Abstract

It is widely accepted that the brain processes related to learning and memory occur at the level of synapses. Individual synaptic connections are strengthened or weakened depending on the ongoing brain activity. In neurobiology, this is called synaptic plasticity. One of the best studied rules of synaptic plasticity is the Spike-Timing Dependent Plasticity (STDP) rule which defines the direction and magnitude of synaptic changes based on the precision timing of pre- and postsynaptic events (spikes). In our work, we implemented a modified STDP rule which considers reaching the threshold value by local excitatory postsynaptic potential as a postsynaptic event. The synaptic plasticity rule also includes metaplasticity, a homeostatic mechanism at the cellular level, that regulates the magnitude of synaptic changes according to previous neuronal activity. Our goal was to use our meta-STDP synaptic plasticity rule for modeling experimental data on synaptic plasticity measured in hippocampal CA1 pyramidal cells. In this work, we used computational modeling methods to: (1) develop a new compartmental model of CA1 pyramidal cell with reduced morphology and validate and compare it with other models using HippoUnit tests, (2) introduce excitatory synapses distributed along the dendritic tree according to experimental data and endow them with the meta-STDP plasticity, (3) stabilize synaptic weights during ongoing spontaneous activity, (4) apply synaptic plasticity induction protocols and reproduce experimental data and make predictions, (5) confirm the role of active ion channels in dendritic spike initiation and synaptic plasticity. Our simulations predicted the induction of heterosynaptic plasticity at unstimulated synapses, the magnitude of which depended on the level of spontaneous activity, the stimulation protocol used, and the dendritic compartment where it was observed. In summary, we conclude that our model is biologically accurate and is suitable for taking into account the complex experimentally observed patterns of homosynaptic and heterosynaptic plasticity.

Key words: synaptic plasticity, metaplasticity, meta-STDP, computational modeling, CA1 pyramidal cells