The role of heterosynaptic plasticity in preventing runaway synaptic dynamics

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Spike-timing dependent plasticity (STDP) and other conventional Hebbian-type plasticity rules are prone to produce runaway dynamics of synaptic weights. Once potentiated, a synapse would have higher probability to lead to spikes and thus to be further potentiated, but once depressed a synapse would tend to be further depressed. The runaway synaptic dynamics can be prevented by precisely balancing STDP rules for potentiation and depression, however, experimental evidence shows a great variety of potentiation and depression windows and magnitudes. We show that modifications at synapses to layer 2/3 pyramidal neurons from rat visual and auditory cortices in slices can be induced by intracellular tetanization: bursts of spikes evoked by short depolarizing pulses applied to postsynaptic cell without presynaptic stimulation. Induction of these heterosynaptic changes depended on the rise of intracellular calcium, and their direction and magnitude correlated with initial state of release mechanisms. We suggested that this type of plasticity may serve as a mechanism that normalizes synaptic weights and prevents their runaway dynamics. To test this hypothesis, we developed a cortical neuron model implementing both homosynaptic (STDP) and heterosynaptic plasticity with properties matching the experimental data. We found that in the model with STDP alone, correlated spike trains induced runaway synaptic dynamics over a broad range of STDP parameters and input patterns. Runaway dynamics manifested itself as saturation of all or a significant portion of synaptic inputs at maximum or minimum weights. Heterosynaptic plasticity effectively prevented runaway dynamics for the tested range of STDP and input parameters. Synaptic weights, although shifted from the original, remained normally distributed and non-saturated within their operating range. Our study presents biophysically constrained model of how interaction of different forms of plasticity – Hebbian and heterosynaptic – may prevent runaway synaptic dynamics but keep synaptic weights unsaturated and thus susceptible for further plastic changes and formation of new memories.

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