Investigation of Cortical Traveling Waves in Array dataset

In this assignment we are going to analyze the activity of *local field potential (***LFP**) recorded with multi-electrode array in motor cortex. The task (Figure 1) is designed to study the encoding of working memory in Premotor Area F5.

Although searching for significant correlations between neural signals (including spikes and LFP) and task variables might be interesting itself, here in this assignment we are going to investigate existence of mesoscopic traveling waves and their properties. Accordingly, you only need to know task timings of rather than task details.

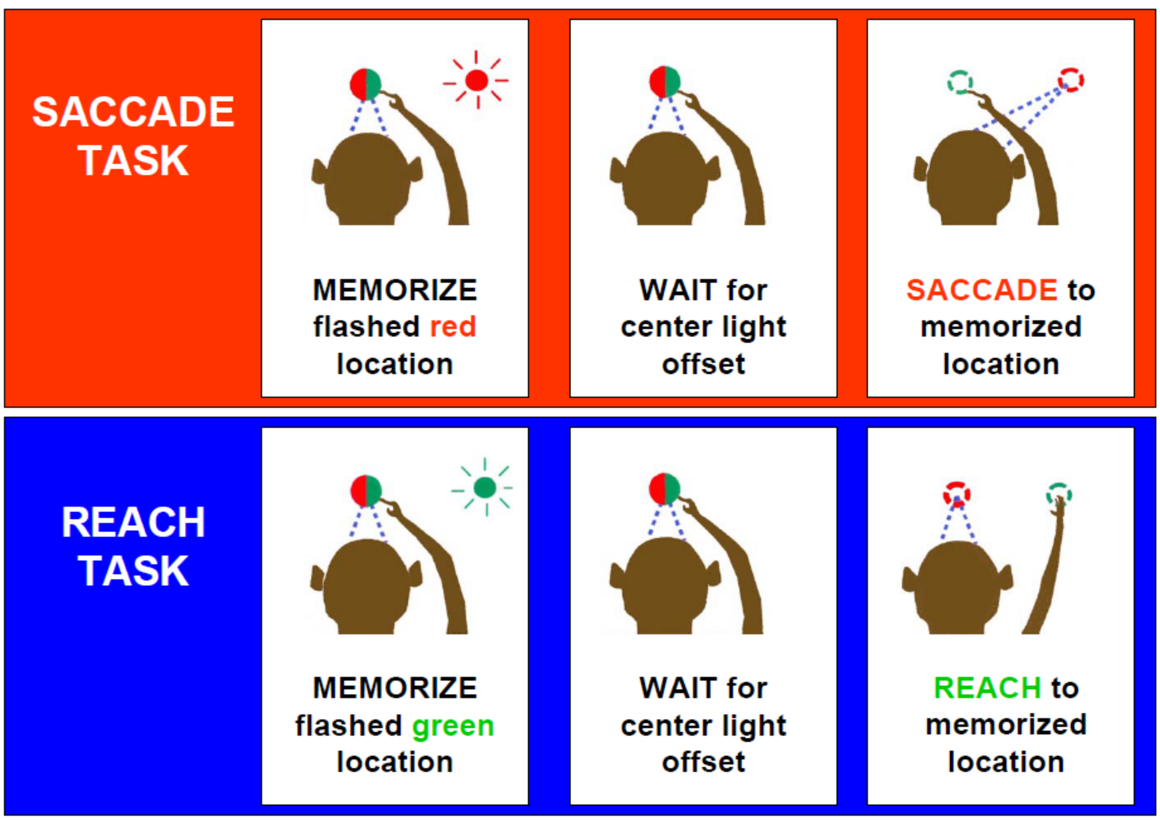

Figure 1 Delayed Response Task

Task Description:

In this task, a monkey learns to follow instruction to receive tasty juice as reward (figure 1). At first, the monkey should keep its eyes on a **fixation point** in center of screen (red/green circle). To make sure monkey is looking at the desired point, we follow its eyes using an **eye tracker**. After a random duration between 300 to 500 ms fixating at fixation point, a cue will be presented in the periphery (step 2). Monkey must remember the spatial position of cue to either saccade or reach to that point after waiting for center light offset (step3). At the end, based on the color of target monkey reach/saccade to the expected location (step 4). If the monkey saccade/reach in the correct position, he will receive tasty juice!

Data Description:

After the monkey gets fully trained in the task, we start recording from the Premotor Area F5, using an electrode array. This array includes 49 single electrodes distributed in an area of $12mm^2$. Distance between neighboring electrodes are 400 μm. (figure 2).

In assignment folder you can find a session of electrophysiological recordings including timing of task.

