Neural Encoding for Primate Arm Movements (March 2023)

Paul Wanczuk

***Abstract*— Hatsopoulos laboratory provided spike sorted data for two neuron recordings from the primary motor cortex of a macaque monkey. The data collected was utilizing the center-out paradigm behavioral task with movements constricted to a 2D plane. From this data, a neural encoding program was developed in Matlab. This program took the data for each neuron, and generated a raster plot for 8 possible movement directions. In addition, peri-event time histograms (PETH) were generated to accompany the raster plots along with a tuning curve for each neuron.**

***Index Terms*— Raster plot, Peri-event time histograms (PETH), Tuning curve, Neural Encoding, Neural spiking, center-out paradigm**

I. Introduction

THE goal of this project was to develop a neural encoding program in Matlab that would generate raster plots, PETH, and tuning curves in order to evaluate a neuron's involvement in certain movements of the arm. The data used to develop this program were provided in a "Project2.mat" struct which included two neuron recordings from the primary motor cortex of a macaque monkey and was provided by the Hatsopoulos laboratory. Behavioral data of the monkey's arm movements were collected using a manipulandum which is an exoskeleton that fits over the arm and constrains movement to a 2D plane. With this setup, the monkey would complete a center-out paradigm task which would have them move their arm in a given direction following a go cue [1]. The subject has 8 possible directions to which it could move which are each 45 degrees apart and range from 0-315 as shown in *Fig. 1*.

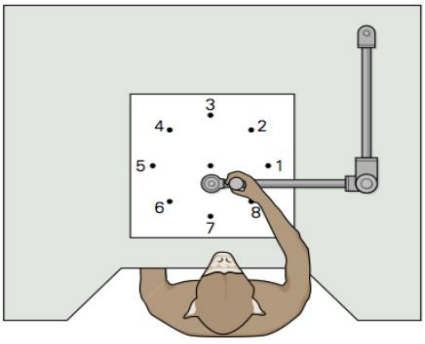

Fig. 1: Representation of the manipulandum and collection of data for types of motion in a monkey model [4]

The data provided included 158 go times which are times where the monkey was required to complete a movement, and time samples for data with one neuron having 9,596 and the other having 11,810 that both went through 1.3x10^3 seconds.

Neural encoding itself, is the study of information processing by neurons [2]. Specifically with the primary motor cortex, it is possible to map the firing of neurons in relation to different types of movements.

The primary method to complete this is developing a raster plot. This method allows for visual examination of variability in responses trial-by-trial [3] [4]. Each of the 8 possible movements receive their own raster plot for all the trials done for the movement. Each trial is stacked on top of one another and each vertical line represents a neuron signal that occurred within 1 second of the go signal in the experiment.

The raster plots are then represented by PETHs which represent the density of neural signals within 0.02 sections over the entire -1 to 1 second time frame along the x-axis. Then to find how the average response of the neuron varies with different motor movements, a tuning curve is generated [3]. This plots the frequency of a signal on the y-axis and the different positions 0-315 degrees on the x-axis.

II. Methods For Neural Encoding

The first step in neural encoding, was generating the raster plots for neuron 1 and 2. In order to complete this, a direction 1-8 had to be selected. Once that is selected, the go time for each trial is determined and neural signals within a one second interval before and after the go signal are recorded.

```
spikeTimes=[neuron(find(neuron>go(indDir(j))-1 & neuron<go(indDir(j))+1))-go(indDir(j))]';
```

(1)

(*1*) describes the code used to obtain the signals before and after the go command and then shifts the data so that the results would appear between -1 and 1 second when plotted.

Following this, PETH graphs are then generated. Similar to the raster plots, the same methods are used to evaluate what neural signals occur during the movement with variable spikeTimes *(1)*.

```
peth(:,i)= peth(:, i) +[histc(spikeTimes,edgesPeri,2)]'
```

(2)

In addition to obtaining the spike times, edgesPeri is used to establish 0.02 second windows that span the -1 to 1 second time frame (*2*). These two components are then put into the "histc"

This was submitted for review on March 27th 2023 for Project 2 in BME 4361 Neural Engineering course. This work has not received any support or funding.

