Spatial Encoding of Reaches in Preparatory Motor Cortical Activity

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One of the open questions in motor neuroscience asks how movements are specified before they are executed. Several studies have examined neural activity that precedes movement in order to understand what aspects of a movement are planned prior to execution. During preparation for hand reaches, individual neurons in premotor cortex (PMd) are known to reflect the direction and distance of upcoming movements, as well as speed (Churchland et al. 2006), target location in visual space (Shen et al. 1997), and target location relative to the eye and hand (Batista et al. 2007). While such evidence provides clues, it is still up for debate exactly how the nervous system plans movements. A crucial step in this process will be to identify the independent parameters present in motor cortical activity. In this study, we asked two main questions (1) what are the spatial factors that describe the upcoming movement in PMd?, and (2) how precisely are they planned before movement onset? Answering these question could help elucidate the role of PMd during motor preparation.

Most studies of preparatory activity have examined how the activity of single neurons correlate with external parameters. Since information is encoded with high redundancy between neurons, population-level analyses can reveal the latent and primary factors of the entire population of neurons in a certain area. It can also be used to quantify the amount of information encapsulated by the factors available in the recorded area. Here, we used population-level analyses to reveal the neural structure of rhesus macaque PMd during an instructed delay reaching task. We found that the primary independent spatial factors do not appear to be direction and distance, but rather appear to be the location in Cartesian space. While the structure of the neural states for upcoming reaches is Cartesian, the distribution of single trials forms an ellipse whose principal axis is oriented in the direction of the reach in neural space. As in behavioral studies of preparation (Messier & Kalaska, 1997), the variance in neural state is smaller for direction than distance. However, while there is less information about distance than direction in preparatory activity, for the purposes of decoding, they can be estimated with equal precision (std = 1.6 cm). This can partially be explained by the fact that speed is also reflected in preparatory activity.

Our findings shed light on the neural structure and the spatial factors encoded in PMd during movement preparation, and how precisely those factors are planned. Revealing the Cartesian structure of preparatory activity gives further insight into the process by which voluntary movements are planned and supports the view that PMd is involved in "high-level" planning of reaches. As one translational application of these results, mapping the population level factors and their decoding precision can be used for designing optimal target locations for brain-machine interfaces.