Analyzing motor cortex neuron's behavior in case of movement

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Neuron's activities are highly correlated with the subject's thoughts, emotions, actions, and movements. each area in the cortex is responsive to a specific motion or movement. In this article, we are concerned with neurons' activities related to the subject's behavior and actions. The premotor cortex is an area of the motor cortex lying within the frontal lobe of the brain just anterior to the primary motor cortex that is responsive to actions and movements. It occupies part of Brodmann's area 6. It has been studied mainly in primates, including monkeys and humans. we have discussed neuron's behaviors in Pre-Motor cortex Ventral (PMv), with the data that has been recorded from this region. Motor neurons are cells in the brain and spinal cord that allow us to move, speak, swallow and breathe by sending commands from the brain to the muscle that carry out these functions. As PMv is a motor area, neurons in this area are highly responsive to movements and actions performed by the subject. The dataset has been recorded while the subject is performing a reinforcement learning task and attaining a reward for certain behavior. Each trial consists of 9 events that are specified in the dataset. neuron's activities are recorded during trials Using this dataset and methods that have been explained completely, we have acquired results that answer multiple questions. Questions about ISI distributions of neurons, the sensitivity of neurons to a specific event, analyzing the type of each trial concerning the subject's behavior. We have explained questions in detail in each section.

PMv | Reinforcement Learning | ISI

Introduction

For years scientists have claimed that each part of the brain is responsible for a specific task. They have developed creative methods to measure signals and indications to conclude about the responsibility of each area. To investigate throughout history Hines has been the first to use the term "premotor cortex", which was adopted later by Fulton and his colleagues (1). However, their "premotor area" contained the supplementary motor cortex (2). Physiological studies have shown that premotor cortex regions become active during complex sensory-guided movements, and often fire 100 milliseconds or more even before the beginning of an action. The primate premotor cortex consists of past, present, and preparatory sections. The premotor cortex can be subdivided into several regions that each have different properties. Movements such as climbing, are more anterior, and simpler and more distal movements are posterior. Most researchers now generally divide the premotor cortex into four sections: a dorsal and caudal section (PMDc), a dorsal and rostral section (PMDr), a ventral and caudal section (PMVc), and a ventral and rostral section (PMVr)(3). Fulton's studies of the nonprimary motor cortex were the beginning of the experimental investigation of this region. the most interesting effect they claimed to observe was a specific deficit in the execution of skilled movements(4). First, much like M1 and the SMA, several studies have shown that PMd and PMv are electrophysiologically excitable and the movements evoked from stimulation range from simple (movement around one joint) to complex (movement around two or more joints) thus showing the potential efferent output of the PMC (5). Furthermore, these electrophysiological studies demonstrated a discrete somatotopic arrangement of body representations, which is a hallmark feature of cortical motor areas. In contrast, damage to PMv resulted in deficits to object manipulation in 3D space with the hand in nonhuman primate studies (6). these studies show that the PMC is a critical part of the motor network and may allow the PMC to directly influence motor output. Thus, these motor characteristics enable the PMC to be placed in an ideal position to compensate for the loss of some other motor functions that have been disabled due to damage to other cortical motor areas as occurs in many cases of clinical stroke (7). PMv neurons also respond to tactile and proprioceptive stimulation (8). Thus, PMv has been implicated in the initiation and control of limb movements based on visual and somatosensory information (9). PMv is important for the integration of visual information derived from extrapersonal three-dimensional space and involved in the spatial guidance of limb movements. PMv neurons respond to somatosensory stimuli applied to either face or arm and visual stimuli corresponding to peripersonal space (10). PMv neurons are selective for the three-dimensional shape of objects to be grasped (11), the direction or movement trajectory in visual space (12), the attention to visuospatial stimuli (13), and decisions making based on somatosensory signals (14). We can use Electrophysiology that is the branch of neuroscience that explores the electrical activity of neurons and searches for patterns in its electrical signals, to develop techniques to listen in on these signals by measuring electrical activity, allowing scientists to decode intercellular and intracellular messages (15). Electrophysiology testing is a functional, not anatomic,

Significance Statement

The purpose of this study is to better understand how movement and actions done by subject are correlated with brain's neurons. we can find out which area in brain is responsible for specific tasks and we can design medicine for it in case of related illness. this study is done by methods and tests that conclude neurons have certain characteristics and results provide a guide on neurons' activities while subject is performing tasks.

both M.K and H.A performed the analytic calculations, simulations and contributed to the final version of the article

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evaluation of the nerve(16). Now using these techniques we observe neurons' activities and conclude about their behavior.