P. Wanczuk, is with the University of Florida, Gainesville, FL 32605 USA (e-mail: pwanczuk@ufl.edu).

Matlab function which outputs a average response of the neuron within the 0.02 second window and can be displayed in the form of a bar graph.

Lastly, a tuning curve is generated to capture how the neuron responds to the different motions they completed. Unlike the raster plots and PETH, one plot is generated for the entire neuron with all the directions. Furthermore, the value for each direction is determined by collecting the number of signals after the go signal which is 0 to 1 rather than the -1 to 1 used for the other methods.

III. Results

First, a raster plot was generated for the first neuron in the dataset (*Fig. 2*).

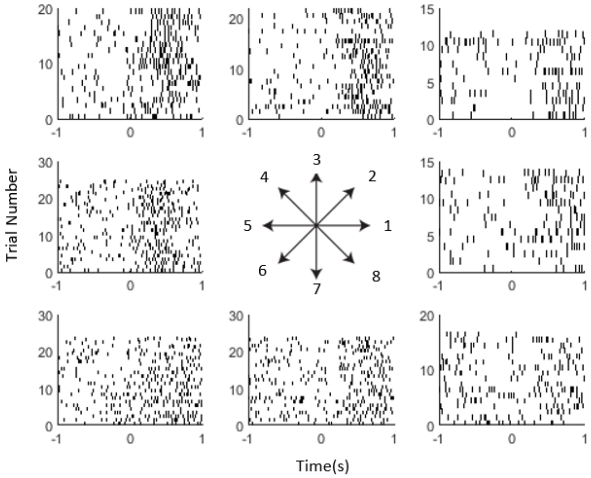

Fig. 2: Raster plot representing firing in the first neuron, 1 second before and after a go command was given to the monkey. The arrows with numbers in the center represent the direction of movement for the corresponding plot. The x-axis for each plot is in seconds and the y-axis represents the trial number for each row.

From Figure 2, the numbers 1-8 are representative of angles ranging from 0-315 in 45-degree increments. This was defined in the program by (*3*) and was later used for the tuning curve. In addition, *Fig. 2* also reveals that not all directions had the same number of trials as directions 5, 6, and 7 had over 20 trials while directions 1 and 2 had under 15 trials.

```
positions=[0 45 90 135 180 225 270 315];
```
(3)

Following this, raster plots for neuron 2 were generated (*Fig. 3*).

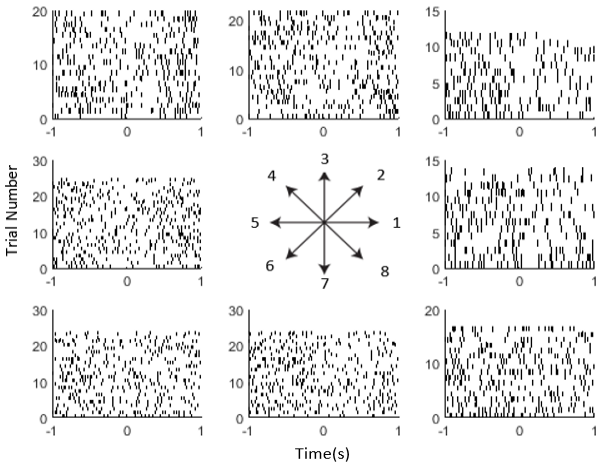

Fig. 3: Raster plot representing firing in the second neuron, 1 second before and after a go command was given to the monkey. Arrows with numbers represent the direction of movement for the corresponding plots. The x-axis for each plot is in seconds and the y-axis represents the trial number for each row.

Similar to the first neuron, the second neuron has over 20 trials in directions 5, 6, and 7. Also, it has less than 15 trials in directions 1 and 2.

Following the raster plots, PETHs were generated for each neuron (*Fig. 4 & 5*).

