

Sensorimotor Gaussian Fields Integrate Visual and Motor Information in Premotor Neurons

Rahul Agarwal, Sridevi V. Sarma, Nitish V. Thakor, Marc H. Schieber, Steve Massaquoi

Premotor cortex (PM) receives inputs from multiple brain regions that carry both visual and somatosensory information, and generates motor outputs that may play a role in both the direct control of movements and in the planning of movements. Understanding how PM encodes information has gained particular importance as efforts have intensified to extract better cortical motor control signals to drive neuroprosthetic limbs. Especially, when a task involves reaching and grasping a visually located target, PM very likely encodes signals that could be useful in guiding an artificial arm.

Premotor ventral (PMv) is active when either the hand is in a particular grasp position or when the animal sees someone else's hand in a particular grasp position (mirroring effect) [1]. In addition, PMv neuronal activity modulates with the position of an object in the peripersonal space relative to a body part, and interestingly, neuronal response is independent of the direction of gaze [2]. Further, stimulation of different PMv neurons [3],[4], results in the movement of the monkey's hand to different final positions and grasp postures, irrespective of the starting position and posture. These studies make it apparent that PMv combines visual and somatosensory information to generate motor commands [1]-[7]. However, it is unclear how visual and somatosensory information are integrated in PMv and what is the exact nature of the motor command.

In this study, we determine a task-independent representation for PMv neuronal signal encoding that is consistent with both its afferent neuroanatomical connections and the many observations of its firing activity under various experimental conditions [1]-[7]. In particular, we analyzed neuronal spiking data from 123 PMv neurons recorded from two primates executing four types of reach-to-grasp tasks (for details see [8]). In addition, 30 different electrodes recorded the hand position and grasp configuration. From this, we computed 4 behavior signal candidate functions of position and hand configuration with respect to the home object in (i) Cartesian co-ordinate space, (ii) joint angle space, (iii) velocity in joint angles, and (iv) acceleration in joint angles. For each neuron we estimated its instantaneous firing rate, λ and sought to explain the behavior of this rate in terms of functions of the 4 types of behavioural signals, x , i.e. $\lambda(t) = f(x(t))$.

Using maximum likelihood estimation from spike train data, we found that in greater than 90% of PMv neurons, firing intensity can be well represented as Gaussian functions of a multi-dimensional vector containing position-configuration of hand (sensorimotor information) with respect to the position-shape of a reference object (visual information). See Fig. 1 for an example of model fits to all 4 tasks. The velocity or acceleration behavioural signal candidates did not fit the data as well. Furthermore, firing activity in most neurons was described when neuronal activity anticipated the hand position-configuration by 175ms, in both the monkeys. These Multidimensional (Sensorimotor) Gaussian Fields can be viewed as generalizations of 1-D tuning curves and analogous to receptive fields in primary sensory areas.

Our findings are consistent with previous investigations and suggest bell-shaped task independent receptive fields in PMv encoding predicted limb position, but not likely limb velocity or acceleration. This allows consistent prediction of 21 degrees of freedom in a limb movement trajectory with considerable accuracy across all four tasks, atleast 175ms before movement.

REFERENCES

- [1] Rizzolatti G, Fadiga L (1998) Grasping Objects and Grasping Actions Meanings: Dual Role of Monkey Rostroventral Premotor Cortex (area F5). *Novartis Found Symp.* 1998;218:81-95.
- [2] Graziano MSA, Hu XT, Gross CG (1997) Visuospatial properties of ventral premotor cortex. *JN Physiol* 77: 2268-92.
- [3] Graziano MSA, Taylor CSR, Moore T, Cooke DF (2002) The cortical control of movement revisited. *Neuron* 36: 349-62.
- [4] Graziano M (2006) The organization of behavioral repertoire in motor cortex. *Annu Rev Neurosci* 29: 105-34.
- [5] Dancause N, Barbay S, Frost SB, Plautz EJ, Stowe AM, et al. (2006) Ipsilateral connections of the ventral premotor cortex in a new world primate. *J Comp Neurol* .
- [6] Fogassi L, Luppino G (2005) Motor functions of the parietal lobe. *Current Opinion in Neurobiology*: 626-31.
- [7] Wise SP, Boussaoud D, Johnson PB, Caminiti R (1997) Premotor and parietal cortex: Corticocortical connectivity and combinatorial computations. *Annu Rev Neurosci* 20: 25-42.
- [8] Mollazadeh M, Aggarwal V, Davidson AG, Law AJ, Thakor NV, et al. (2011) Spatiotemporal variation of multiple neurophysiological signals in the primary motor cortex during dexterous reach-to-grasp movements. *The Journal of Neuroscience* 31: 15531-43.

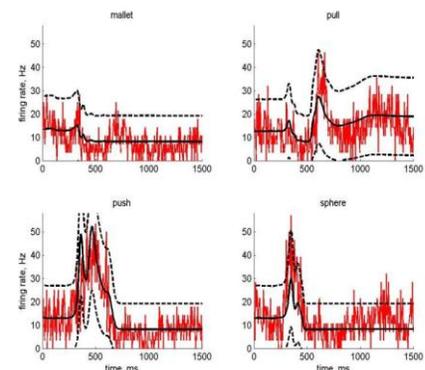


Figure 1. Model fit for a neuron for all 4 types of tasks: Reach and 1. Rotate a Mallet 2. Pull a Cylinder 3. Push a Button 4. Rotate a Sphere. Thick black line is model prediction with 95% confidence bounds (dashed lines). Red line is histogram plotted from cross-validation data. 500 ms marks the start of the movement.

This work was supported in part by Burroughs Wellcome Fund CASI Award 1007274, NSF CAREER 105556, and NIH R01NS073118-02. R. A., S.V.S and N.V.T. are with the Department of Biomedical Engineering, Johns Hopkins University, Baltimore, MD, USA (410-516-5294; fax: 410-516-5294; e-mail: ragarw11@jhu.edu). M.H.S is with Department of Neurology, General Neurology, University of Rochester Medical Center, Rochester, NY, USA. S.M. is with Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, USA