Dataset

Our dataset is an available electrophysiology dataset that is available on the internet. the dataset is high-dimensional and multi-scale datasets that contain recordings from the motor cortex with a 10-by-10 Utah electrode array during controlled reach-to-grasp movements for two monkeys (L and N). the activities of a large number of simultaneously recorded single neurons (93 and 156, for L and N respectively) along with the continuous neuronal "raw" signals. sampling rate is 30 kHz and it's band-passed filtered to 0.3 Hz-7.5 kHz.

During a trial, the monkey had to grasp the object using either a side grip (SG) or a precision grip (PG). The PG had to be performed by placing the tips of the index and thumb in a groove on the upper and lower sides of a cubic object, respectively. For SG, the tip of the thumb and the lateral surface of the other fingers were placed on the right and left sides of the object . The monkey had to pull the object towards him/her against one of two possible loads requiring either a high or low pulling force (HF and LF, respectively). As a result, four different types of trials are SG-LF, SG-HF, PG-LF, PG-HF. In each trial, the grip and force instructions for the requested trial type were provided to the monkeys independently through two consecutive visual cues (CUE and GO) which were separated by a one-second delay. Both cues were coded by the illumination of specific combinations of two LEDs of a five-LED cue panel positioned above the target object. Details on how the task, the trial scheme, and the corresponding behavior of the monkey were controlled are stated in Sec. 'Behavioral control system'. The datasets of both monkeys were recorded in the late morning. The recording session of monkey L and N lasted 11:49 and 16:43 min in which they performed 204 and 160 trials, respectively. However, monkey L performed only 70 precent of all trials correctly, whereas monkey N completed 90 precent of all trials during the recording. Nonetheless, the high percentage of error trials in monkey L are mainly caused by too early movement onsets reflecting the eagerness, but also the nervousness of monkey L's character . In contrast to these error types, monkey L used only 12 times the wrong grip compared to monkey N who performed an incorrect grip type 16 times during the session. For both monkeys, the trial types alternated randomly between trials leading to slightly different numbers of trials with the same trial type in each dataset.(17)

Methods

We use MATLAB R2020b for our processing and figures. for preprocessing, with labels we reject the trials that don't reach the Reward event.

We use raster plot to see the behaviors of neural spikes in every trial to see how a neuron responds to a specific task. to plot this specific plot, we put a dot in time that a neuron spike in every trial. the y axis is for trials and the x-axis is the time which is locked to the start of a trial.

One of the most important things to analyze is the behavior of the neurons in the firing rate of neural spikes. for this aim, we can use PSTH to see how neurons firing rate changes over time. in PSTH, with a window, we can find the rate overall

