Spatial locations decoded by human hippocampal wide-band signals in a virtual navigational environment

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Introduction

This is a behavioral study in the field of cognitive neuroscience that aims to decode and determine specific memorized locations and its search trajectories during memory recall using hippocampal local field potential signals. We hypothesized that this memory process might resemble physical path search strategies such as Lévy flight.

Background

Hippocampus is the brain part responsible for memory processing. Theories on cognitive maps stipulate that hippocampal neural activity is related to the spatiotemporal coding of one's spatial environment.

Types of Memory

- **Long-term (including episodic and semantic):** Episodic memory refers to the detailed retrieval of previous episode, such as what, where, and when something occurred. Semantic refers to the retrieval of factual information learned over several years.
- **Short-term (working memory):** refers to the temporary maintenance of information

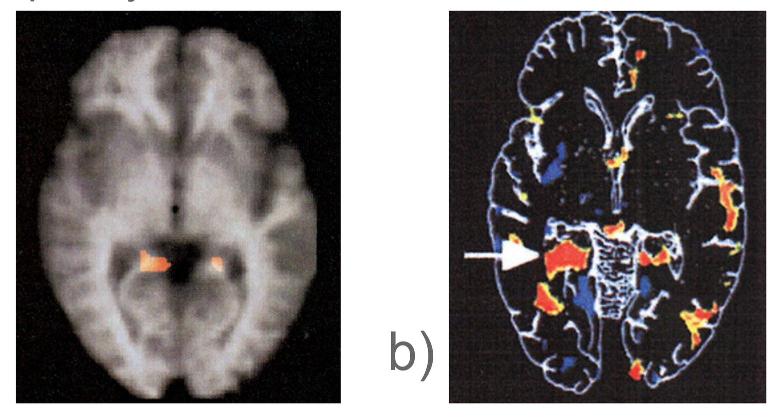

Figure 1. Hippocampal activity during a) memory retrieval and b) consolidation [1,2]

Types of Hippocampal Oscillations

- **Gamma-frequency:** encoding of current sensory information in memory
- **Theta-frequency:** produce an integrated representation of the current environment
- **Sharp-wave ripples:** memory consolidation and erasure of hippocampal memory traces

