Making Chaos out of Order
Observations on the EEG dynamics of peak performance

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INTRODUCTION

There is considerable interest in the analysis and interpretation of EEG rhythms using the concepts of nonlinear dynamics, also known as chaos theory. These concepts are derived from the study of complex systems that exhibit properties such as extreme sensitivity to initial conditions, strange attractors, nonlinear limit cycles, and behavior that is difficult or impossible to predict. However, the basic foundations of chaotic behavior can be initially approached in terms of nonchaotic, linear systems, exemplified by phenomena such as simple pendulums, springs and masses, and so on. With this in mind, we have begun to develop a model that begins with simple concepts, and provides a rationale for understanding intrinsic EEG rhythms, the ability to affect them by external or internal events, and implications for brain stimulation and peak-performance training. To this simple model, we then introduce the nonlinear properties that produce chaotic behavior, and identify their importance.

THE BASIC MODEL

The EEG signal may be simply conceptualized as the motion of a physical object such as a mass attached to a spring, or a pendulum at the end of a string, that is moving in response to an external force (Fig. 1). In such systems, the key properties are the mass of the object, the qualities of the spring or string such as length, tension, etc., and the nature of any excitation such as an externally applied force. The salient properties of such systems are that they oscillate in a natural way in response to perturbations, they have a characteristic "resonant" frequency (or frequencies), and they require energy in order to act.

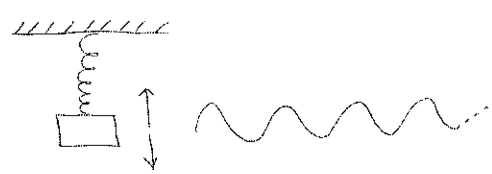

FIGURE 1

Figure 1. A mass connected to a spring that is attached to a rigid support, will describe an oscillating motion that can be represented as a sinusoidal wave. The qualities of the wave are determined by the properties of the physical objects, and also by by the nature of the disturbance that causes the motion to occur. A greater disturbance will cause a greater motion.

One such system is a mass attached to a spring, that is perturbed by an outside force. The mass will move back and forth at a characteristic frequency, which will then die out, coming again to rest, after some period of time. During such behavior, kinetic energy is manifested in the moving mass, potential energy is present when the spring is compressed or expanded, and the transformation between these two forms of energy occurs in a repetitive and bidirectional fashion. These properties characterize this model as a classical linear, second-order, oscillating system, with no chaotic behavior.

This model provides the basis for a simple analogy with a living brain. In the brain, our moving object is a neuronal mass (a recruited group of neurons) that is pooled into synchronous activity, producing a visible EEG wave. The EEG measured from the scalp is produced mainly by the co-ordinated activity of large numbers of pyramidal cells in (layer IV of) the cerebral cortex. (In fact, only about 50% of such cells are oriented so as to produce measurable scalp potential, so our EEG is an incomplete indicator).
When a large enough number of co-ordinated neurons (this number being related to "mass"), their synchronized electrical activity produces a wave we can measure on the scalp.

Mass, which can be subjected to motion, is produced when the neurons are pooled, and have the possibility to be fired in synchrony, in response to endogenous (internal to the brain) or exogenous (external to the brain) stimulation , or "force". If a large number of neurons are pooled, this constitutes a large mass, and a smaller number of pooled neurons constitutes a smaller mass. When a pooled mass of neurons polarizes or depolarizes in unison, it generates an electrical field that can be recorded from the cortex, and manifested as an EEG. The pooling itself is mediated by collateral neuron networks that provide a widespread, inhibitory effect on the cells, thus modulating their firing and effectively enabling or disabling them from participating in pooled firing, in response to any incoming afferent stimulation.

A MODEL FOR EEG WAVES - FALLING INTO ACTION

Endogenous EEG rhythms are thought of as resulting from rhythmic potential variations driven from an intrinsic "stimulus," most notably the volleys of action potentials arriving from the lower brain via the reticular activating system (RAS). The RAS in this case is serving as the agent that pushes, or pulls, the neuronal mass, initiating the cortical activity. If the RAS is inactive, rhythmic cortical activity ceases, since the cortex does not generate significant intrinsic rhythms of its own. (This strictly true only for EEG frequencies in the range of 1 - 30 Hz. The cortex does have an intrinsic rhythm in the 40 Hz range, as demonstrated in decorticated tissue). While the RAS is the dominant generator of alpha-range (8-12 Hz) rhythms, there exist several other "pacemaker" sites, including the amygdala, hippocampus, and the hypothalamus, which is involved in sleep-related delta activity, and is also active in the immune system. Overall, the cortex can be thought of as containing many collections of neuronal masses that are pooled into various groups and ready for stimulation, but that generate no rhythms unless stimulated from outside the cortex.

Cortical neuron pools, like mass-and-spring assemblies, have response characteristics that include a "resonant" frequency, which is the intrinsic frequency at which they will oscillate if stimulated. When stimulated by an incoming burst of afferent activity, the cortical mass will exhibit a rhythmic discharge, that will die out if stimulation is not repeated. This intrinsic resonant frequency is based on internal properties of the neuronal pool at that moment in time, and does not depend on the frequency of the stimulation. Rather, it determines the nature of the response that will occur when stimulation occurs. In addition to the dynamic transformation between kinetic and potential energy, at any given moment in time, the system may contain a certain amount of kinetic as well as potential energy, and this will determine not only its immediate behavior, but will also determine how it will respond to a particular perturbation.

