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Enhancing information processing by synchronization

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Synchronization is a generic dynamical feature of brain activity, occurring on a range of spatial and temporal scales in different cortical areas. There have been several suggestions about the functional role of synchronization, e.g. that it dynamically links elementary features into coherent percepts, performs magnitude-invariant pattern matching [1] or that it is just an epiphenomenon of the cortical dynamics. Here, we explore the different idea that synchronization serves as a mechanism to enhance differences in input patterns presented to a recurrently coupled neural network. Our idea is motivated by gamma oscillations observed in local field potential (LFP) recordings from macaque monkey area V4, which allow a support vector machine (SVM) to predict the stimulus shown to the animal with great accuracy [2]. These gamma oscillations are modulated by attention such that activity patterns for different stimuli become more distinct. This change in neural activity is accompanied by a pronounced increase in classification performance of the SVM. We investigate a recurrent network of randomly coupled integrate-and-fire neurons driven by Poissonian input spike trains. All synaptic connections have equal strength. The input rate distribution over all neurons in the network is fixed, with about half of the neurons being stimulated by a low rate, and the remaining neurons with a high rate. However, the assignment of these input rates to specific neurons is permuted for every stimulus, thus leading to specific stimulation patterns. Parameters are adjusted such that the network only weakly synchronizes in its ground state, corresponding to the non-attended condition in the experiments. Simulations of the network are done with N different patterns, and over M trials. Average activity is convolved with an alpha-function modeling the mapping of the population activity into LFPs. From these LFPs, power coefficients between 5 Hz and 200 Hz are computed and used as inputs for a SVM classifier, which had a performance of 35% correct for $N = 6$. We simulated the influence of attention by increasing the internal coupling strengths by 20%. While still being in a weakly synchronized regime, the LFPs for different stimuli now become more distinct, increasing SVM classification to 42%. Performances and power-spectra correspond well with experimental findings (Figure 1). In summary, this example not only proposes a novel mechanism for the enhancement of a neural representation under attention. It also introduces a new concept of how synchronization can render neural activities more distinct, (e.g. if higher areas like V4 collect information from local features). Hereby recurrent interactions amplify differences in the input rates and hence prevent information loss from a normal, synaptic averaging procedure.

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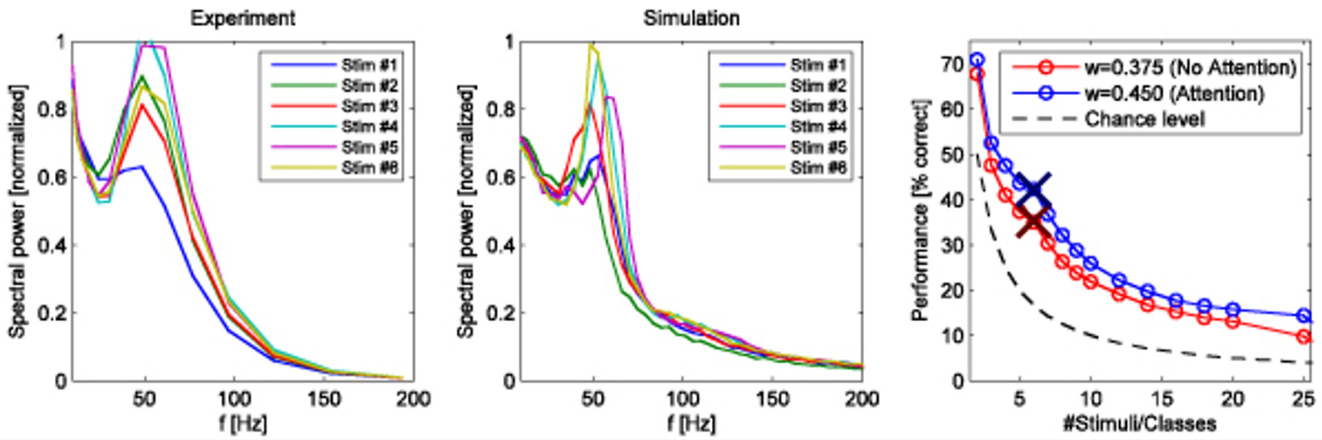

Figure 1

Comparison of model and experiment [2]. Left, spectral activity patterns from V4 for six different stimuli (adapted from [3]). Middle, spectral activity patterns from the model. Right, classification performance predicted from the model for increasing numbers of stimulus classes (lines, circles, dark crosses: empirical values for $N = 6$).