidance (ROSA, Medtech Surgical, Inc). In all patients we recorded 126 channels (maximal amplifier allowance) and discarded the less informative contacts by visual inspection before the recording start. The decision to implant, the selection of the electrode targets and the implantation duration were entirely made on clinical grounds without reference to this research study.

Only patient R1 was recently intervened and has been seizure free for 4 months (Engel 1A). Patient L2 is currently seizure free 16 months after thermocoagulation. Patients L1 and R2 are awaiting surgery.

2.1. *Picture naming task*

In the picture-naming task participants were asked to name 228 pictures presented in three different blocks in two different days. Pictures were black and white line drawings of familiar objects from a wide range of semantic categories

Table 1 – Patients are divided in two groups, L1 and L2 with left temporal lobe epilepsy, R1 and R2 with right temporal lobe epilepsy.

Subject	Sex	Handedness	Electrodes (right)	Epilepsy onset zone	Reaction time (average ± SD ms)	Accuracy %	Anomia %	Semantic %
L1	Female	R	11 (4)	Left hippocampus and temporal cortex	952 ± 149	69	72	28
L2	Male	R	13	Left temporal cortex	888 ± 234	61	83	17
R1	Male	R	3 (9)	Right hippocampus	880 ± 140	93	83	17
R2	Male	R	0 (15)	Right temporal basal cortex	850 ± 113	94	50	50