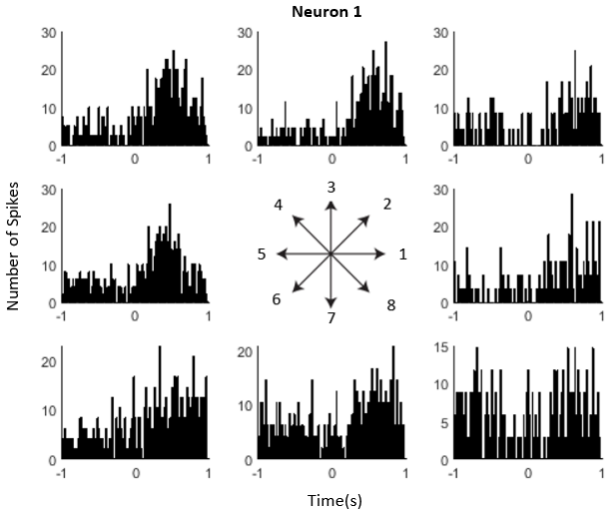

Fig. 4: PETH for each direction in Neuron 1. This expresses the number of spikes (y-axis) within each 0.02 bar over the time range -1 to 1 seconds (x-axis).

The PETH for neuron 1, depicted in *Fig. 4*, expresses an increase in neural activation after a go command (0 seconds) is given for most of the directions. The direction with approximately the same activity throughout the trials was direction 8.

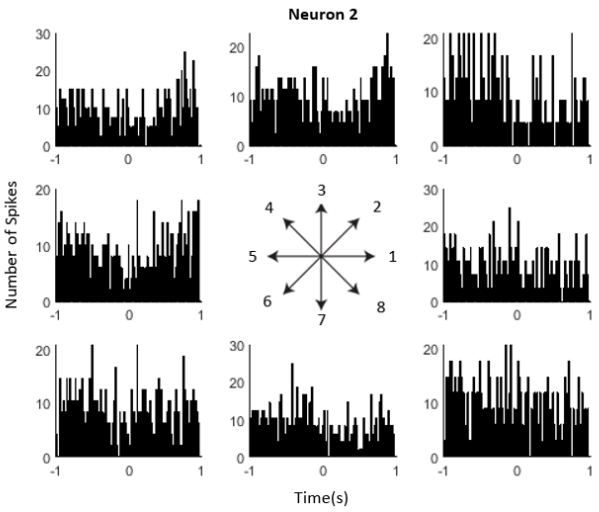

Fig. 5: PETH for each direction in Neuron 2. This expresses the number of spikes (y-axis) within each 0.02 bar over the time range -1 to 1 seconds (x-axis).

The PETH for Neuron 2, depicted in *Fig. 5*, shows how there is very little change or a decrease in activity after the go signal is given. The only directions that had some increase in activity were direction 3, 4, 5 but the increase was minimal.

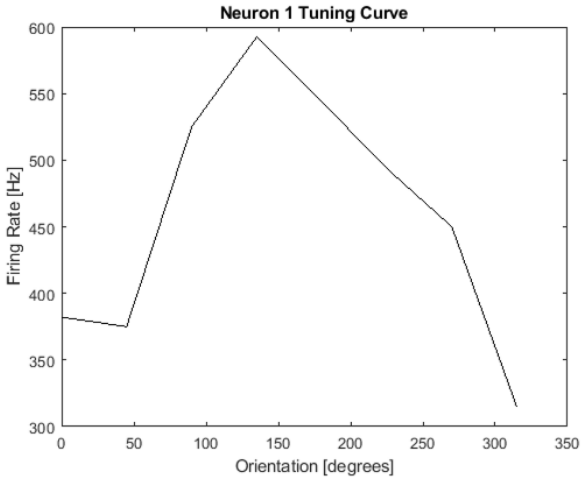

Fig. 6: This is the tuning curve for Neuron 1 including the angles 0-315 on the x-axis and the firing rate in Hz on they y-axis.

Fig. 6 provides a visual representation of the tuning curve and the relationship between the different directions and firing rate.

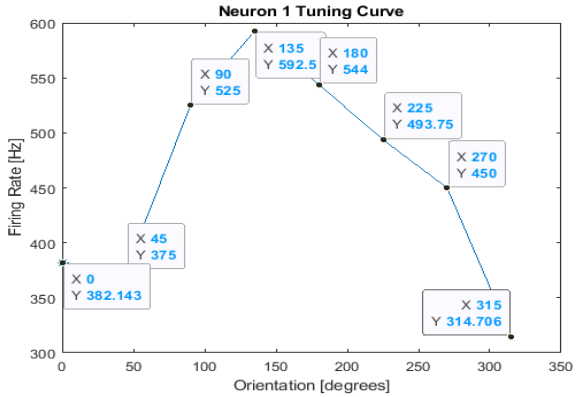

Fig. 7: Neuron 1 tuning curve with each direction labeled.