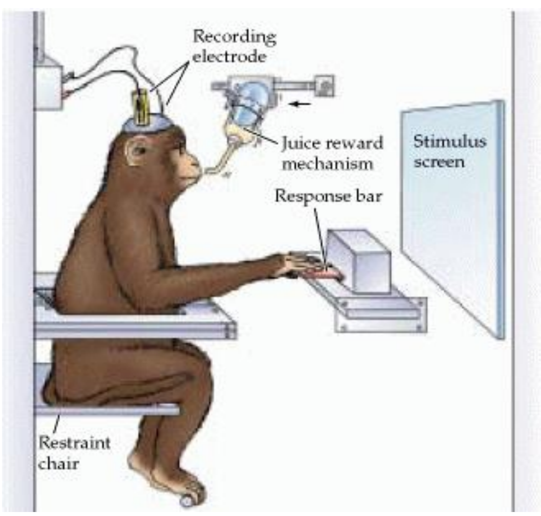

Figure 2 Electrophysiology setup

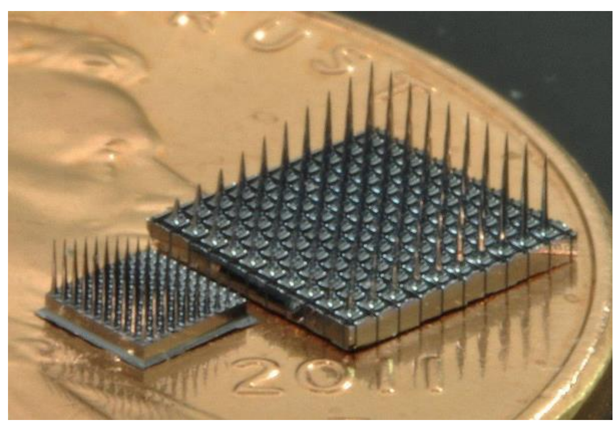

Figure 3 Similar microelectrode array. (pith size 0.4mm, area = 12mm^2)

LFP analysis

As you know, since the start of course we have only used the band-pass filtered of raw extracellular signals to detect spikes. Generally, the extracellular potential results from current flow in the extracellular space, which in turn is produced by

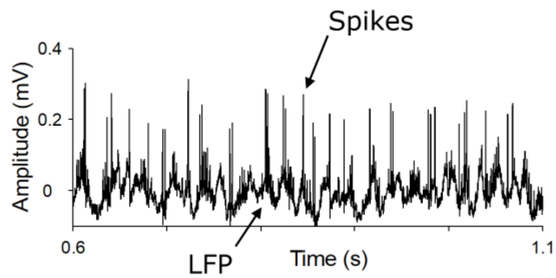

Figure 4. (Extracellular potential)

transmembrane potentials in cells. These cellular events can be fast, 1*ms*, for action potentials which give rise to spikes and slow, up to 100*ms*, for post-synaptic potentials in dendrites and soma, which give rise to LFP. The low pass filtered of raw extracellular signals are known as local field potential (LFP). In this assignment all the LFP signals are down-sampled with 200 Hz to avoid time consuming runtimes in your further simulations.

The relationship between LFP and the firing of neurons depends on the brain state, however in many cases LFP convey extra information that is not encoded in single neurons.

In this part you are going to investigate any time-frequency modulation in LFP signals.

a) Find out the most dominant frequency oscillation. To do so you must plot averaged **power spectrogram** after doing color noise cancelation [see Reference 2].
b) Cluster electrode group based on their dominant oscillation frequency. is there any topography in this clustering map? Guess why?
c) Plot **power spectrum** of LFP signals through the time. (Note: Although you can calculate power spectrogram using simple Fourier transform, it is better here to use advanced methods such as Welch and Multitaper).

d) Which Band frequency shows stronger power? Compare the timing patter of this power frequency blub with task timing. Compare your result with Hatsopoulos et.al 2006.

Phase propagation (Traveling waves)

a) Use a band-pass Butterworth filter (I suggest 2nd order!) to select most dominant oscillation of each electrodes LFP signal.
b) Using Hilbert transform calculate instantaneous phase of filtered signals and store its result in a (7*7*number-of-trails*number-of-time-points) matrix named $\phi(x, y, t)$
c) First design a demo to show the COS($\phi(x, y, t)$) during different time points. Do you see any traveling waves?!
d) Based on what you have learned from reference papers (and also your creativity!), calculate the Phase Gradient Directionality, Direction of Propagation, and Speed of these traveling waves.
e) Add calculated traveling waves properties to your Demo for validation.
f) Is there any preferred direction propagation for traveling waves? Design a test to validates its significance.
g) Compare calculated averaged phase propagation speed with anatomical criteria's in Sejnowski et.al 2018 (0.1-0.8m/s)

Good luck!

References

[1] S. Ben Hamed, J.R Duhamed, F.Bremmer , W.Graf, **Cerebral Cortex,** 2002
[2] Doug Rubino, Kay A Robbins & Nicholas G Hatsopoulos, **Nature Neuroscience**, 2006.
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[4] Lyle Muller, Frédéric Chavane, John Reynolds and Terrence J. Sejnowski, **Nature Reviews Neuroscience**, 2018