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A network of reverberating neuronal populations encodes motor decision in macaque premotor cortex

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Background

We investigate, through in-vivo experiments and theoretical models, the dynamic mechanisms subserving motor decision tasks. The proposed computational framework is based on local reverberations in multiple neuronal subpopulations. Signatures of such reverberations are identified in the simulated multi-modular network of spiking neurons and recognized in the analysis of recorded neural activity. The reported experimental results are compatible with a neuronal substrate in which several local populations undergo sudden transitions as a late reaction to a visual stimulus. Often, such transitions are very plausibly supported by strong local recurrent feedback as in models of decision making [1]. Transitions also occur without clear evidence of local reverberation; the combined evidence suggests the coexistence of "active" and "passive" modules, the latter responding to the activity of the first ones, which together cooperate in order to represent a distributed and well stereotyped motor program.

Results

We recorded from dorsal premotor cortex (PMd) of two monkeys required to reach quickly a target randomly appearing in one of two opposite peripheral positions (movement conditions) after a go-signal (no-stop trials), but to withhold the movement whenever an intervening stop-signal was shown after a random delay (stop trials). We selected recordings showing a significant increase, in at least one movement condition, of MUA activity during no-stop reaction time (the epoch between the go signal and the movement onset). Sixty-one percent (68/112) of these recordings are characterized by a sharp upward transition (SUT) of the MUA signal, the time of which is strongly correlated with the movement onset at the single trial level. On average, upward transitions precede the movement onset by 110 ms and are completed in less than 100 ms.

The predictive value of the SUT time of occurrence is strengthened by the behavioral outcome of the stop trials. In "wrong" stop trials, when the monkeys fail to cancel the movement, an early SUT is observed while either none or later SUT are observed in "correct" stop trials. Taken together the evidences from stop and no-stop trials support the speculation that the occurrence of a SUT in PMd is causally related to movement onset. In a sizable fraction of the recordings during the reaction times, the MUAs have a bimodal distribution, which suggests the existence of two preferred levels of firing rates; this is consistent with observations from single unit recordings [2] and compatible with attractor-like dynamics of the probed neuronal population [1,3,4]. We furthermore probed during reaction time the Fourier spectral features of the raw electrophysiological signal in 20 ms sliding windows. Low-activity and high-activity periods show clearly different modulations of the spectral power in medium (50–

230 HZ) and high-frequency (230–1080 Hz) bands. MUA with unimodal distributions do not show the above modulation of power spectra; their transitions can be thought to be driven by the input they receive from other reverberating modules.

Simulations of multiple populations of synaptically coupled leaky integrate-and-fire neurons with recurrent excitation and inhibition [4] reproduced qualitatively well the observed MUA dynamics. In particular, randomness in SUTs emerges from intrinsic fluctuation of spiking activity. For strong enough AMPA/NMDA recurrent couplings, simulations reproduced both bimodal distributions of firing rate and spectral modulations observed from experiments, reinforcing the picture of neural populations capable of multi-stable dynamics and high input susceptibility, supported by local activity reverberation, as a plausible interpretation of experimental evidence.

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