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# Intracranial Measurements of Gamma Band Frequencies in Theory of Mind Cognition

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## Introduction

The Theory of Mind (ToM) refers to the ability to assign mental states to oneself and others. The development of this social cognitive ability is a major issue in people with Autism Spectrum Disorder (ASD). Although we understand what the impairment consists of on a psychological level, how and why this deficit manifests on a physiologic level remains elusive. Current treatment of the ASD remains primarily psychological with a heavy emphasis on behavioral therapy. A deeper understanding of the neurophysiologic mechanisms and neural networking in ToM cognition can bring us closer to adapting neuromodulatory advancements for the treatment of behavioral deficits in ASD.

The majority of physiologic research in ToM comes from neural imaging, namely fMRI. These fMRI studies point to the temporal parietal junction (TPJ), the medial prefrontal cortex (mPFC), and the anterior and posterior cingulate cortex (ACC/PCC) as primary components of ToM networking. The downfall of fMRI data is the poor spatial resolution. Intracranial electrocorticography (ECoG) has the ability of providing unrivalled temporal resolution of neurological data because the electrodes are recording directly from the surface of the brain. Due to the invasive nature of this approach, this is not a common way to obtain neural recordings of cognitive processes.

Here we intend to integrate the analysis of inter-personal behavior engaging ToM with analyses of oscillatory cortical activity taken intraoperatively. During our study, we obtained ECoG data during adapted classical ToM tasks from patients undergoing neurosurgical procedures for resections of tumors and seizure foci. These procedures already incorporate the use of ECoG electrodes and generally allow access to a large portion of exposed brain tissue. This presentation presents data and conclusions from 1 of the 4 subjects used in this study. We hypothesize that ECoG data taken during ToM tasks will allow us to increase the spatial and temporal resolution of gamma band frequencies in the TPJ associated with ToM cognition.

## Materials & Methods

The subjects for this study were patients undergoing intraoperative awake craniotomies for tumor and seizure foci. Three electrode strips were placed directly on the surface of the temporal parietal junction and local field potentials were recorded (Figure 1). To evaluate theory of mind recordings we verbally provided several short stories followed by questions from four different categories (Table 1). The first three represent theory of mind questions and the last acted as a control. These questions will be administered before and after surgical resections. We then evaluated the data for consistencies in neural activity in the TPJ region. The response time analyzed consisted of 1 second prior to the subject's response until 3 seconds after. Time-frequency data was taken from each type of question and analyzed as an average represented as time vs frequency spectral data (Figure 2).

| Introduction | Sarcasm question | Metaphor question | Simile question | Literal probe |
|---|---|---|---|---|
| George was daydreaming in class. His teacher asked him a question and he did not respond | The teacher walks up to George and says, 'George, it's lovely to see you paying attention.' *What does the teacher mean by this?* | George replies, 'I was on another planet.' *What does George mean by this?* | The teacher says to George, 'It's like you're wearing ear plugs.' *What does the teacher mean by this?* | George says, 'Sorry, I was not being a good student. I was daydreaming.' *What does George mean by this?* |

*Table 1. Example of the stem and questions used during the study.*

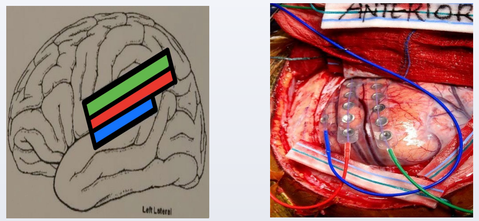


*Figure 1. Images represent anatomical and intraoperative electrode placements. Within each strip is individual electrode channels with lowest being most anterior.*

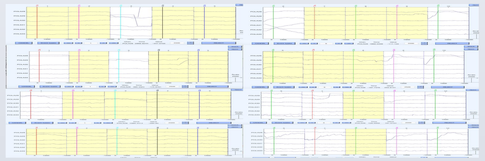

*Figure 2. Example of data from the blue electrode strip. Each row shows 6 channels that have 1 question type. Left shows 1.1α, 2.1α, 3.1 α 4.1α, and 5.1α that are answers to sarcasm questions from different prompts . Columns represent -1 to 3 seconds of response.*

