Amrita Shah — Fall 2022

BIO 347 — Homework 5

Persistent Activity in Prefrontal Cortex (PFC)

These experiments involved recording the neural activity in certain areas of the prefrontal cortex as monkeys performed a task. This task was the comparison of two frequencies of vibrations by reporting which stimulus had a higher frequency. The subjects would be required to remember the first stimulus frequency during the delay period between the two stimuli, in order to compare them afterward. This is known as working memory. It is hypothesized that neurons involved in implementing the working memory would exhibit persistent firing in their neural activity. Firing would continue during the entirety of the delay period and would be constant throughout the delay period.

The first neuron chosen was neuron 6 from recording session R14055_001. This neuron shows persistent activity, with a relatively constant firing rate during the delay period. It carried a signal about the f1 stimulus frequency throughout the delay period, from ~200ms to ~3700ms (Fig. 1a). This is also seen in the raster plot (Fig. 1b), as the density of spikes, visualized as dots on the plot, is generally consistent throughout this delay period between ~100ms and ~3600ms. It exhibits strong tuning which peaks at roughly 35-40 Hz (Fig. 1c). High firing rate does not always encode for the same working memory content. Initial stimuli of 10-18 Hz produced overlapping conditional firing plots. Between 2500ms and 3300ms, all three initial stimuli resulted in a firing rate of roughly 30 (Fig. 1a), showing that a specific firing rate does not always encode for the same stimulus frequency in the working memory. These features in the conditional firing rate are consistent with the hypothesis on working memory implementation, as firing persisted and remained constant throughout the delay period.

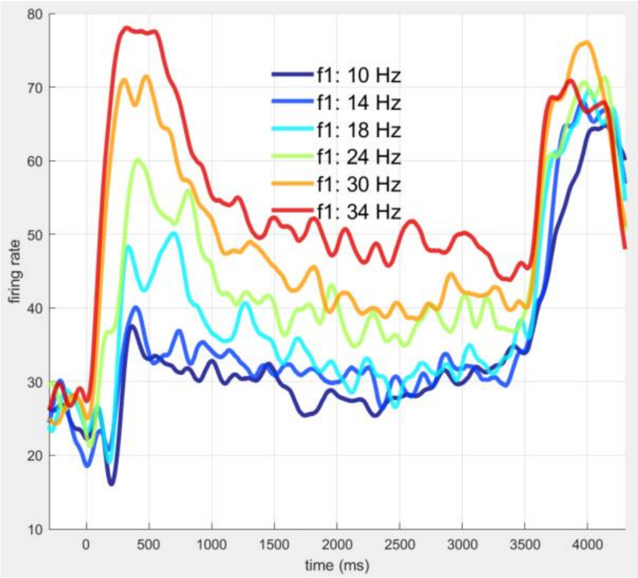

Figure 1a: Conditional firing rate for neuron 6 from recording session R14055_001.

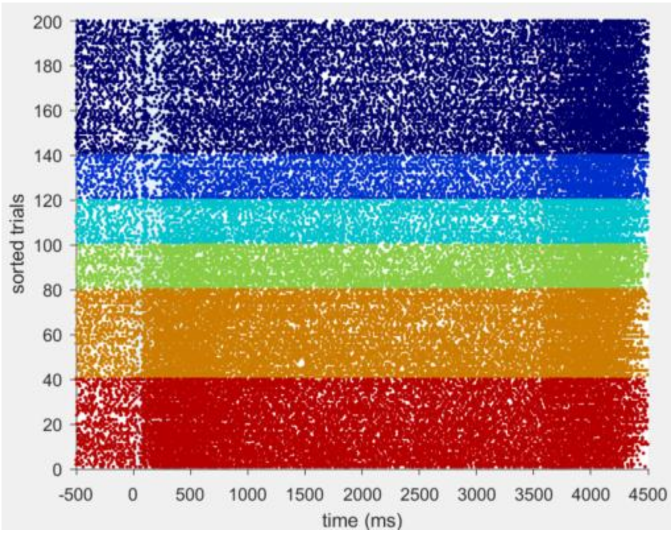

Figure 1b: Raster plot for neuron 6 from recording session R14055_001.

