Decoding Visual Narrative Processing: A Multimodal sEEG-Visual Signal Framework for Mapping Neural Dynamics

Yu Sun, MS[1], Fan Ma, PhD[1], Hua Xu, PhD[1]

[1]Yale University, New Haven, Connecticut, United States

Introduction

Despite growing interest in naturalistic neuroscience, the mechanisms by which **specific visual features shape large-scale brain connectivity** remain insufficiently understood. Prior studies have demonstrated that movie stimuli can evoke distinct neural responses, with intracranial sEEG amplitude fluctuations reflecting shifts in narrative and emotional content[1]. Yet, the **direct correspondence between dynamic visual input and directional patterns of neural interaction** has not been fully characterized. In this study, we introduce a data-driven pipeline to extract consistent **directional relationships** from trial-based sEEG recordings. Our findings reveal that the **occipital and temporal cortices**—regions central to visual and semantic processing—**consistently engage in synchronized, directional interactions** in response to visual narrative stimuli, highlighting their pivotal role in integrating sensory and contextual information.

Objectives

This study aims to characterize how visual narrative stimuli shape directional brain connectivity by analyzing intracranial sEEG recordings collected during naturalistic movie viewing. Specifically, we sought to identify consistent, trial-independent directional relationships among cortical regions and to determine how these interactions—particularly between the occipital and temporal cortices—reflect neural synchronization and polarity shifts associated with dynamic visual and emotional features of the narrative.

Methodology

Preprocessing steps (per subject and trial):

- Remove pauses from the raw signal.
- Downsample data to 1 Hz by averaging every 2048 raw samples.
- Crop each trial to the valid stimulus interval.

Event detection:

- Within each electrode's time series, identify high-amplitude excursions (top and bottom 3 values per trial).

Temporal reference:

- Use Electrode 0 as the reference point—its peak activity defines the candidate event window for other electrodes in the same trial.

Directional pair construction:

- Compare the relative timing of extreme values across electrodes.
- Create a directed pair (A → B) when electrode A's extreme precedes electrode B's extreme.

Reproducibility filter:

- Retain only those directional pairs that appear consistently across all trials for a given subject.
- The result is a robust set of reproducible functional linkages between cortical sites.

Graph construction:

- Modeled directional relationships as a graph where:
  - Nodes = cortical regions (based on electrode localization).
  - Edges = stable directional connections between region pairs.

Network analysis:

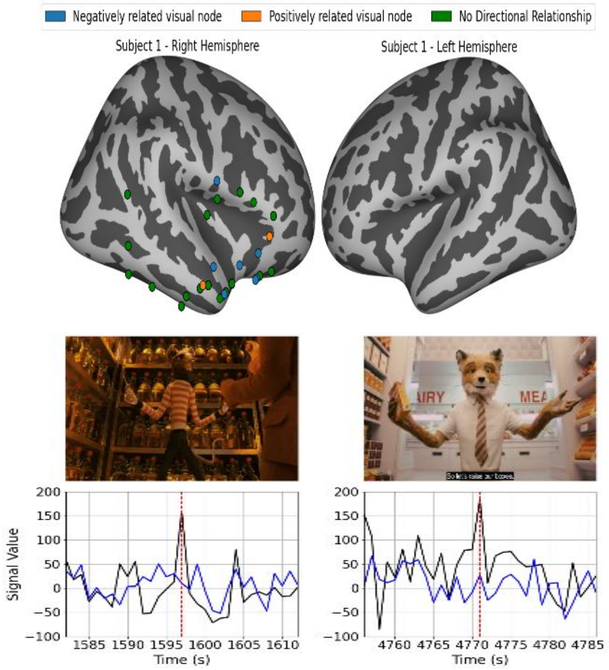
- Applied Weakly Connected Component (WCC) analysis to identify subnetworks of regions showing recurrent directional influence.
- Components captured regions with shared temporal ordering but not necessarily cyclic connectivity.

