ACTIVITAS NERVOSA SUPERIOR

Activitas Nervosa Superior, 50 (2008) 114-117

MINI-REVIEW

CHAOS, COGNITION AND DISORDERED BRAIN

Petr Bob*

Department of Psychiatry, First Faculty of Medicine, Charles University, Prague, Czech Republic
Received October 15, 2008; accepted October 30, 2008

Abstract

Important feature of chaotic transitions is a self-organization that presents a spontaneous order arising in a system when certain parameters of the system reach critical values. Recent findings suggest that these principles may implicate new concepts for understanding consciousness and cognition. Self-organization may produce random-like processes that could explain "randomness" in neural synchronization related to cognitive functions and consciousness, and also in mental disorganization related to psychopathological phenomena.

Key words: Brain; Chaos; Cognition; Psychopathology

INTRODUCTION

History of nonlinear mathematics which describes the so-called chaotic phenomena and complexity in nature has its roots in the last years of 19th century. The concept of dynamical chaos was for the first time developed by French mathematician Henri Poincaré (1854-1912), who studied predictability in a system behavior and found that chaotic randomness does not mean a true randomness because it is caused by unpredictability and sensitivity with respect to stimuli that influence system behavior and determine disproportional changes. The sensitivity is related to the quality of prediction of a system's behavior regarding an information loss over time that leads to decrease in the accuracy of prediction of later system's development. In his "Science and method" (p. 68) Poincaré wrote: "A very small, unnoticeable cause can determine a visible very large effect; in this case we claim that this effect is a product of random. . . However, even if the natural laws were perfectly known, we will ever be able to know the initial conditions with some approximation. If this allows us to know the future with the same approximation that is all we want. We will say that the phenomenon is foreseeable, that it is governed by laws; however this is not always the case, it is possible that very small initial differences lead to very large one in the final state. . ."

Chaos theory and biological systems

Later development of the chaos theory initiated by Edward Lorenz in 1961 has led to comprehensive discovery of chaotic phenomena with applications in many fields of scientific research such as in physics, meteorology, astronomy, economy and about 100 years after Poincare's discovery also in the field of neuroscience and psychology. Aim for using this method in the field of neuroscience and psychology similarly as in other disciplines is the understanding of relatively short periods in the behavior of a system which are extremely sensitive to very little changes (the so-called sensitivity on initial conditions). In this context recent that in a real brain are deterministic causal mechanisms of behavior simultaneously active with chaotic generation of behavioral patterns and their dominance changes during the time (Kantz & Schreiber, 1997; Birbaumer et al., 1995).

The theory of nonlinear dynamical systems and chaos theory deals with deterministic systems that exhibit complex and seemingly random behavior. This

Correspondence to: Petr Bob, petrbob@netscape.net

interdisciplinary area of science influenced also research in physiology because of the complexity of living systems (Elbert et al., 1994; Dokoumetzidis et al., 2001; Freeman, 1991, 2000, 2001). The values of the measured properties of many physiological systems look random and their determinants are often unknown because of high complexity of the factors affecting the phenomena under consideration in physiological research (Elbert et al., 1994; Freeman, 2000; Dokoumetzidis et al., 2001; Korn & Faure, 2003). Main idea of randomness relies on the concept that every complex system has a large number of degrees of freedom which cannot be directly observed and are manifested through the system's fluctuations (Elbert et al., 1994; Dokoumetzidis et al., 2001; Freeman, 1991, 2000, 2001). Recent research shows that the chaotic deterministic dynamical systems display the random-like behavior often indistinguishable from pure random processes (Elbert et al., 1994; Dokoumetzidis et al., 2001). In this context the concept of self-organization has been proposed because the chaotic dynamics tends to produce a spontaneous order and patterns of organization in the physiological systems (Elbert et al., 1994; Freeman, 2001; Dokoumetzidis et al., 2001; Korn and Faure, 2003). The self-organization patterns typically are linked to instability states that may enable a new mode of behavior. The sudden phase transitions called bifurcations represent a form of system's behavior which is deterministic and in the state space of the system's behavior is compressed to a subset called the attractor (Elbert et al., 1994; Freeman, 2001; Dokoumetzidis et al., 2001). In the physics state (or phase) space means the abstract multidimensional space in which every possible state of the system corresponds to a unique point in the space that may be visualized by state space diagram. The number of dimensions or parameters of this space represents degree of freedom of the system and every dimension may be represented as axis. For example mechanical system may be described by all possible values of position and momentum or in the thermodynamics states or phases of a chemical system may be described as function of pressure, temperature or composition (Elbert et al. 1994; Dokoumetzidis et al. 2001). Complex macrosystem such as living organism may be therefore described by many state functions such as temperature, blood pressure, electrical activity, for example EEG, ECG, electrodermal activity (EDA) and also other physiological, behavioral or cognitive characteristics (Elbert et al., 1994).