Fig. 7 represents the firing rate associated with each direction, and expresses that directions 3, 4, and 5 were most influential on neural firing in neuron 1.

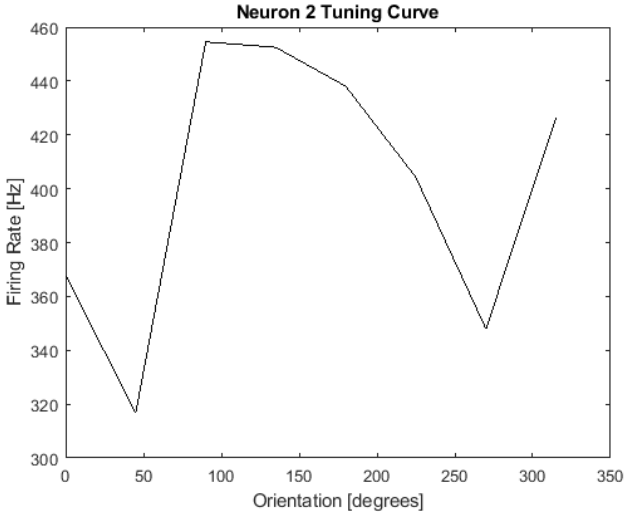

Fig. 8: This is the tuning curve for Neuron 2 including the angles 0-315 on the x-axis and the firing rate in Hz on they y-axis.

Fig. 8 presents a visual representation of the tuning curve and change in firing rate with a change in orientation.

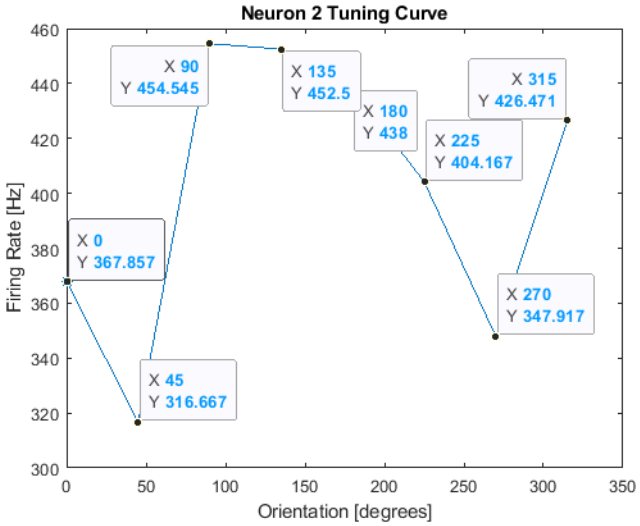

Fig. 9: Neuron 2 tuning curve with each direction labeled.

Fig. 9 provides the firing rate values for each orientation, and expresses how direction 1, 2, and 7 were least influential on the firing rate of neuron 2.

IV. Discussion

Based on the tuning curves for neurons 1 and 2 (*Fig. 7 & 9*), the nerves do appear to have directional tuning. Specifically, neuron 1 appears to be most sensitive to movements between 90-180 degrees. This is because the firing rate of the neuron for these movements were over 500 Hz. The 90-180 degrees were associated with directions 3, 4, and 5.

For neuron 2, the directional tuning was not as clear. The values for the neuron firing rate for most of the directions were over 400 Hz, with only directions 1, 2,

and 7 having significantly lower firing rates. This could possibly represent that this neuron is not tuned to orientations 0-45 and 270 degrees. When comparing the two tuning curves of neurons 1 and 2, the ranges and maximum firing rates were significantly different. Neuron 1 had a maximum of around 600 Hz and a low close to 300 Hz while neuron 2 only had a maximum frequency of approximately 460 Hz. This could mean that neuron 1 is more sensitive to change in orientation of movements compared to neuron 2.