## Results

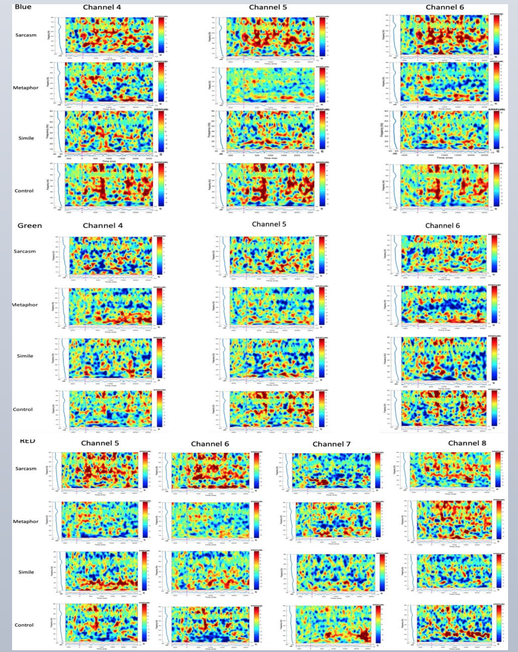


*Figure 3. Results of spectral analysis of frequency vs time data for TPJ relevant channels.*

## Discussion

TPJ is most accurately represented by blue electrodes 4-6 and red electrodes 5-8. During the response to the sarcasm prompt there are differences in gamma activity that are unique in frequency and time. As we looked at data further from this region, such as the green electrode strip, gamma activity was decreased or inconsistent. These findings are are likely representative of this region being associated with processing the perceptual view of someone else's motivation. Sarcasm is an ideal prompt for ToM cognition due to the obvious opposition of a literal prose. The findings where not consistent with our hypothesis in the categories of simile and metaphor likely due to the interpretation requiring additional associations. These associations may rely on the ability to recruit other neural pathways involved in associative knowledge and memory not accounted for in this concept.

One aspect to consider regarding information processing is integration of visual and auditory cues when forming a response. Although there is a bilateral response in field potentials of the TPJ with ToM tasks, consistencies between the two are thought to be stimulus dependent. An interesting study evaluated this by focusing on the differences of the left and right TPJ. The fMRI study done on congenitally blind subjects showed high neural pattern correlations to similar perceptual tasks remain unchanged in the right TPJ but the left TPJ demonstrated decreased similarities. (Koster-Hale 2014)

Limitations of this study include barriers with the population used and data analysis. By analyzing data using patients undergoing intracranial resections there were physical constraints. One of the problems was the fixed position required for the surgery made it difficult to communicate with patients and maintain their attention. Additionally, their intraoperative state led to complications such as nausea and drowsiness. These patients also may have not had ideal brain function due to their pathological states. Problems with data analysis arose with the equipment used. Consistent dulling of frequencies around the 60 Hz band can be seen due to mechanical frequencies in the operating room. The data acquired also had a low sampling rate which decreased the resolution of our data.

Future studies of ToM would benefit from using patients with implanted electrodes such as the ones used to monitor patients with severe epilepsy. These are ideal for this type of study because the implanted hardware contain large electrode grids with decreased artifact (Figure 4). This would also allow for more complex tasks including those with visual stimuli. Studies have also shown associations with frequencies in the high gamma range ( >80 Hz). Using higher sampling rates during acquisition would allow for a better resolution of high frequency data.

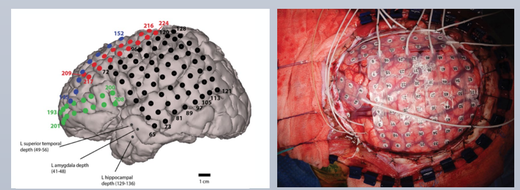


*Figure 4. Images represent an example of the large area accounted for by implanted intracranial electrode grids used on epilepsy patients (Nagahama 2018)*

A better understanding of the temporal and spatial frequencies involved in ToM cognition can lead to earlier diagnostic studies and interventions in patients with developmental disorders. Currently the diagnosis of autism is primarily based on behavior analysis and developmental delays. A better understanding of the neural deficits and patterns involved in these patients can allow for screening of high-risk patients. One possible therapeutic application is brain stimulation therapy. Once we have a better understanding of the location and types of frequencies involved, electromagnetic frequency stimulation may allow for the strengthening of these connections. This type of therapy has shown promising results in patients with severe depression.

## Conclusion

The findings of from the intraoperative ECoG recordings obtained in this study show promising results that call for future research that can match the temporal and spatial resolution of oscillatory cortical activity during theory of mind cognition. The spectral analysis obtained with intracranial data strengthens associations of gamma band frequencies and the TPJ being a critical component of the perceptual awareness of others motivation. Further research in this field can elucidate mechanisms that will lead to earlier neurophysiological diagnostic evaluations and therapeutic modalities of developmental disorders such as autism spectrum disorder.

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