Chaos, brain and cognition

Although this nonlinear mathematical approach to the so-called chaotic phenomena and complexity in nature has its roots in the Poincare's work in the last years of 19th century, its application to the field of psychology and neuroscience is relatively new. Aim for using this method is the understanding of relatively short periods in the behavior of a system which are extremely sensitive to very little changes (the so-called sensitivity to initial conditions). This sensitivity during critical times characterizes initiation of new trends in the system's evolution which later emerge as very different macroscopic patterns of neural activity and mental processes (Elbert et al, 1994; Freeman, 1983, 1991, 2000; Meyer-Lindenberg et al., 2002; Faure & Korn 2001; Globus & Arpaia 1994; Korn & Faure 2003). Chaotic transitions probably emerge in a wide variety of cognitive phenomena and possibly may be linked to specific changes during development of mental disorders such as depression or schizophrenia (Korn & Faure, 2003; Melancon & Joanette, 2000; Gottschalk et al., 1995; Barton, 1994; Huber et al., 1999; Paulus & Braff, 2003), and might underlie psychological hypersensitivity to outside stimuli and their pathological processing. A possible role of chaotic transitions in psychopathology was proposed also for dissociative states that present discontinuities in mental life and there are several hypotheses which link the dissociation to critical chaotic shifts of discrete behavioral states (Putnam, 1997) and underlying competitive neural assemblies which form mental representations of dissociated states (Bob, 2003, 2007) with the resulting self-organization of behavioral patterns during critical periods (Pediaditakis, 1992; Sel, 1997).

According to Freeman chaos underlies the ability of the brain to respond flexibly to the outside world and to generate novel activity patterns, including those that are experienced as fresh ideas. Chaos thus expresses the underlying unpredictable order of attractors and enables the complex behavior of the brain (Freeman, 1991; 2000; 2001; Skarda and Freeman, 1987). On the psychological level these neurophysiological processes probably correspond to prototypes of intentional behavior (likely located in the limbic system) (Freeman, 2001). Chaos in the brain may implicate the degree of unpredictability of mental and behavioral events which is in accordance with the extent of variations in the space-time patterns of the activity of chaotic systems (Freeman, 1999). The discovery of chaos has also profound implications for the study of brain functions as a dynamic system that has a collection of attractors which forms an "attractor landscape" in the web of synaptic connections modified by prior learning (Skarda & Freeman, 1987) corresponding to intentional archetypes (Freeman, 2000).

These intentional archetypes as pre-existing chaotic fluctuations are enhanced by input, forcing the selection of a new macroscopic state and the attractor determines the response. Conceptually, the linear view proposed by stimulus-response reflex determinism is not appropriate for the dynamics that leads to nonlinear chain of cause and effect from stimulus to response that is present during chaotic brain processes (Freeman, 1999). In these chaotic self-organizing systems is "linear causality" replaced by "circular causality" that represents a concept useful for describing multilevel interactions between microscopic neurons in assemblies and the macroscopic emergent state variable that organizes them. Circular causality can serve as the framework for explaining the operation of awareness and intentional action when the multimodal macroscopic synchronized patterns converge simultaneously into the limbic system, and the results of integration over time and space are simultaneously returned to all of the sensory systems (Freeman, 1999).

Together recent data suggest that chaotic-like cognition could be related to chaotic brain processes that might be a cause of random-like disorganization in mental processes. These changes in the chaotic dynamics might represent specific characteristics of dissociative states and chaotic-like cognition in schizophrenia and it raises the question about a conceptual nature of the chaotic states in mental life and cognition.

CONCLUSION

Important feature of chaotic transitions is a self-organization that means the spontaneous order arising in a system when certain parameters of the system reach critical values (Isaacs et al. 2003) and this may implicate new concepts for understanding consciousness and cognition. For example, in brain simulation studies of interacting neural assemblies the abrupt switching between synchronous and stochastic random activity has been observed (Bauer & Pawelzik, 1993). This neural random-like activity may implicate that the cortical oscillatory activity which leads to "self-synchronization transitions" may serve as a paradigm for synchronization phenomena and a mode of self-organization in populations of interacting neurons (Kuramoto 1984; Acebron et al. 2005). These findings could have a great significance because synchronization phenomena linked to integration of different neural events into a coherent whole enable mental phenomena and consciousness (Singer 2001; Lee et al. 2003). In this context nonlinear dynamics and chaos theory may significantly contribute to understanding of neurobiological mechanisms that occur during psychopathological states.

