

Tuning ramping neuronal activity and reaction time by balanced synaptic input in a decision making circuit

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Neurophysiological studies on nonhuman primates have discovered that in some brain areas such as lateral intraparietal (LIP), single-neuron activities correlated with time integration of sensory information during perceptual decisions. To study the mechanism of the decision related neural activity, we have previously proposed a spiking neural network model [1] which exhibits ramping neuronal activity with reaction times in the range of hundreds of milliseconds and approximately Gaussian reaction time distributions, consistent with the behavioral data from the monkey experiment. In the present study, we show that our model can be extended to produce reaction times longer than one second and asymmetrical reaction time distributions with a broad exponential tail, as observed in some human studies of simple decisions.

The main idea is that ramping activity in a decision circuit (like LIP) is under the influence of top-down signals, presumably from the prefrontal cortex. One candidate mechanism that instantiates gain modulation assumes that noisy excitatory and inhibitory synaptic inputs to a neuron covary in a balanced configuration. On the single neuron level, theoretical and experimental works have shown that the balanced synaptic input modulates the gain of a neuron in response to external drives [2]. How a balanced synaptic input affects a highly recurrent neural network is unknown. We implemented a balanced synaptic input in our attractor decision-making model, and tested the possibility that such a gain modulation provides a mechanism to dynamically adjust the rate of ramping activity, thereby determining a desired range of reaction times as well as the shape of reaction time distribution.

We found that the balanced input significantly slows down the ramping activity. While the mean reaction time can be extended to about two seconds, the distribution of reaction time follows a broad exponential tail with a maximum reaction time close to five seconds. This is because a decreased gain of single cells leads to a weakened competitive interaction between neural pools selective for different choice alternatives. Long reaction times and skewed reaction time distributions can be produced by the linear ramp-to-threshold (diffusion) model, a popular cognitive model for simple decisions. However, whereas in the diffusion model a lower drift rate required for a longer reaction time leads to poorer performance, in our neural circuit model the addition of a balanced synaptic input improves the decision performance.

We further show that by changing the balanced input strength, we can switch the network between different states: quiescence, competition (decision making) and bistability. Thus the balanced input indeed can serve as a mechanism that dynamically tunes the network behavior without the need of changing intrinsic properties of the network such as synaptic strength or membrane conductance.

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References

- [1] Wang XJ. *Neuron* 2002;36:955-968.
- [2] Chance FS, Abbott LF and Reyes AD. *Neuron* 2002;35:773-782.