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Spatiotemporal dynamics of calcium and calmodulin at the spine

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Calcium levels in spines play a significant role in determining the sign and magnitude of synaptic plasticity. Recent experiments using calcium sensitive dyes have allowed measurements of calcium transients in whole spines, however experimental resolution does not allow imaging of the spatial distribution of calcium within the spine [1,2,5]. Calcium can activate Calcineurin or bind to CaM and consequently activate CaMKII which is key mediator of synaptic plasticity. A main source of calcium influx into the spine is from the NMDA receptors. There are four different subtypes of obligatory NR2 subunits of NMDA receptors, NR2A/B/C/D. In the mature cortex the majority of the synaptic NMDA receptors are constituted by NR1/NR2A and in the immature cortex by NR1/NR2B. Experiments have shown that the subunit composition of NMDA receptors has an influence on the sign of synaptic plasticity, but different experiments resulted in different and possibly conflicting results [3,4]. NR2B has slower kinetics and higher affinity for Glutamate than that of NR2A. In addition NR2B receptors have a binding site for CaMKII.

For the study of the spatiotemporal dynamics of Calcium and Calmodulin we implemented a compartmental model of the spine head including the neck. We also simulated an intrinsic calcium buffer and calcium pumps on the surface of the spine. Calcium pumps and as well as NMDA receptors were simulated by Markov models [7]. Using this model we observe the spatiotemporal distribution of calcium and calcium-calmodulin transients. We find that the calcium pumps as well as the geometry of the neck affects the spatiotemporal dynamics of calcium and consequently of calmodulin, and that different NMDA receptor subunits differentially affect this distribution.

Finally, in the past it has been shown that stochasticity of calcium transients can affect plasticity rules [6]. We hypothesize that the main source of stochasticity of calcium transients at the spine arises from the stochasticity of NMDA receptor opening and presynaptic release. We investigate the validity of our hypothesis using a stochastic model for the spine. In that way we compare the calcium and calmodulin dynamics of the stochastic model with those of deterministic and hybrid models.

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