Neurotherapy: More than an Extra Feedback Loop to the Pathological Brain

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ABSTRACT

Neurotherapy is a complementary treatment used in various disorders of the central nervous system (CNS), such as epilepsy and attention deficit hyperactivity. The method is subsumed under the behavioral medicine, and is considered to be an operand conditioning in psychological terms. However, its mechanisms are not well understood yet. In this article, we discuss the drawbacks of a conventional control engineering approach to analyze such a complex process (i.e. EEG-biofeedback) which elicits alterations on a complex system (i.e. CNS). Based on the results and observations we gained on the course of our clinical studies with epilepsy patients, we discuss the plausibility of a general systems theoretical approach to the neurotherapy process. Using the concepts of complexity, open systems, self-organization, and self-regulation, we underline the necessity of a systems theoretical framework. We show the analogies of the EEG-biofeedback process to other operand conditioning experiments explained via the methods of the synergetics.

Keywords: EEG-biofeedback, neurotherapy, complexity, self-regulation, systems, synergetics

1. INTRODUCTION

Biofeedback is the method of feeding back a quantitative parameter of a physiological function of the body to the perception of the person trough artificial equipment so that the subject learns to control the quantitative parameter voluntarily. Consequently, it is expected that the person gains the skill of controlling the physiological dynamics generating the certain parameter which otherwise proceed unconsciously. If the quantitative parameter is obtained from the electrical brain activity (EEG), then it is defined as EEG-biofeedback, neurofeedback [1], or cortical self-regulation [2, 3] and if it is used for a therapy purpose then it is referred to also as neurotherapy [4].

The method is introduced as a complementary therapy in various disorders of the CNS, such as epilepsy, attention deficit disorder (ADD), attention deficit hyperactivity disorder (ADHD), and depression at changing rates of success. According to the treated disorder the parameter extracted from EEG may vary: a certain frequency band [1], slow cortical potentials (SCPs) [2, 5] or evoked potentials.

In our studies, we developed a flexible neurotherapy system which can be configured for different disorders and adapted to the individual needs and characteristics of the subject [6]. The system is designed for polygraphic recordings, and thus allows simultaneous monitoring of other physiological processes such as respiration and heart activity. Using the system we realized training sessions with healthy controls and clinical applications with refractory epilepsy patients. These sessions were based on learning and training the self-regulation of the central or fronto-central SCPs (i.e. direct current (DC)-shifts) [7]. The scalp DC-shifts were also investigated during various modifications of the S1-S2 paradigm. At these measurements, the vertical and horizontal electrooculogram (VEOG resp. HEOG), the electrocardiogram (ECG) and the respiratory curves were acquired simultaneously with the EEG/DC.

2. OBSERVATIONS

On the course of our studies we encountered several phenomena:

1) During the neurofeedback training process, the “intuitively” evolved varying respiration patterns correlated to the DC-shifts recorded on the scalp. The control of the DC-shifts, however, is not sustained via only respiration feedback. There observed to be an

interaction between the SCPs generated upon neurofeedback process and the respiration patterns [8].

2) The SCPs can be distorted by the spreading of the changes in the eye-potentials caused not only by slow eye and head movements, but also due to a not occurred light adaptation. These sources of error must be monitored during a neurofeedback process [9]. On the other hand, a synchronous similar pattern (excluding the artifacts due to ocular movements) is observed in vertical electrooculogram (VEOG) during the generation of contingent negative variation (CNV) upon a modified S1-S2 paradigm.

3) Application of acoustical or visual stimuli for the S1-S2 paradigm results in differences in the topological distribution of the resulting variations in the SCPs [10]. Visual and acoustic components do not influence the process in the same manner.

These observations indicate that the complex interactions between the higher CNS functions such as perception and information processing, and vegetative physiological functions of the body such as respiration and heart beat, are crucial in the neurofeedback process. These functions are inseparable in the context of training the self-regulation.

The CNS not only has a higher regulatory task to coordinate these functional subsystems of the body as a whole system, but also itself is a functional part of it, and depends on these subsystems. Therefore, the process of the neurotherapy can not be considered only as an extra feedback loop to the brain. Furthermore, analyzing a complex process (i.e. the neurofeedback) which causes alterations on a very complex system (i.e. the nervous system) exceeds the borders of conventional system analysis approaches.

3. THE MICROSCOPIC AND MACROSCOPIC LEVELS

The traditional control engineering approaches to the systems and feedback mechanisms are mainly based on the assumption of a “closed system”. In the recent decades, this approach is seriously debated especially when the system considered has a biological nature. The “openness” of the biological systems was first stated by the biologist von Bertalanffy [11]. In terms of thermodynamics, open systems are those which exchange energy, matter and information with their environment. Living systems are open systems exchanging energy, matter and information with their environment, *thus* maintaining their structures and functions. Additionally, dealing with biological systems means dealing with complex systems. In this context we regard the human physiology including brain functions as dynamics of a complex open system. Mainzer [12] states that the complex system approach offers the possibility for modeling the neural interactions of the brain processes on the microscopic scale and the emergence of the cognitive structures on the macroscopic scale. Thus, it seems to be possible to bridge the gap between the neurobiology and the cognitive sciences of the mind, which traditionally has been considered as an unsolvable problem.

