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Chaos, Brain and Epilepsy: A Bioengineering Approach

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The normal state of the brain exhibits chaos in the spatial and temporal domain. Electroencephalographic (EEG) recordings from the surface (scalp EEG) and depth (intracranial EEG) of the human and animal brain are characterized by spatio-temporal chaos. Over the last 20 years, analysis of measures of chaos (Lyapunov exponents, Kolmogorov entropy etc.) from continuous (time resolution of msec), long-term (days) EEG over multiple brain sites (space) has revealed similarities with dynamical phenomena (e.g., chaos synchronization, hysteresis) exhibited before and after phase transitions of complex nonlinear systems. Novel concepts, like "dynamical resetting" and "feedback decoupling" control of the dynamics of the brain, have also been recently developed, especially in connection with epilepsy. Epilepsy is very prevalent (afflicts 1% of the population and is second only to stroke), debilitating and at times devastating (status epilepticus is a life-threatening condition) neurological disorder. The pathology of dynamics in the epileptic brain is characterized by an intense and long-term synchronization of chaos at normal brain sites with the chaos at the epileptogenic focus (foci). This pathology is reset by seizures themselves or by a successful external intervention (e.g. anti-epileptic drugs or deep brain stimulation). Examples of the underlying concepts from animal and simulation models, as well as from patients with epilepsy, will be presented. It will be shown that the impact of these findings on the understanding of the mechanisms of epileptogenesis may constitute the basis for a) improvement of the diagnosis and prognosis of epilepsy patients, and b) design and development of much needed new and effective therapies (e.g., brain pacemakers) for epilepsy and other brain dynamical disorders. It is expected that this line of research, being mathematically general enough and having produced significant results in the most complex living system, the brain, could also assist with the prediction and control of catastrophic transitions in networks of other complex biological and physical systems.

Key Words: Spatio-temporal chaos, Spatial synchronization, Prediction and control of epileptic seizures, Brain resetting