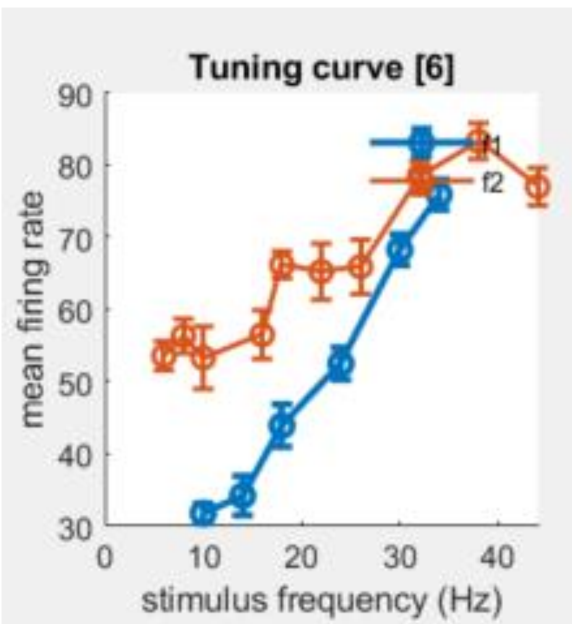

Figure 1c: Two tuning curves for neuron 6 from recording session R14055_001.

The second neuron chosen was neuron 7 from recording session R14060_001. This neuron showed ‘late activity’. It exhibited a decrease in firing rate at the beginning of its delay period at roughly 200ms, followed by a steady increase during the rest of the delay period until roughly 3700ms (Fig. 2a). The firing rate was therefore not constant during the delay period. Similar trends are seen in the raster plot (Fig. 2b), as the density of spikes, visualized as dots on the plot, decreased sharply at roughly 100ms, then increased until the end of the delay period at roughly 3600ms. The neuron continues to fire throughout the delay period, increasing over time. During this period, it encodes the f1 stimulus identity. High firing rate does not always encode for the same working memory content. All initial stimuli produced overlapping conditional firing plots. Between 1500ms and 3400ms, initial stimuli of 10-30 Hz resulted in very similar firing rates, increasing from roughly 30 to roughly 37 (Fig. 2a), showing that a specific firing rate does not always encode for the same stimulus frequency in the working memory. This neuron has strong tuning, shown as the mean firing rate peaks at around 35 Hz (Fig. 2c). These features in the conditional firing rate are surprising and somewhat contradict the hypothesis. It is shown that neurons involved in implementing the working memory would exhibit persistent firing after the first stimulus presentation. However, this firing rate does not have to be constant throughout the duration of the delay period (Fig. 2a).

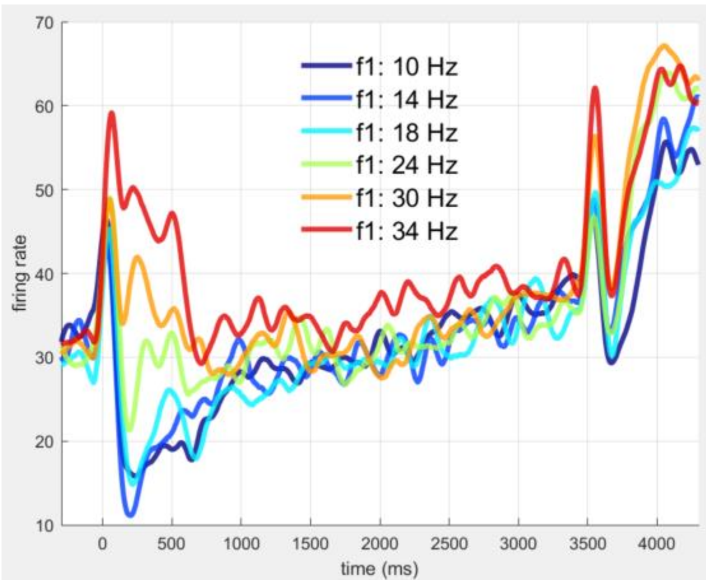

Figure 2a: Conditional firing rate for neuron 7 from recording session R14060_001.

