Antagonistic Cross-links and Reciprocal Couplings Emerge in Optimal Multisensory Integration

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Abstract:

Information from multiple modalities is integrated in the brain in a near-optimal way as predicted by Bayes' rule. However, the underlying neural mechanism and the optimal network architecture are largely unknown. Based on a decentralized architecture suggested by physiological and theoretical studies, we investigate how multisensory information is encoded in different components of a Bayes-optimal modular network. In this architecture, each module is able to function independently. To achieve inter-modular communication, each module receives direct inputs from other modalities through the cross-links, and indirect inputs from other multisensory modules through reciprocal couplings. The inputs from the lower-order areas are assumed to represent the unisensory likelihoods, and the steady state activity of the multisensory modules are assumed to represent the marginal posterior distributions in the corresponding modalities. Through theoretical analysis and simulations of recurrent neural network training, we found that the unisensory likelihoods are encoded in the same-channel connections and the multisensory prior information is encoded in the cross-talks in a distributed manner. The most striking discovery is that the feedforward cross-links and the reciprocal couplings form an antagonistic pair. The feedforward cross-links are inhibitory in the short range but excitatory in the long range, serving to cancel out noises and improve integration for cues with moderate disparity, whereas the reciprocal links are excitatory in the short range but inhibitory in the long range, stabilizing a more reliable population activity. This antagonistic pattern persists for a range of correlation strengths and a variety of correlation structures. The complementary roles played by different types of cross-talks between multisensory areas can be verified in future experiments on the brain.