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Title: Modeling gain neuromodulation of recurrent cortical networks for cognitive switch

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Behavioral adaptation to new environments is a key ingredient of a successful strategy for a living system and it requires a trade-off between the stability of a chosen interpretation of external events and the ability to suddenly change “rule”, to improve the performance in a changing environment. Complex cognitive tasks can require animals to go through several processing stages, each one representing a mental state containing the information about past experiences, and the “instructions” to parse new events and generate the proper motor response. Here we provide evidence that a multi-modular recurrent network of leaky integrate-and-fire (IF) neurons can realize arbitrarily complex schemes of distributed attractors and event-driven transitions between attractors. We show that such networks can implement task switching protocols, often used in psychophysics experiments, to test the ability of the system to respond differently to the same stimulus, depending on the rule in effect. Transitions between attractors in such noisy and distributed cortical networks can be implemented if a balance between the global and local synaptic interactions emerges: global connectivity between two modules has to be more diluted (only about 14%) than the local one within a module.
Guided by the experimental results, we investigated the role of neuromodulators in our model. Acetylcholine (ACh) and norepinephrine (NE) are known to modulate both the excitatory and inhibitory local synaptic transmission. In particular, NE facilitates the exploration of new strategies/rules when the animal performance degrades due to a change of the environment/context. We find in our simulations different effects of NE depending on the how the balance of synaptic transmission is affected. When local excitation is more preserved than inhibition, an increased “gain” provides a stronger response to the same stimulus. The opposite gain modulation appears if local inhibition is relatively stronger. Under this condition, cortical modules behave more “linearly” and lose their ability to have high-frequency attractor states, resetting to a spontaneous activity state: such disruption of the inner bias and the presence of endogenous fluctuations in neuronal activity are found to be a natural way to implement a stochastic selections of possible stimulus-related responses. Among testable predictions, we report how unbiased responses have relatively longer reaction times due to the competition within the network.

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