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Bilateral frontotemporal neuronal dynamics during natural conversation: Single-neuron insights for BCI technologies

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Introduction: Recent neurotechnology advancements, particularly single-neuron recordings in humans, offer unprecedented insights into language processing at previously inaccessible spatiotemporal scales [1,2]. This study leverages bilateral single-neuron recordings from human frontotemporal cortices during natural dialogue to uncover cellular processes involved in language production and comprehension. By analyzing structural features of speech from word to sentence and dialogue levels, along with their temporal dynamics, we provide a unique perspective on language representation across cortical regions. These insights could help the development of advanced communication-restoring brain-computer interfaces (BCIs) and deepen our understanding of the neural basis of human communicative competence.

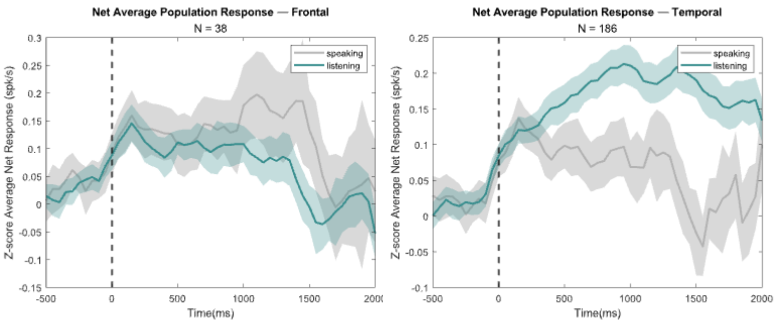

Figure 1: *Population response of frontotemporal neurons during speaking versus listening*

Material, Methods and Results: We conducted semi-chronic recordings from 251 neurons across both hemispheres in five participants implanted with Utah arrays in temporal (i.e., MTG, STG) and frontal (i.e., LPFC) regions. Participants engaged in natural conversations with familiar people (friends and family) and healthcare professionals (doctors, nurses, etc.) while we simultaneously recorded neural activity. Employing speech-tracking algorithms, we segmented dialogues into individual utterances and mapped them to specific linguistic constructs using natural language processing and word embedding techniques. We then identified neurons with selective responses to these constructs and modeled their ensemble activities. Our analysis revealed distinct neuronal populations in both hemispheres that selectively represented various aspects of language production and comprehension. The temporal lobe distinguished between speaking and listening, displaying greater activity during comprehension, while the frontal lobe exhibited comparable activity patterns in both comprehension and production (Fig.1). We observed dynamic transitions in neuronal activity patterns during turn-taking and identified neurons that encoded speaker identity. Notably, the activity patterns of these neurons demonstrated predictive capabilities for upcoming linguistic elements and conversational flow. Employing BERTopic to create dense topic clusters, we discovered that sentences within the same topic elicited highly similar neuronal responses, as measured by cosine similarity. In contrast, comparisons with no-topic sentences yielded lower similarity scores, indicating topic-specific neural representations together suggesting a rich representation of linguistic information at cellular scale.

Conclusion: This research provides new insights into the bilateral dynamics of language processing at the cellular level, illuminating linguistic and pragmatic components of human communication. By revealing some of the basic cellular building blocks underlying natural language processing, we offer a neuron-based framework for understanding communication disorders and a prospective platform for developing BCIs capable of decoding and generating natural language.

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