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Synergetic principles for the treatment of brain diseases

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Abstract

Inspired by laser theory, in the 1960s Hermann Haken founded synergetics, an interdisciplinary field of research explaining the emergence and self-organization of patterns, dynamics and structures in open systems far from thermodynamic equilibrium. From the very beginning, fundamental self-organization principles were studied in a variety of systems, e.g. in physics and biology. The generality of these mechanisms and principles was striking. Furthermore, these studies led to paradigmatic insights. It turned out that self-organization is crucial, e.g., for human motor control, visual perception or psychological processes. Apparently simple, but powerful mathematical models enabled to predict spatio-temporal behavior in systems of stunning complexity. Over the years, Hermann Haken's synergetics turned into a scientific school, a community of researchers employing productive approaches and providing tool kits for the study of complex systems. Brain function was investigated at different levels and for different purposes.

Depending on the mutual timing of neurons, the strength of the neuronal interactions is controlled by synaptic plasticity. The well-rehearsed and adaptive interaction of a multitude of sub-systems in the brain enables perception, memory and other forms of normal brain function. However, pathological alterations may occur, and deleterious spatio-temporal patterns of brain activity may emerge. A number of brain diseases are characterized by abnormally strong neuronal synchronization. Based on synergetic and fundamental plasticity principles, a desynchronization stimulation approach was developed. Its goal is to cause an unlearning of abnormal synaptic connectivity by shifting neuronal populations from abnormal attractor states to more physiological, desynchronized attractor states, ultimately inducing therapeutic effects that persist after cessation of stimulation. From a clinical standpoint, long-lasting therapeutic effects are crucial, e.g., to avoid side effects or to establish novel non-invasive treatments. A number of theoretical, computational, pre-clinical and clinical studies with different stimulation modalities have been and are currently being performed to utilize synergetic principles for therapeutic purposes.