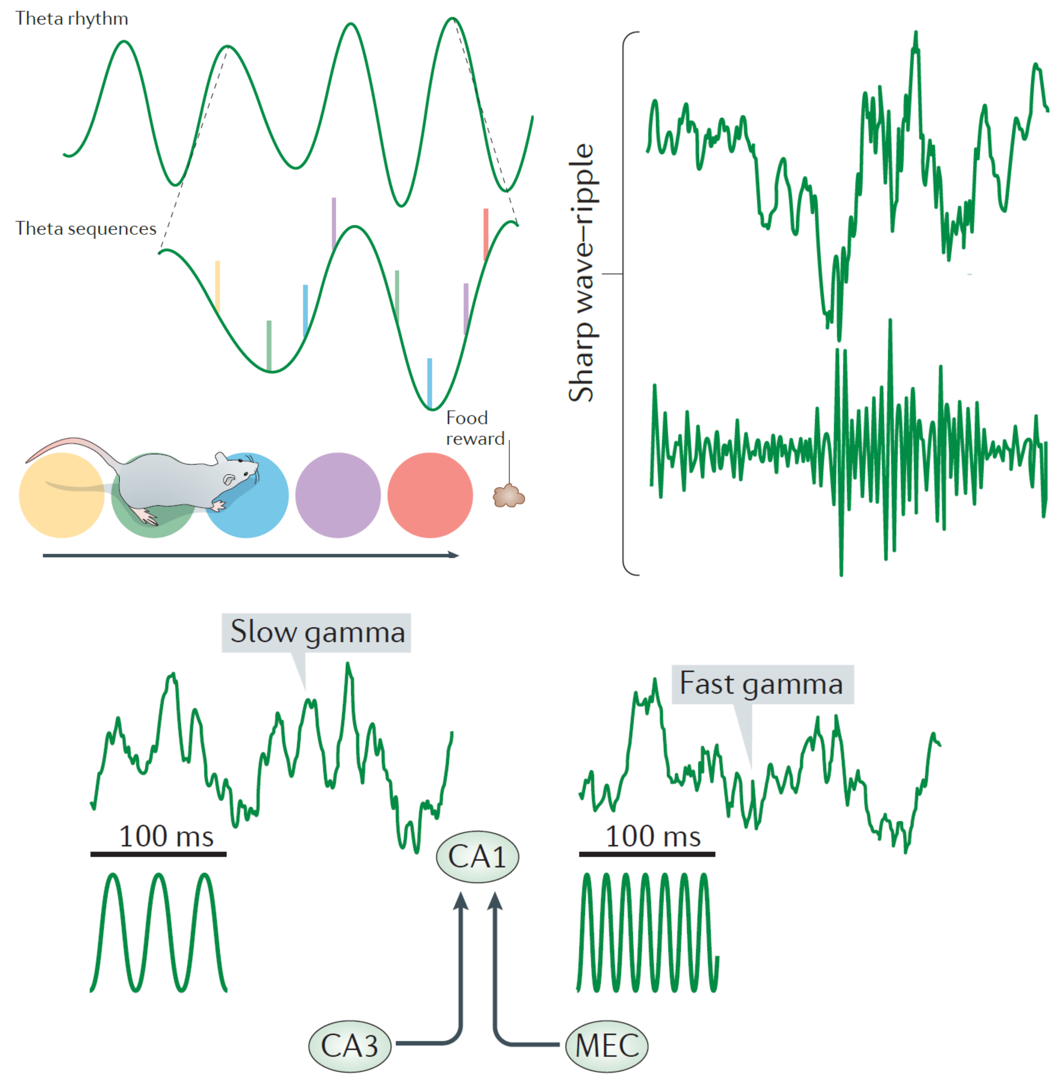

Figure 2. Types of hippocampal oscillations in a rodent's brain [3]

Lévy flight

Levy flights are a class of random walks that express efficient search strategies.

Intervals in memory retrieval can be described by Levy flight distribution

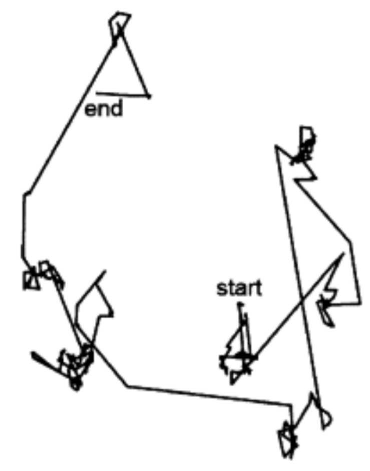

Figure 3. Levy flight distribution example [4]

Methods

Participants performed a passive navigation task in a Virtual Reality (VR) environment within a circular track at a constant speed. Within the track, a set of local cues composed of every day-life objects, obtained from the "texture city prefabs" library for Unity 3D, were randomly selected and placed equidistantly.

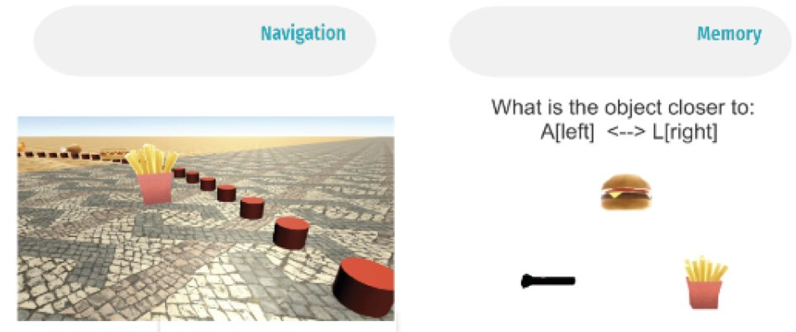

Figure 4. Experimental Setup(Left) and Procedure(Right)

Local field potentials (LFPs) were acquired from 6 epileptic patients and a deep learning method was used to decode the encoded locations and search processes in memory.