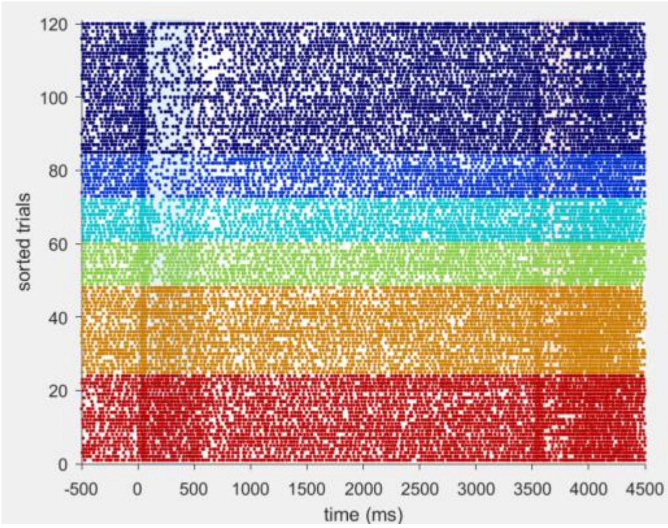

Figure 2b: Raster plot for neuron 7 from recording session R14060_001.

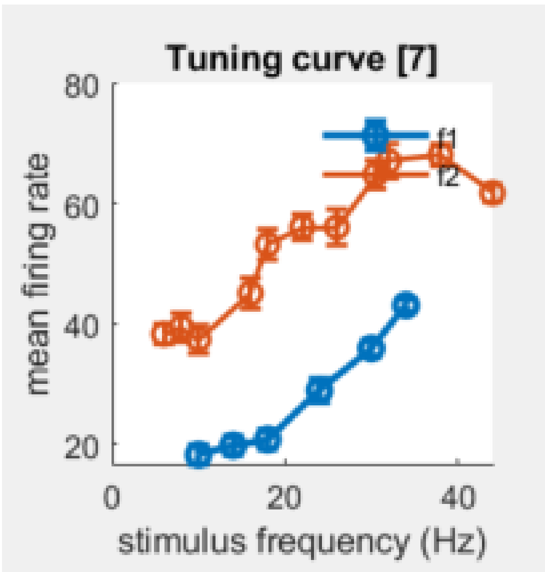

Figure 2c: Two tuning curves for neuron 7 from recording session R14060_001.

The data recorded from the prefrontal cortex neurons discussed above exhibit the neural activity involved in working memory implementation. It is shown that a neuron's firing during the delay period between the f1 and f2 stimuli presentations remains persistent but need not be at a constant rate. This somewhat contradicted the initial hypothesis. This result makes sense, since a specific firing rate does not always encode for the same stimulus frequency in the working memory, as shown in the conditional firing rate plots (Fig 1a, 2a). Various stimulus frequencies resulted in the equivalent firing rates during the delay period.

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The above two neurons offered examples of two patterns of activity among prefrontal cortex neurons. Neuron 6 from recording session R14055_001 is an example of a ‘persistent’ neuron, which carries a constant firing rate for the entire duration of the delay period. Neuron 7 from recording session R14060_001 was an example of a ‘late’ neuron, which carries the signal during the end of the delay period, but not during the beginning (Romo et al., 1999). It is possible that this later increase in firing rate in ‘late’ neurons is associated with the anticipation of an upcoming second stimulus. Late neurons were found to scale the timing of their response with the length of the delay period. That is, the speed in evolution of response characteristics decreased proportionally as delay period duration increased (Brody et al., 2003). Another pattern of activity among PFC neurons discussed by researchers was the firing rate increasing sharply, then decreasing over the delay period. Such ‘early’ neurons carry the signal during the beginning of the delay period, but not during the end (Romo et al., 1999). Various patterns of activity exist among PFC neurons, and it is possible that different types of neurons are associated with different patterns (Romo et al., 1999). Further investigation is required in order to determine such distinctions between neural activity patterns.

References (Discussion is extended for extra credit)

Brody, C. D., Hernandez, A., Zainos, A., & Romo, R. (2003). Timing and neural encoding of somatosensory parametric working memory in macaque prefrontal cortex. *Cerebral Cortex*, *13*(11), 1196–1207. https://doi.org/10.1093/cercor/bhg100

Romo, R., Brody, C. D., Hernández, A., & Lemus, L. (1999). Neuronal correlates of parametric working memory in the prefrontal cortex. *Nature, 399*(6735), 470–473. https://doi.org/10.1038/20939