A model for reactive plasticity following cortical deafferentation and focal stroke

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It is still under debate to what extent structural plasticity in terms of synaptic rewiring are the cause for cortical remapping after a lesion or accompanied with motor skill-learning. Recent two-photon laser imaging studies demonstrate that synaptic rewiring is persistent in the adult brain and is dramatically increased following brain lesions or after a loss of sensory input (deafferentation). To study the time course of synaptic rewiring following a lesion, we propose a novel neural network model. We use a recurrent neural network model as a vehicle to model structural plasticity. The algorithm for an activity-dependent network formation used here is based on the neurite outgrowth algorithm by Van Ooyen et al. [3]. As an extension of the former model, we represent discrete axonal and dendritic elements separately in order to study the time and spatial course of synapse formation, pruning and synaptic turnover. Axonal and dendritic elements merge in a random fashion to synapses. If one cell reduces an axonal or dendritic element bound in a synapse, the synapse will be erased but the opposite element remains and can rebind with a different element to a new synapse. Model neurons increase and decrease axonal and dendritic elements in an activity-dependent fashion. Hence, synaptic rewiring is subject to shifts in the excitation-inhibition equilibrium. We apply this model to experimental data on cortical remapping following somato-motory deafferentation in the fashion of the early Merzenich work [2]. Here we show by our model that disinhibition of neurons close to the deafferented neurons induces an increase in axonal elements (axonal sprouting) that re-occupy the deafferented neurons. There is a gradient in the number of new synapses formed between neighbouring and deafferent neurons caused by a fading disinhibition with increasing distance from the deafferentation. By this study we demonstrate that maintaining network homeostasis and rebalancing deafferented neurons by synaptic rewiring can result in post-lesioning cortical remapping. Thus, the model bridges the gap between activity-dependent morphological changes on the neuronal level and a changing connectivity of cortical maps on an anatomic level. Furthermore, we can influence the time course of network reorganization by external stimulations. The positive effect of a chronic excitatory stimulation promoting recovery saturates after 100 time steps corresponding to about 100 days in rehabilitation but can be postponed by periodic inhibition. These theoretical results have large consequences for neurological rehabilitation i.e. for focal stroke patients as they can be tested experimentally and even in clinical applications.

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References