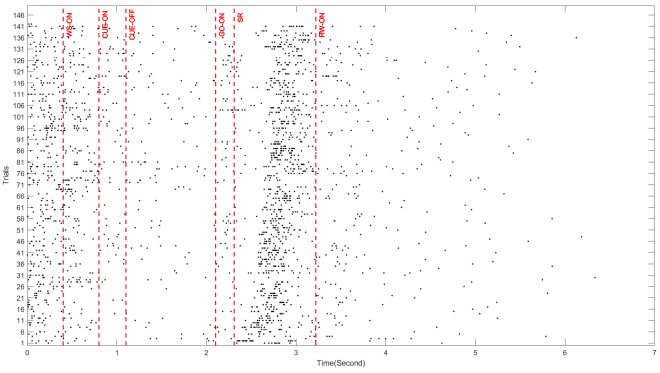

Fig. 1. Raster Plot for Neuron 0 from Electrode 1 for all trials

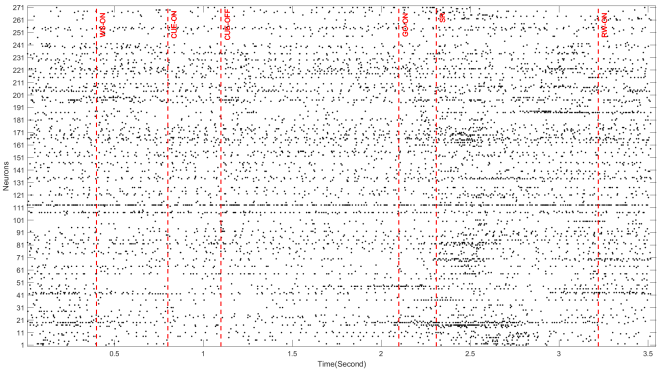

Fig. 2. Raster Plot of All neurons for Trial number one

trials with raster plot to see the rate of neurons at the time of the window.

PSTH formula :

$$r(t) = \int_{-\infty}^{\infty} w(\tau)p(t-\tau)d\tau$$

A key tool to evaluate a hypothesis is a statistical test, based on mathematical theorems that verify whether an opinion is true or not. we have used a permutation test that is a non-parametric test for evaluating specified hypotheses in order to answer certain questions.

Results

First of all, we plotted the raster plot in two manners. first, we plot a raster plot for a single neuron from electrode 1 for all trials(fig.1), and then a raster plot for all neurons for a single trial(fig.2). using different event times, we time-locked the start of each trial to TS-ON, then obtained a raster plot in mentioned two manners. also, we obtained PSTH plot with a bin size equal to 1000 for a neuron in all trials(fig.3), as an alternative method to reach a general conclusion about neurons activities.

We can see that after the SR event there is a peak in PSTH, similarly, in the raster plot we see that neurons are actively firing. because recordings are made from a motor area, neurons are more sensitive to events associated with action like SR.

Now using histogram we can find ISI distribution of neurons. we see that the distribution is very similar to exponential distribution. by assuming that ISI distribution is exponential

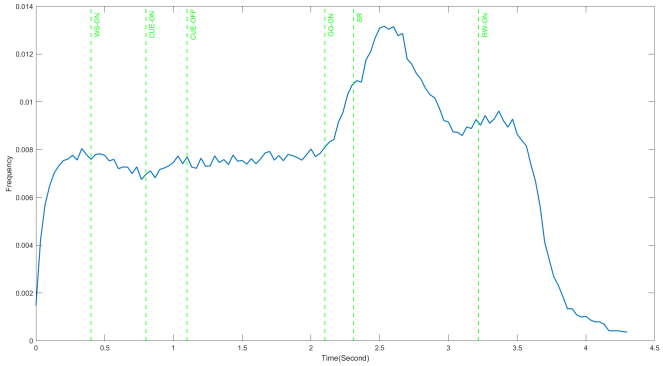

Fig. 3. PSTH For All trials For All Neurons

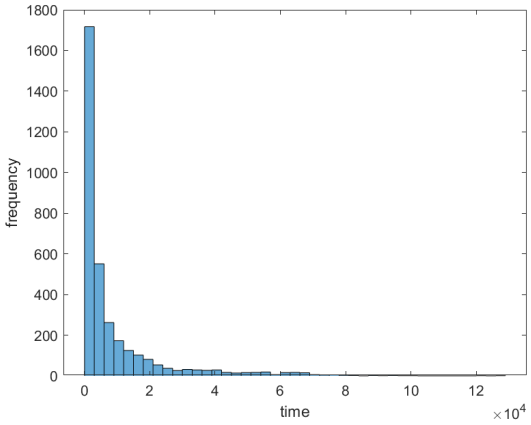

Fig. 4. histogram of ISI distribution

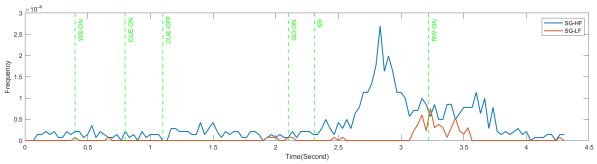

Fig. 5. PSTH For SG trials

distribution, we can prove that neurons firing point process follows a poisson distribution. assume $N(t)$ be the number of firing by time, X_i be the i^{th} inter-spike interval and $T_i = \sum_{n=1}^{n} X_i$ the waiting time for n^{th} firing. the key observation is that the events $N(t) = n$ and $T_n \geq t \geq T_{n+1}$ are the same.