We hypothesize that the neurofeedback process intervenes with this “gap”, at a “mesoscopic” level, since it involves the interactions between the psychological and neurobiological processes. We propose to consider the extracted EEG parameter used for the feedback as a parameter of the “mesoscopic” level between the psychological (the macroscopic level) and neurobiological levels (the microscopic level):

Psychological processes	- Macroscopic level
Extracted EEG Parameter	- Mesoscopic level
Neurobiological processes	- Microscopic level.

4. SELF-REGULATION AND SELF-ORGANIZATION

According to Schwartz [13] the concept of self-regulation is fundamental to behavior therapy, and it is also fundamental to living systems. It is, in this sense, not a coincidence that EEG-biofeedback is also referred to as cortical self-regulation. A self-regulating system is able to maintain its essential variables within limits acceptable to its own structure in case of unexpected disturbances. This can be only achieved through feedback mechanisms which detect disturbances, and accordingly activate (positive feedback) or inhibit (negative feedback) the related mechanisms. In the natural systems both positive and negative feedback mechanisms are commonly observed.

Another property of the natural systems is that they are self-organizing. Self-organization at the microscopic level is addressed to be the fundamental mechanism of the spontaneous pattern formations at the macroscopic level in open systems which are far from equilibrium. To our understanding, self-regulation and self-organization are two highly interrelated phenomena which are determined by the nonlinear interactions at the microscopic level. The synergetics as pioneered by Haken [14] offers an advanced theoretical framework for the self-organization phenomenon giving rise to emergent new qualities at the macroscopic level. In synergetics, the circular causal relations of different levels are explained through order parameters and the slaving principle [14, 15]. Hence, a synergetical approach seems to be a reasonable paradigm which can overcome the drawbacks in analyzing and understanding the complex process of neurotherapy.

5. LEARNING, OPERAND CONDITIONING AND COORDINATION

EEG-biofeedback is a process of *learning*. In terms of psychology, it is defined as an operand conditioning. At the microscopic level, according to the widely accepted hypotheses of Hebb [16], learning is explained through strengthening synapses between neurons which are repetitively activated simultaneously. Hebb also suggests that learning should be understood as a kind of self-organization in a complex brain model. At the macroscopic level we encounter the studies in behavioral psychology regarding different forms of conditioning. From the systems analysis point of view, again the synergetics offers us a theoretical framework and tools for analyzing a process of learning via the concepts of control parameters, order parameters and enslaving. The synergetics defines learning via the effects of the learning process on the "order parameters" of a system. Order parameters are descriptors of a complex system at the macroscopic level which enslave the individual subsystems and determine their motion. They are, however, in turn determined by the motion of the subsystems. This phenomenon is called circular causality. According to Haken [15], there may be several mechanisms by which the motion patterns described by order parameters can change:

a) The dynamics of the order parameters may change in that the potential landscape undergoes a transition.
b) New order parameters may emerge by means of the cooperation of old order parameters.
c) New order parameters may emerge from microscopic parts as a consequence of changes in the control parameters at the microscopic level.

An important example of analyzing an operand conditioning process with the methods of synergetics is the pedalo experiment [15], in which the movement patterns of subjects are analyzed during the process of learning to drive a pedalo. In this example, it is demonstrated that as learning proceeds, fewer and fewer degrees of freedom dominate the movement pattern, and that, eventually, the movement is governed by a single complex order parameter.

Although the EEG-biofeedback process is not concerned with motoric movements, there are analogies to the pedalo experiment in terms of learning a specific "coordination" of the involved subsystems. In the pedalo experiment, the subsystems are motoric units such as parts of arms and legs which are under our voluntary control, whereas in the EEG-biofeedback process, these subsystems are units of the CNS involving the cognitive functions, and the autonomous nerve system such as respiration and heart beat. The analogies are that, a) as a result of the learning process a new specific coordination is achieved among the subsystems in both cases, b) this new coordination can be recalled and activated by the subject when the corresponding situation is encountered. In case of a disorder such as epilepsy or ADHD, the gained skill of specific coordination of these functions results in moving the system state away from the pathological situation.

6. CONCLUSIONS

The neurotherapy (i.e. EEG-biofeedback) is a complex process in which not only cognitive functions such as perception and information processing, but also vegetative functions such as respiration and heart beat are involved. This process elicits alterations on the human nervous system and physiology as a whole system. Therefore, it can not be regarded as a simplified control feedback loop as in the analysis of closed systems.

As a process of learning, the neurotherapy has analogies to the operand conditioning experiments analyzed in the realm of the *synergetics*. A synergetical approach can provide further tools to understand the dynamics of the neurofeedback process which can be regarded as *learning* a specific *coordination* of cognitive and other autonomous physiological functions. Such an analogy results in further tasks such as determining the accurate *control* and *order parameters* of the neurofeedback process and quantifying them.

These considerations provide us a theoretical framework at the system level that can help us have a deeper understanding of the neurotherapy process, and accordingly model its diverse influences on the human physiology.

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7. REFERENCES

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