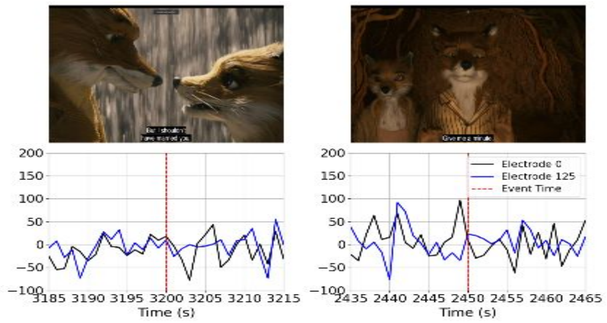
Activation characterization:

- Each component was assigned a net activation sign (positive or negative) based on the predominant polarity of extreme signal values within that region group.
- This reflected excitatory-like (positive) or inhibitory-like (negative) dominance during stimulus processing.

Interpretation:

- The component-based structure highlighted clusters of coherently activated regions following temporal order.
- Across participants, the occipital and temporal cortices consistently emerged as key hubs within these directional networks.
- These findings underscore their synchronized engagement during visual narrative processing.





Result

Overall finding:

- Across participants, sEEG amplitude fluctuations closely aligned with dynamic narrative events, serving as neural markers of story-driven engagement.
- Aggregated analyses revealed reproducible directional synchronization across subjects—most prominently in the occipital, temporal, and limbic regions.
- These regions showed temporally ordered activations that intensified during emotionally salient or visually complex scenes.
- Findings suggest that distributed cortical networks jointly encode shifts in visual attention and emotional salience throughout the movie.

Figure 1a – Directional network visualization:

- Displays a representative subject's directional relationships among electrode clusters.
- Highlights how distinct cortical groups synchronize during pivotal narrative moments.
- Shows directional coupling peaking at dramatic plot junctures.
- Bidirectional interplay between visual signal features and node-specific activations revealed alternating positive and negative relationships, reflecting the balance between excitatory and inhibitory cortical states.

Figure 1b – Narrative context comparison:

- Compares two cinematic frames:
  - Left: Emotional climax → heightened, synchronized neural activation.
  - Right: Neutral segment → lower amplitude and reduced coordination.
- Demonstrates that temporal coordination and polarity shifts were consistent across participants, confirming robustness of the observed neural dynamics.

Interpretation:

- Intracranial sEEG activity systematically tracks emotional and cognitive contours of the narrative.
- Results highlight how the human brain dynamically orchestrates engagement with complex visual storytelling.

Discussion & Future Work

Key findings:

- Robust occipito-temporal interactions were observed during narrative engagement.
- These interactions reveal how visual information and emotional salience are dynamically integrated in the human brain.
- Across participants, directional coupling between occipital and temporal cortices aligned with narrative transitions, showing coordinated interplay between early visual processing and higher-order semantic interpretation.
- Results extend models of naturalistic visual processing, demonstrating that directional sEEG patterns can track shifts in plot intensity and emotional resonance in real time.

Mechanistic interpretation:

- Polarity shifts (occipital positivity, temporal negativity) suggest mechanisms for salience prioritization and contextual feedback.
- These findings align with predictive coding frameworks, where:
  - Occipital regions encode sensory evidence for upcoming visual events.
  - Temporal regions generate top-down predictions guiding perception and emotional appraisal.
- The bidirectional exchange between these regions supports a hierarchical feedback loop for adaptive cognition during complex narratives.

Future directions:

- Conduct larger, multimodal studies integrating sEEG with eye tracking, physiological markers, and deep-learning-based visual feature extraction.
- Extend analyses to non-invasive modalities (EEG, fMRI) to assess generalizability of observed connectivity patterns.
- Develop computational models linking directional brain dynamics with behavioral and perceptual measures to clarify how predictive feedback and emotional salience shape naturalistic cognition.

Reference

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