Establishing the Directionality of Information Flow in Transient Networks Facilitating Episodic Memory Processes

Emma Gibbens, Class of 2025

Across a myriad of neurological and psychiatric disorders, cognitive deficits feature prominently and are often difficult to treat. To facilitate the development of diagnostic tools and therapeutic interventions for these cognitive deficits, a deeper understanding of the communication between the neural sources that facilitate complex cognitive processes, including memory processes, is required.

Memory tasks are complex cognitive processes that require coordination between various brain regions. Episodic memory specifically is the retrieval of information about personal experiences. Another essential element of memory processing, post-retrieval monitoring, is a type of cognitive control of memory that requires the evaluation of the quality of the memory retrieved with respect to its relevance to the task at hand. While parietal and prefrontal cortex activation is observed for both processes, more prefrontal cortex activation is observed when greater cognitive control of memory is required. Specifically, the dorsolateral prefrontal cortex (dlPFC), inferior parietal cortex (IPC), and hippocampus have all been implicated in the process of post-retrieval monitoring. Functional magnetic resonance imaging (fMRI) studies have shown a greater activation of the right dlPFC in tasks requiring post-retrieval monitoring (Henson et al., 2000), while the left IPC is believed to integrate information coming from the hippocampus and compare that information with task criteria (Simons & Mayes, 2008). The study this summer sought to elucidate how these areas are communicating with each other.

To perform high-level cognitive tasks, multiple brain regions communicate through temporary functional neural networks. These networks are generated from neural oscillations, which allow for synchronized and phased firing of distant brain regions simultaneously. Oscillations at theta frequency (4-8 Hz) in particular have been implicated in various memory processes. Although prior studies have examined oscillations in post-retrieval monitoring, they've used correlational metrics which don't provide information about directionality. Previous investigations of directionality have revealed substantive differences in how information flows between areas depending on the direction of flow. For example, one study investigating the bidirectional flow between the hippocampus and prefrontal cortex facilitating verbal episodic memory processes found that hippocampus to prefrontal cortex flow occurred in the delta-theta band (0.5-8 Hz) and was stronger than flow in the reverse direction, which occurred in the beta band (12-30 Hz; Das & Menon, 2021). Thus, establishing the directionality of the flow is significant for a complete understanding of information flow, elucidating the differences between the feedforward and feedback mechanisms within the memory process. Unfortunately, that previous directionality research didn't investigate post-retrieval monitoring. As such, we sought to employ similar metrics of directionality to further elucidate the underlying neural networks supporting post-retrieval monitoring.

Electroencephalography (EEG) is a uniquely useful neuroimaging tool as it allows for direct measurement of signals originating from the brain, non-invasively, and almost instantaneously through electrodes interfacing with the subject's scalp. With the use of EEG, improved electrode localization techniques, and Granger causality analysis, we investigated where and when information is flowing in the brain during a verbal memory retrieval task. We hypothesized that there is directed flow of information at theta frequency from the left IPC to the right DLPFC during post-retrieval monitoring in episodic memory. EEG was measured from 12 participants while they conducted a verbal episodic memory task requiring post-retrieval monitoring. Because EEG is measured at the scalp level, 3D head images depicting the positions of the electrodes on each participant were also captured. By identifying precisely where the electrodes are placed, the signals observed at the scalp level are better able to be traced to their underlying neural sources. Additionally, a complementary project this summer sought to update and revise a manuscript currently being prepared for submission that improves the data analysis methods for this study. This previous study provides recommendations for other researchers employing directionality metrics and informs us of the appropriate pre-processing steps that will help protect against the identification of spurious connectivity. After pre-processing the data with these optimized methods, connectivity analysis will be conducted using a measure derived from Granger causality, which allows for the identification of causal interactions from time-series data (Seth et al., 2015). Higher Granger causality values in the left IPC → right DLPFC direction than the right DLPFC → left IPC direction would validate left IPC to right DLPFC information flow during post-retrieval monitoring. Data collection and analysis will be continued throughout the next academic year with my honors project in Neuroscience. Ultimately, should this research be successful, it could aid in the development of diagnostic tools in those mental illnesses that exhibit disruptions in oscillatory dynamics.

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