This work was supported by research grants MSM0021620849, MSM0021622404 and support of research project of Center for Neuropsychiatric Research of Traumatic Stress 1M06039 by Czech Ministry of Education.

REFERENCES

Acebron, J.A., Bonilla, L.L, Perez, C.J., Ritort, F., & Spigler, R. (2005). The Kuramoto model: a simple paradigm for synchronization phenomena. *Reviews of Modern Physics*, *77*, 137-185.

Barton, S. (1994). Chaos, self-organization, and psychology. *American Psychologist, 49*, 5-14.

Bauer, H.U., & Pawelzik, K. (1993). Alternating oscillatory and stochastic dynamics in a model for a neuronal assembly. *Physica D, 69*, 380-393.

Bob, P. (2003b). Dissociation and neuroscience: History and new perspectives. International *Journal of Neuroscience, 113*, 903-914.

Bob, P. (2007). Chaotic patterns of electrodermal activity during dissociated state released by hypnotic abreaction. *International Journal of Clinical and Experimental Hypnosis, 55*, 435-436.

Dokoumetzidikis, A., Iliadis, A., & Macheras, P. (2001). Nonlinear dynamics and chaos theory: Concepts and applications relevant to pharmacodynamics. *Pharmaceutical Research, 18*, 415-426.

Elbert, T., Ray, W.J., Kowalik, Z.J., Skinner, J.E., Graf, K.E., & Birbaumer N. (1994). Chaos and Physiology: Deterministic Chaos in Excitable Cell Assemblies. *Physiological Reviews, 74*, 1-47.

Faure, P., & Korn, H. (2001). Is there chaos in the brain? I. Concepts of nonlinear dynamics and methods of investigation. *Comptes rendus de l'Academie des sciences. Serie III, Sciences de la vie, 324*, 773-793.

Freeman, W.J. (1983). The Physiological Basis of Mental Images. *Biological Psychiatry, 18*, 1007-25.

Freeman, W.J. (1991). The physiology of perception. *Scientific American, 264*, 78-85.

Freeman, W.J. (1999). Consciousness, Intentionality, and Causality. *Journal of Consciousness Studies, 6*, 143-172.

Freeman, W.J. (2000). Mesoscopics neurodynamics: From neuron to brain. *Journal of Physiology (Paris), 94*, 303-322.

Freeman, W.J. (2001). Biocomplexity: Adaptive behavior in complex stochastic dynamical systems. BioSystems, 59, 109-123.

Gottschalk, A. M., Bauer, M. S., & Whybrow, P. C. (1995). Evidence of chaotic mood variation in bipolar disorder. *Archives of General Psychiatry, 52*, 947-959.

Huber, M.T., Braun, H.A., & Krieg, J.C. (1999). Consequences of deterministic and random dynamics for the course of affective disorders. *Biological Psychiatry, 46*, 256-262.

Isaacs, A., Daintith, J., & Martin, E. (2003). *Oxford Dictionary of Science*. New York: Oxford University Press.

Korn, H. & Faure, P. (2003). Is there chaos in the brain? II. Experimental evidence and related models. *Comptes Rendus Biologies, 326*, 787-840.

Kuramoto,Y. (1984). *Chemical oscillations, waves and turbulence*. New York: Dover Publication.

Lee, K.H., Williams, L.M., Breakspear, M., & Gordon, E. (2003). Synchronous gamma activity: a review and contribution to an integrative neuroscience model of schizophrenia. *Brain Research Reviews, 41*, 57-78.

Melancon, G., & Joanette, Y. (2000). Chaos, Brain and Cognition: Toward a Nonlinear Order? *Brain and Cognition, 42*, 33-36.

Meyer-Lindenberg, A., Zeman, U., Hajak, G., Cohen, L., & Berman, K.F. (2002). Transitions between dynamical states of differing stability in the human brain. *Proceedings of the National Academy of Sciences of the United States of America, 99*, 10948-10953.

Paulus, M.P. & Braff, D.L. (2003). Chaos and Schizophrenia: Does the Method Fit the Madness? *Biological Psychiatry, 53*, 3-11.

Pediaditakis, N. (1992). Deterministic non-linear chaos in brain function and borderline psychopathological phenomena. *Medical Hypotheses, 39*, 67-72.

Putnam, F. (1997). *Dissociation in Children and adolescents. A developmental Perspective*. London, New York: The Guilford Press.

Sel, R. (1997). Dissociation as complex adaptation. *Medical Hypotheses, 48*, 205-208.

Singer, W. (2001). Consciousness and the Binding Problem. *Annals of the New York Academy of Sciences 929*, 123-146.

Skarda, CH.A. and Freeman, W.J. (1987). How Brains Make Chaos in Order To Make Sense of the World. *Behavioural and Brain Sciences, 10*, 161-95.