This means that we can write :

$$P(N(t) = n) = P(T_{n+1} \geq t) - P(T_n \geq t)$$

$$\frac{(\lambda t)^n e^{-\lambda t}}{n!} = f_{n+1}(t) - f_n(t)$$

Where f_n denotes the tail probability of an erlang(n,λ) distribution which is the distribution of T_n assuming independent exponential inter-spike intervals. but equality works in both directions, so if we are given that inter-spike intervals are exponential and independent, then the right hand side is $f_{n+1}(t) - f_n(t)$, and it follows that $P(N(t) = n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!}$ so point process of spikes is poisson.

Now we can claim that neurons are sensitive to the SR event, as recordings are made from the motor area in the brain, it is expected to have more activity and firing when the subject is performing an action. we observe that after the SR event, the peak of firing occurs in PSTH plot and this approves this opinion.

The question is "can we prove that SR-ON event is effective on firing rate statistically", after choosing SR-ON as the most effective event on firing rate of neurons,we consider 0.5 second before until 1.5 second after the event, then we define Null and alternative hypothesis, Null hypothesis claims this event has no effect on firing rate, and Alternative hypothesis claims that the event increases firing rate. using permutation test,choosing samples and finding z score, we find p-value significant(0.0001) and alternative hypothesis is accepted.

We can perform this test with fano factor too, fano factor is obtained from following formula :

$$Fanofactor = \frac{\sigma^2}{\mu}$$

After calculation of fano factor for 0.5 second before the SR-ON event and 1.5 second after that, by performing permutation test(Null and Alternative hypotheses are same as previous part) , p-value is significant(0.0149) and similar to previous test alternative hypothesis is accepted.

As it was mentioned before, there is 4 type of trials, based on how subject has done the trial. using decimal numbers in the dataset for each trial, we can define what type of trial each is. after defining this 4 groups, PSTH plot can show firing difference of neurons in this 4 groups(fig.5 fig.6)

We observe difference between PG and SG trials. this difference in firing for different trials was expected, because movements task is different, so neuron fire in different manner.

Final question that we want to answer is " is neuron's behavior oscillatory or not ?". to answer this question, we calculate PSTH plots for neurons and obtain mean of them. we filter the mean signal using highpass filter to eliminate DC from signal. by considering Fourier transform of the filtered signal we observed that frequency spectrum is concentrated at specific frequency(fig.7).(18) so firings of neurons are oscillatory.

conclusion

In this article, it was shown that PMv neurons are sensitive to movement tasks and in case of acting, they fire actively at a higher rate than before. we proved this hypothesis using statistical tools, PSTH, and raster plots. also, we observed different behavior of neurons in case of different trial classes and oscillatory behavior of neurons.

It was expected to obtain these results and it was compatible with what was studied in the principle of neuroscience Course.

In further experiences and studies, activities of neurons in different areas can be discovered to have better solutions for mental diseases.

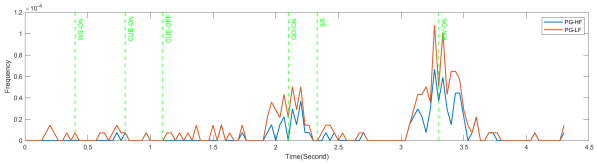

Fig. 6. PSTH For PG trials

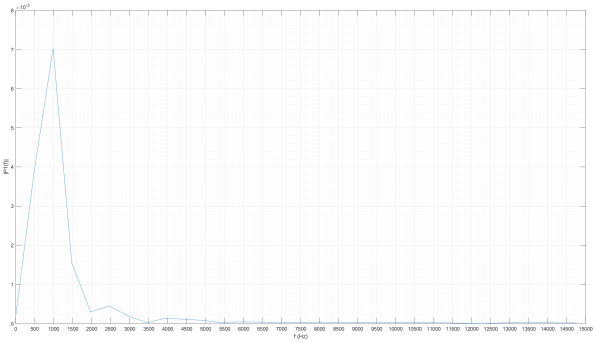

Fig. 7. Frequency spectrum of mean of PSTH plots of neurons

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