Stimulus reconstruction from in vivo spiking activity of neuronal populations in somatosensory cortex

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Sensory stimulation leads to distributed activity across a wide population of neurons in the mammalian somatosensory cortex. It is presumed that information about the sensory stimulus is likewise distributed across a population of neurons, but it remains unknown how information content grows with the number of neurons in the observed population. We aimed to predict the onset times and angles of individual whisker deflections from the activity of simultaneously recorded layer 2/3 neuronal populations, in vivo.

Layer 2/3 neurons located above the layer 4 barrel were bulk loaded with the calcium sensitive indicator Oregon-green BAPTA-1 AM and imaged using 2-photon microscopy (TPM). TPM allowed us to monitor both spiking and non-spiking neurons within these populations with single action-potential and single neuron resolution. In addition, this spiking activity was related back to neuron position within the somatotopic map with high (<5 µm) spatial resolution.

We then evaluated several techniques for stimulus information extraction from neuronal activity patterns, ultimately deciding on a correlation based algorithm for its simplicity and effectiveness. We used this method to predict the time and angle of whisker deflection from neuronal population activity. We found that the activity of one neuron alone allowed for prediction accuracy only slightly above chance levels. However, as the number of simultaneously recorded neurons that were included in the analysis was increased, prediction errors of both type I (false positives) and type II (undetected stimuli) decreased. We defined a measure of the total extractable information based on the mutual information of Shannon, and found that this quantity increases linearly with the number of available neurons.

Using the spatial discrimination capacity of TPM, we observed a highly significant increase in accuracy for the prediction of stimulus onset times among neuronal populations inside the barrel column, as opposed to those in the septal area between barrel columns. However, this anatomical difference was not evident for the prediction of stimulus angle. Both individual neurons and local neuron populations varied widely in the relative amounts of information they contributed about the stimulus.

By extrapolating these results to a larger population of neurons, we were able to estimate that near perfect reconstruction of stimulus onset time could be accomplished with between 175 and 201 Layer 2/3 neurons, while reconstruction of stimulus angle could be accomplished with between 244 and 291 neurons. We conclude that sensory inputs to the barrel cortex can be accurately reconstructed from a relatively small population of layer 2/3 neurons, and that stimulus features that are not available in the activity of any individual neuron can be faithfully represented by neuronal populations.