

Mechanisms to induce metastable brain dynamics

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We present two mechanisms to induce metastability in oscillatory models for brain dynamics. Metastable states switch in a cyclic or acyclic way. The first mechanism is realized in generalized Kuramoto models with non-reciprocal adaptive couplings [1]. The non-reciprocity refers to the type of coupling according to Hebbian or anti-Hebbian rules and to different time scales on which the couplings evolve. The main effect of this specific combination of deterministic dynamics is an induced metastability of anti-phase synchronized clusters of oscillators. What is responsible for the sudden irregular changes in the order parameters is individual oscillators which change their cluster affiliation from time to time. This way they provide "weak ties" between clusters of synchronized oscillators, where an individual oscillator may represent an entire brain area. The importance of weak ties are known from social system applications. The second mechanism is based on heteroclinic dynamics realized in generalized Lotka-Volterra equations. Here we summarize results of earlier work on how to design the attractor space in order to observe heteroclinic cycles of heteroclinic cycles by a suitable combination of rates, and how to control the switching dynamics in phase space such that fast oscillations are modulated by slow oscillations. Such modulations are experimentally observed in brain dynamics. One of the desirable features of these dynamics is to enable fast adaptation to new external input. In view of this, we analyze relaxation times of heteroclinic motion toward a new resting state, when oscillations in heteroclinic networks are arrested by a quench of a bifurcation parameter [2]. The quench is from a parameter regime of oscillations to a regime of equilibrium states. As it turns out, the relaxation is underdamped and depends on the nesting of the attractor space, the size of the attractor's basin of attraction, the depth of the quench, and the level of noise. In the case of coupled heteroclinic units, it depends on the coupling strength, the coupling type, and synchronization between different units. Depending on how these factors are combined, finite relaxation times may support or impede a fast switching to new external input. Heteroclinic dynamics has applications to other fields, ranging from cell dynamics to ecological systems.

References:

[1] S. Nag Chowdhury and H. Meyer-Ortmanns, to be published in *Frontiers in Network Physiology* (2026).

[2] M. Aravind and H. Meyer-Ortmanns, *Chaos* 33(10), 03138 1-10 (2023).