Title: Slow ramping neural activity before voluntary actions emerges from spontaneous fluctuations in spiking neural networks

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The ability to initiate actions endogenously is critical to goal-directed intentional behavior. A ubiquitous finding from neuroscientific studies of self-initiated action is that endogenous movements—even fully spontaneous ones—are preceded by slow buildups of brain activity in medial frontal regions (the EEG readiness potential or RP: Libet et al., 1983; Shibasaki & Hallett, 2005; fMRI: Soon et al., 2008; Sakata et al., 2018). Individual neurons in medial frontal cortex (MFC) ramp their firing rates in a similar timeframe before spontaneous actions (Fried et al., 2011). So-called “stochastic fluctuation models” (SFMs) link the buildups to slow fluctuations in neural activity that trigger movement upon crossing a threshold (e.g. Schurger et al., 2012; Schurger et al., 2018; Maoz et al., 2019; Moutard et al, 2015) or bias the timing of movement (Schmidt et al., 2016). Aligned to movement and back-averaged, the fluctuations will resemble a slow-ramping signal with onset several seconds before movement. SFMs imply that the onset of slow-ramping does not reflect a specific neurocognitive event, and they therefore have vastly different implications than traditional interpretations of the RP (e.g. Libet et al., 1983). However, it is not clear how SFMs could be implemented via the joint dynamics of individual neurons.

We simulated spiking neural networks with clustered connectivity and a mixture of fast and slow synaptic dynamics to investigate slow ramping signals. We found that slow synapses stabilized spontaneous fluctuations, facilitating the emergence of slow ramping before threshold crossings. Individual simulated neurons exhibited slow ramping with an average ramping onset of about 2 seconds before threshold-crossings, with a majority decreasing their firing rates (61%). For comparison, we re-analyzed a dataset of human MFC neurons (n=512; by Fried, Mukamel, & Kreiman, 2011) recorded during a self-initiated action task. Simulated ramping had a striking similarity to slow ramping in real data, where a majority of neurons also decreased their firing rates (63%). Furthermore, decoding analyses indicated that the networks exhibited population-level ramping akin to real data. An EEG proxy extracted from the network also showed a gradual negative deflection beginning around 2 seconds before threshold-crossing, reminiscent of the RP. Finally, our model predicts that neurons that ramp together will also exhibit correlated activity before ramping onset. We conclude by validating this model-derived hypothesis in real data. These results support the hypothesis that pre-movement buildup signals reflect fluctuations triggering action upon crossing a threshold.