Body movement is consisted of a wide range of complex actions, especially in primates. Throughout these years, different regions of cortex have been associated with motor actions. These areas are premotor cortex, primary motor cortex & supplementary motor area, which are located in the frontal lobe. Moreover, substantial amount of studies has turned their attention to hand movements. The reason is the various aspects & parameters, such as direction, speed, force, etc., that contribute to this special motion.

Until now, most of the researches have focused on the spatial tuning of movement related areas. However, there hasn’t been sufficient evidence regarding the temporal responses of the motor cortex & the roles of individual neurons in coding movement parameters. On the one hand, it is not clear that there need be any straightforward relationship. On the other hand, a large body of work has stressed the simple relationship between the measured responses of motor cortex neurons and kinematic parameters such as reach direction and speed. [PAPER 1]

In this paper we have approached these issues by analyzing the electrophysiological datasets recorded from the motor cortex of a male macaque monkey during a delayed reach-to-grasp task. This experiment is done in four types of tasks, different in direction & force of grasp. Each task is consisted of a handful of events that have been manually timestamped and allow us to investigate neural responses with regard to time of these events. Also, through examining single neuron activities in each type of grasp, we inspect the notion of aspects like force & direction, being coded by individual neurons. All these analyses are done by statistical testing on two key features, extracted from spike trains; firing rate & Fano factor.

Materials and Methods

The dataset used in this paper is made available by the German Neuroinformatics Node of the International Neuroinformatics Coordination Facility (INCF). It contains recordings from the motor cortex with a 10-by-10 Utah electrode array during controlled reach-to-grasp movements for two macaque monkeys (L and N) and the data that we used for our analysis was gathered only from the right hemisphere of monkey N, the male monkey. The Utah array was surgically implanted a few millimeters anterior to the central sulcus, aimed to be located in the arm/hand representation of the primary motor cortex with the most anterior electrodes encroaching upon the premotor cortex. Particularly in monkey N, the array encompassed two areas; M1 and the premotor ventral cortex (PMv).

Fig. The left picture shows the orientation of the implanted array regarding the wire bundle (white triangle) and the picture to the right indicates its default orientation. Also in the picture of the implanted array, M1 and PMv areas can be distinctly recognized by the putative border (the vertical dotted line).

After leaving out the four inactive corner cells of the array, each of the 96 recorded neural signals was differentially amplified and filtered with a 1st-order 0.3 Hz high pass filter (full-bandwidth mode) and a 3rd-order 7.5 kHz Butterworth low pass filter. The band-pass filtered neuronal signals were digitized with 16-bit resolution at 0.25 V/bit and a sampling rate of 30 kHz, in the following called “raw signal”. Then the LFP data was extracted from a copy of the raw data, digitally low-pass filtered at 250 Hz (Butterworth, 4th order), and down sampled to 1 kHz. Furthermore, by filtering and sorting different combinations of the raw signal through waveform detection, 271 different spike trains have been obtained which represent different neural masses, including single and multiple unit activities. To investigate neurons individually, we concentrated our analyses only on the 156 single unit activities (SUAs).

In the task provided by the monkey, he had to grasp the object using either a side grip (SG) or a precision grip (PG) and then pull the object towards him against one of two possible loads requiring either a high or low pulling force (HF and LF, respectively); finally, he would have received the maximum reward if he had pulled the object in the correct grasp for at list 500 ms. The mixture of these experiments leads to four types of task, allowing us to examine on the direction and force of grasp. This experiment was orchestrated by exactly time distanced digital instruction signals given to the monkey through different LED combinations. Each signal represented a specific event initiated from the control system in LabVIEW. Also, there were some events initiated by the monkey recorded through digital or analog signals, representing his movements and interaction with the object.

Fig. Events and their chronological orders. The first event is TS-ON, which is only internally set by LabVIEW to mark the start of the trial. After that, the monkey receives three signals: WS-ON, CUE-ON and GO, subsequently to warn him of the trial start, give him the grasp direction and to signal the movement start (also giving him the required force type). SR event, marks the time he has lifted his hand from the rest position switch and is going to reach the object. RW-ON and STOP(WS-OFF) happen respectively after the monkey has pulled the object for the required duration, and to mark the end of the trial.

For monkey N, the recording day lasted for one hour with the dataset i140703-001 as first out of 3 recording sessions in the late morning. The recording session of monkey N lasted 16:43 min in which they performed 160 trials. However, he successfully completed 90% of all trials during the recording and performed 19 error trials, which consisted of 16 grip type errors and 3 early movement initiation errors. According to the dataset paper, the four different tasks were distributed equally so that after removing the error trials we would be left with almost the same number of correct trials for each task.

Table.

We extracted the spike trains representing SUAs, by choosing the ones with the ‘an\_sua’ flag in the dataset. We also removed the error trials based on their recorded events and whether or not the trial included a reward event. At the end, we gathered 142 trials (one error trial was undetected) for each of the 156 single neuron spike trains. In order to analyze each task separately, we categorized the asks into the desired four types by examining the CUE and GO event labels. The result was 35 trails for each LF task and 36 for each of the HFs. Additionally, we separated neurons of the M1 area from the PMv based on their channel IDs, considering the orientation of the implanted array (Which indicates that the array IDs 45,47,49,53,55, and 73 to 94 are located on the PMv).