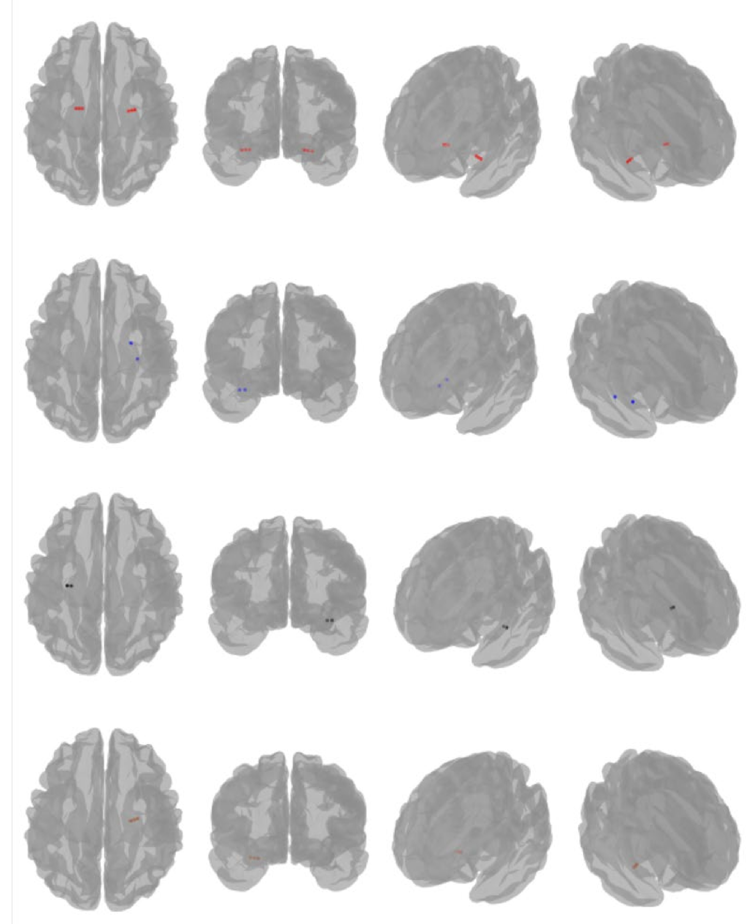

Figure 5. Visualization of electrodes in hippocampus

Data Analysis

We acquired hippocampal LFPs from 6 epileptic patients and used a deep learning method to decode the encoded locations and search processes in memory.

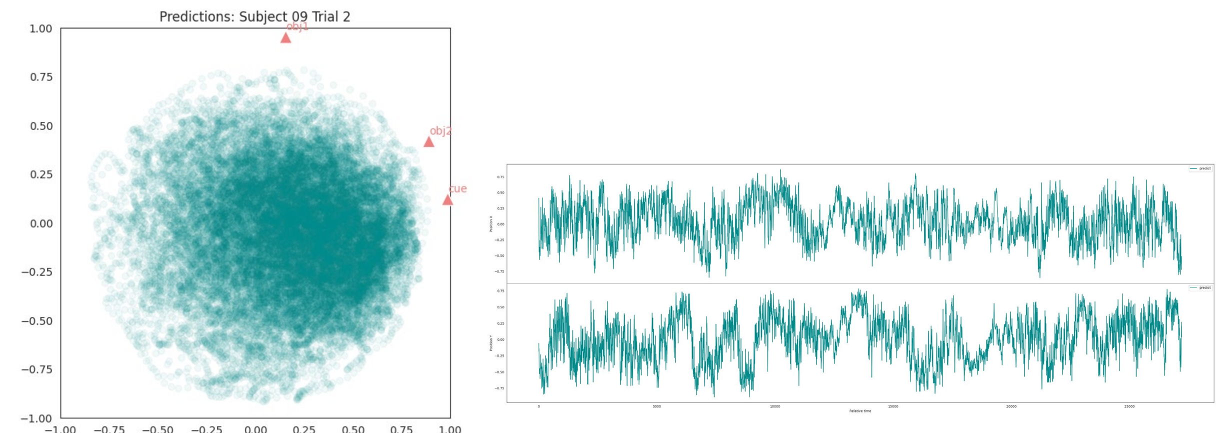

Figure 6. Subject 9 Hippocampus: decoding results (2D Left, 1D Right)

the model will transform the wide-band neural data into frequency space via a wavelet transformation, which was fed into a convolutional network for training models to reveal behavioral states in the order of millisecond. We also fitted the decoded memory search paths with classical Lévy flight distribution $P(l) \sim l^{-\mu}$, where $1 < \mu < 3$.

