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Spike-timing-dependent plasticity in a recurrently connected neuronal network with spontaneous oscillations

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Introduction

Spike-timing-dependent plasticity (STDP) is believed to generate structure in neuronal networks by modifying synaptic weights depending on the spike-time information contained in the spike trains at the scale of milliseconds. In addition to spiking-rate-based information, STDP captures the effect of spike-time correlations at a short time scale (down to milliseconds), which is neglected by rate-based learning. This includes, for example, interaural time difference in auditory pathways [1] and repeated coincident spikes within input trains [2]. The impact of STDP in the presence of periodic neuronal activity has only just begun to be addressed, in particular the investigation of its role in modifying synchronisation in recurrently connected networks [3,4].

Methods

Extending a previously developed framework based on the Poisson neuron model [5], we investigate the effect of STPD on the recurrent connections of a neuronal network with no external input that is only driven by spontaneous oscillatory activity. We examine frequencies above 10 Hz, which correspond to the time scale of a typical choice for the learning window function of STDP. In this case, the weight dynamics is affected by the neuronal correlation structure induced by the periodic spiking activity. The asymptotic distribution of the weights is investigated using a fixed-point analysis upon a dynamical system of equations. Numerical simulations are used to support the analytical results.

Results and discussion

The strong competition resulting from STDP leads to the splitting of an initially homogeneous distribution of recurrent weights. In addition, STDP causes the firing rates to stabilise in a similar manner to the case of non-oscillatory spontaneous activity, which also ensures an equilibrium on the mean incoming recurrent weight for each neuron [5]. We consider a network of two identical neuronal groups where only one group (A) has oscillatory spontaneous activity, while the other group (B) has a fixed spontaneous firing rate. The connections within group A and those from A to B tend to become either potentiated or depressed at the expense of the other recurrent connections, depending on the frequency of the oscillatory spontaneous activity for group A. When both groups A and B have oscillatory spontaneous activity, the frequencies and respective phases (if applicable) determine the evolution of the recurrent weights, which can result in the strengthening of within-group connections or the emergence of feed-forward pathways. Our results elucidate the rich interplay between STDP and the spike-time correlation structure in biological-like neuronal networks that have oscillatory activity.

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