Directional Flow of Information During Memory Retrieval
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Throughout this past summer, our project focused on identifying the direction of information flow during memory retrieval. Disruptions in oscillatory dynamics have been linked to many neurological and psychiatric disorders such as anxiety, depression, and schizophrenia (Basar & Guntekin, 2008; Uhlhaas & Singer, 2006). Gaining a better understanding of the mechanism through which these neural networks function and the directionality of these oscillatory dynamics could lead to the development of better diagnostic tools and treatments for neurological disorders.

To investigate the direction of information flow during memory retrieval, we focused on episodic source memory. Episodic memory is a form of long-term memory in which someone can explicitly describe an event and tell it with context. Within episodic memory, there is item and source memory. Item memory is like the 'what' (ex. Have I seen the person before?). Source memory, on the other hand, is like the 'where' (ex. Where have I seen this person before? How did we meet?). We focused on episodic source memory as it actives more of the frontal network that has previously been implicated in memory retrieval processes. One of these memory retrieval processes is 'post-retrieval monitoring', which is when your brain sorts through given information and picks the information that is most relevant and useful to the task at hand. The prefrontal cortex, an area of the brain considered the cognitive control center, searches through all the memories that the hippocampus, an area heavily implicated in various memory processes, sends to it to determine what to use. Based on previous fMRI studies around post-retrieval monitoring, we know that the left inferior parietal cortex (IPC) and the right dorsolateral prefrontal cortex (DLPFC) are both heavily involved in post-retrieval monitoring processes, along with the hippocampus (Nyhus, 2018).

While fMRI can tell us what brain areas are involved, it isn't good at telling us the exact moment things happen. To fill that gap, we used electroencephalogram (EEG). EEG measures and records the electrical activity of the brain via electrodes that are attached to a cap and uses a conductive gel to amplify the signals. It can tell us about neural firing with millisecond precision; however, the special resolution is not as reliable. Due to the activity being measured at the scalp, localization is relatively limited to the cortex, making it difficult to measure the deeper brain structures reliably. To remedy this, we use a technique called source localization. At the beginning of each session, we take a 3D head scan of all our participants wearing the cap which allows us to mark the location of all the electrodes later in the data processing and better identify specific structures involved in generating the EEG signals. From these scans, we obtain data in the form of neural oscillations. These are all synchronized rhythmic patterns of electrical activity produced by neurons in the brain. The synchronization of these oscillations mediates interactions between the neurons and different brain regions, something known as functional connectivity. From all these different oscillations, we focused on theta oscillations (4-8 Hz) as theta oscillations have been shown to mediate interactions between different brain regions during memory retrieval (Anderson et al., 2010; Nyhus & Curran, 2010). In a study by Anderson et al., they determined that there was bidirectional information flow between the prefrontal cortex and the medial temporal lobe (containing the hippocampus) via a theta frequency during free memory recall (Anderson et al., 2010). Unfortunately, this study did not focus specifically on directionality during post-retrieval monitoring. However, it emphasized the importance of determining the directionality of information flow to fully understand the underlying neural networks.

Our project aimed to further explore the underlying neural networks of memory retrieval and tease apart the directionality during post-retrieval monitoring. We hypothesized that information flows from the left inferior parietal cortex (IPC) to the right dorsolateral prefrontal cortex (DLPFC) at a theta frequency during memory retrieval tasks. To determine the directionality of information flow, we employ a computational technique called Granger Causality Analysis. This model assumes that causes precede and predict their effects. While it doesn't establish a 100% causal relationship, it can indicate a predictive relationship. This means that if prediction model of Y that includes past X and past Y can perform better than a model of Y that only includes past Y, one could say that X 'g-causes' Y. This model allows us to determine some directionality, as a time lag between two areas can allow us to compare signals to determine if a signal in one area is 'g-causing' the signal in another, indicating directionality.

Throughout the summer we collected data from 14 participants who completed a task requiring the use of episodic source memory retrieval, adding to the data of a previous honors project. Moving forward, data processing will be done on the EEG data and will then be put into a Granger Causality analysis model to determine directionality. Evidence that information flows from the left IPC to the right DLPFC via theta band oscillations will confirm our hypothesis. Success in gaining a greater understanding of these neural networks could aid in developing diagnostic tools for mental illnesses linked to disrupted oscillatory dynamics.

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