Results

We produced trial-wise decoded memory search maps within the navigational environment and found that the decoded locations reliably predict the subject's memory performances. Leveraging on the high temporal resolution (0.5 ms / step), we revealed that the memory search trajectory follows a truncated power law, suggesting Lévy flight foraging search in the episodic memory space.

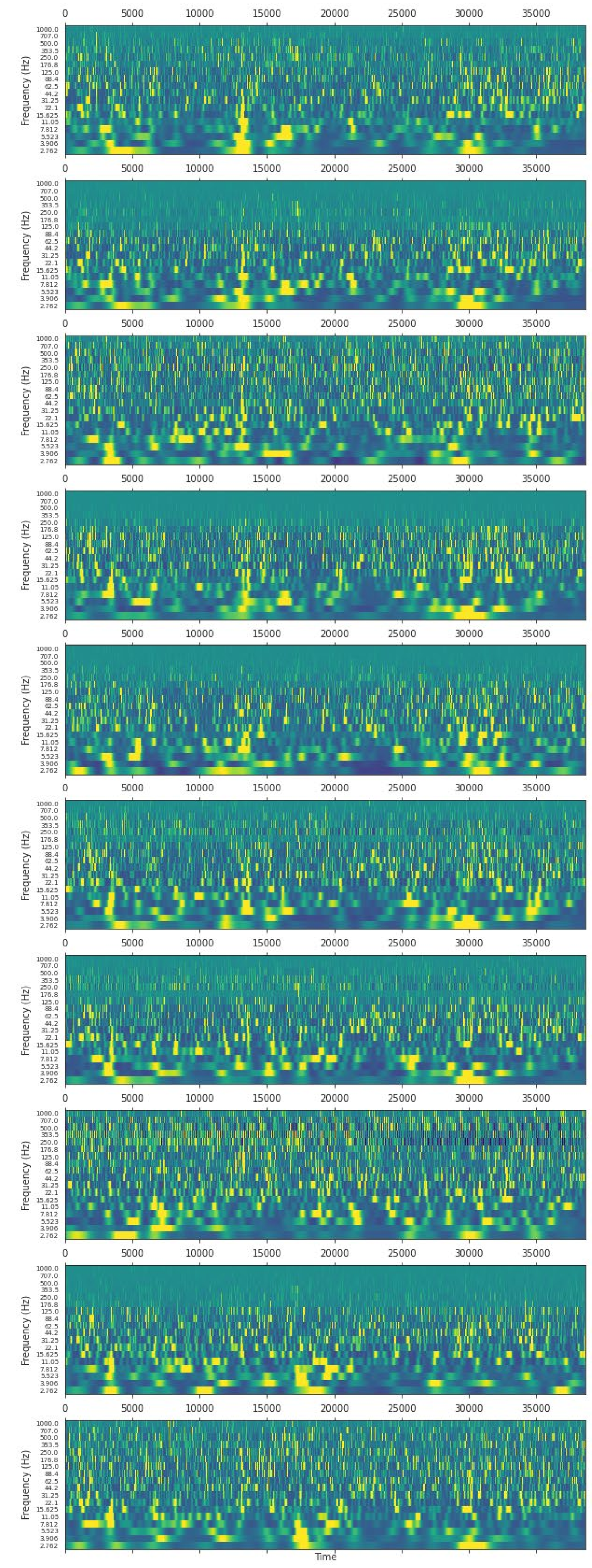

Figure 7. Subject 9 Hippocampus: decoding results in Time-Frequency space

Ongoing Analysis

A similar analysis will be conducted on the precuneus brain region to verify the accuracy of results and demonstrate if other brain regions also have the same prediction effect as the hippocampus.

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