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Representation of syntax in intracortical inferior frontal gyrus signals

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Introduction: Brain-computer interfaces (BCIs) that decode speech have largely decoded phonemes and relied on large language models to form those into words and sentences. Forming words and sentences requires proper grammar, including syntax, both on word (tense, grammatical number, person) and sentence (subject/object/verb order) levels. Despite the critical role of syntax in natural language processing, electrophysiological evidence for its representation in the brain remains limited. Evoked responses in the inferior frontal gyrus (IFG), particularly in pars triangularis, showed some modulation with tense processing[1]. Imaging and lesion studies link IFG damage to deficits in syntax comprehension and agrammatism. However, the precise role of the IFG, especially pars opercularis, in syntactic processing remains unclear, including the specific type of processing involved and the extent of syntactic information represented at the neuronal scale. Decoding syntax directly from brain signals in the IFG could potentially improve BCIs by enabling more fluent and contextually appropriate sentence generation for individuals with impaired speech.

Materials, Methods, and Results: We recorded intracortical activity from a human participant as part of the Reconnecting the Hand and Arm to the Brain clinical trial. We recorded broadband (30 kHz sampling rate) signals with a 64-channel Utah array placed in caudal IFG (caudal border of pars opercularis). The participant silently read phrases, with missing verbs, displayed on a monitor at the start of each trial (phrase onset). After 2~2.5 s, the root verb was displayed on the screen (verb onset), and the participant determined how to conjugate the verb in agreement with the context of the phrase. After a go cue, the participant spoke the conjugated verb aloud. The task was designed to evaluate multiple types of syntax: different tense (present/past), person (first/second/third), number (singular/plural), and mood (imperative/indicative).

We analyzed a total of 1460 trials over 7 sessions. We extracted spike band power (300 Hz–1 kHz) and binned it at 100 ms. We observed that ~40% of the electrodes modulated prior to voice onset, while up to 20% modulated after voice onset. To decode each type of syntax, we built support vector machine decoders with a radial basis function kernel at multiple offsets between neural and task times. We used 10 causal bins of history as neural features, resulting in 520 features. We then computed principal components (PCs) of these features and used the first 25 PCs as inputs to the SVM decoder. We held out 30% of trials as a test set. We repeated the decoding procedure 30 times and compared the mean accuracy to the empirically shuffled (chance) accuracy distribution. We observed significantly above-chance decoding accuracy (~60%; $p<0.05$, permutation test) between verb and voice onset for tense decoding, and accuracy of 65% ($p<0.05$, permutation test) about 400 ms after phrase onset for person/mood (second imperative vs. third singular indicative) decoding.

Conclusion: These results suggest that caudal IFG may play a role in processing syntax for speech production. This information appears to occur at different times relative to the processing of the phrase context and to verb conjugation, depending on the aspect of syntax. This suggests that this area may be involved in multiple aspects of speech production. This could ultimately provide a useful input for a speech BCI.

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