This claim can be justified by referring to the raster plots and PETHs of each neuron. Looking at the raster plots (*Fig. 2 & 3*), the plot for neuron 1 appeared to have less dense region prior to a given go signal. This is more clearly seen in the PETH plots for each direction.

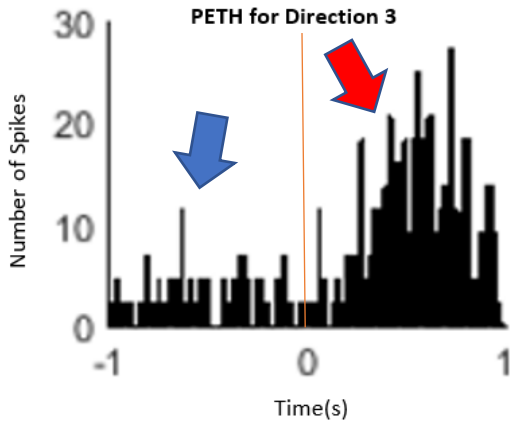

Fig. 10: Depicts the PETH for direction 3 in neuron 1. Blue arrow highlights the region of the plot before a go cue, and the red arrow highlights the region after a go cue. The difference of these regions is divided by the orange line which signifies the start of a go cue.

Fig. 10 above, provides how the neural activity in neuron 1 significantly changes for direction 3 after the go cue is provided to the monkey. When looking at a direction for neuron 2, the variation in neuron activity following the go cue is significantly lower (*Fig. 11*). This leads to the conclusion that neuron 2 may not be tuned for the directions as significant changes in spike frequency does not occur after a go cue is given.

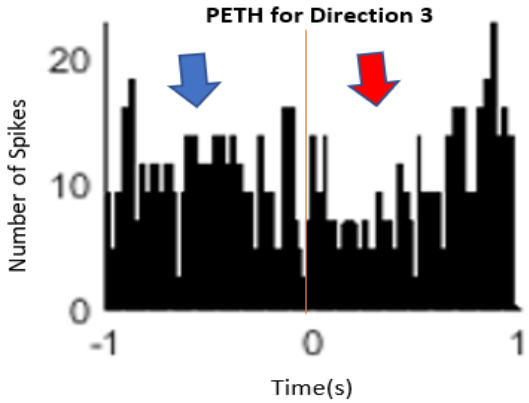

Fig. 11: Depicts the PETH for direction 3 in neuron 2. Blue arrow highlights the region of the plot before a go cue, and the red arrow highlights the region after a go cue. The difference of these regions is divided by the orange line which signifies the start of a go cue.

In conclusion, the data collected for each neuron was able to generate raster plots and PETH to visualize the activation of a neuron in relation to a go signal and a movement in a direction. In addition, a tuning curve allowed for the visualization of a neuron's response to different directions. This led to the conclusion that neuron 1 is more directionally tuned than neuron 2.

REFERENCES

[1] J. Wang, L. Bi, W. Fei and K. Tian, "EEG-Based Continuous Hand Movement Decoding Using Improved Center-Out Paradigm," in *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 30, pp. 2845-2855, 2022, doi: 10.1109/TNSRE.2022.3211276.

[2] M. Velliste, S. D. Kennedy, A. B. Schwartz, A. S. Whitford, J.-W. Sohn, and A. J. C. McMorland, "Motor cortical correlates of arm resting in the context of a reaching task and implications for Prosthetic Control," Journal of Neuroscience, 23-Apr-2014. [Online]. Available: https://www.jneurosci.org/content/34/17/6011.

[3] N. Ghani, "Neural Encoding," Neural Encoding Overview, 10-Feb-2018. [Online]. Available: http://www.columbia.edu/cu/appliedneuroshp/Spring2018/Spring18SHPAppliedNeuroLec3.pdf.

[4] A. Georgopoulus, "ON THE RELATIONS BETWEEN THE DIRECTION OF TWO-DIMENSIONAL ARM MOVEMENTS AND CELL DISCHARGE IN PRIMATE MOTOR CORTEX," *The Journal of Neuroscience*, vol. 2, No. 11, pp. 1527-1537, 1982