Consider, for example, the funnel-shaped coin receptacles that are found in museums, and are used to deposit donations (Figure 2). The coin is released at the top of the funnel, whereupon it begins to travel in a circular path around the basin, moving down the side, rotating faster and faster, in smaller and smaller circles. When it is at the top of the funnel, it takes a long time to complete each circle, and is following a wide path. This is analogous to a low-frequency, high-amplitude wave such as delta, theta, or low alpha. As it moves downward, it takes a shorter time to complete each circle, and is following a narrower path. This is analogous to a high-frequency, low-amplitude, wave such as beta or gamma.

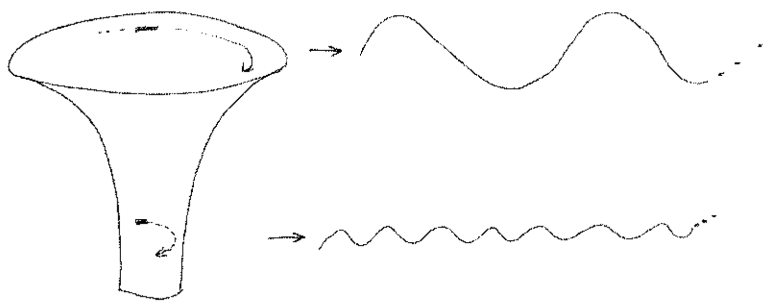

FIGURE 2

Figure 2. A coin rolling down a funnel also describes a sinusoidal motion. In this case, the resulting wave is determined by the properties of the funnel, and also by the position and velocity of the coin. At the top, it describes a large, slow wave. At the bottom, it describes a faster, though smaller, wave.

At the top of the funnel, the coin has maximal potential energy (due to gravity), which is released as the coin moves downward and transforms potential energy (height) into kinetic energy (speed). Traveling at the top of the funnel, the coin is analogous to a neuronal pool producing a large, low-frequency wave, and at the bottom, the coin is producing a small amplitude, high-frequency wave. Note that at all times the total energy is the same (neglecting friction), but that the coin's behavior, and response to a perturbation, would be different at each time. When moving rapidly in small arcs, it will be harder to change its trajectory, than when it is moving slowly, in large arcs. In terms of the brain, a relaxed, coherently firing neuronal pool will be more receptive to input than an agitated, busy brain preoccupied with a lot of high-frequency activity that will not let stimulation in. Note that the brain state corresponding to higher potential energy is more sensitive to differences in input, and is more able to distinguish subtle stimuli.

Once a pool of neurons has begun to act in synchrony, and produce a measurable EEG signal, we say that the pool is "in motion." Like a physical object in motion, this pool of neurons can be said to have "momentum," which is proportional to the product of the mass and the velocity. It also can be said to have "kinetic energy," which is proportional to the product of the mass and the velocity squared. In order to produce this energy, one of two things must happen. Either the energy must be introduced from the outside, or the stimulus must cause the pool to convert potential energy into kinetic energy, thus springing in to motion. However, a system with a lot of momentum, or kinetic energy, will be harder to change than a system that has less momentum. Moreover, a system with a lot of potential energy (such as a coin at rest at the top of the funnel) will be easy to affect, or bring into motion, with a minimal introduction of energy (simply dropping the coin).

A coin poised at the top of the funnel, ready to be released, can have any of an wide range of orientations. The orientation of the coin, even as it is as rest, will determine the trajectory that will ensue in response to the coin being released (Figure 3). If, for example, a coin is released to follow trajectory A, it will follow a circular path to the bottom, generating output A. If it is released along trajectory B, it will travel more directly down the funnel, quickly falling through the bottom, and producing a less complex response. Note that the releasing action itself requires minimal energy. The orientation of the coin, combined with the shape of the funnel, is analogous to the setup of the neuronal pools by collateral neurons, which will determine the exact pools of neurons, and their intrinsic frequencies, when motion ensues. It is important to note that the starting energy level for both A and B are the same in the beginning, and it is the configuration of their basins, and the orientation of the coin, that determine the outcome, not the amount of energy imparted onto the coin. This underlies the fact that there is an effortlessness about preparing for peak performance, that the key is in organizing, planning, and releasing correcting action, rather than simply increasing the level of effort or energy expended.

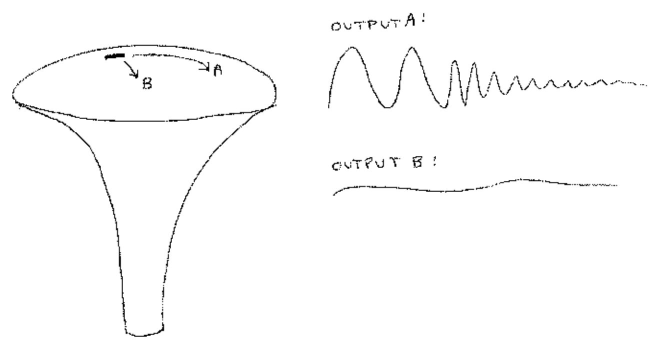

FIGURE 3

Figure 3. Depending on how the coin is released, the resulting wave will be different. If it is released at a sharp angle, and with a great deal of energy, it will describe an output with high amplitude, and a lasting response. If it is released directly into the center, or if it is simply dropped, it will describe a low-energy, low-frequency path as it simply falls through to the bottom.

PHYSIOLOGICAL MODEL & APPLICATION TO PEAK PERFORMANCE

Thus, preparation for peak performance can be thought of an orientation, in preparation for release, which requires little energy for the transformation of potential into kinetic energy, producing the most skillful and efficient desired action. It is in the nature of a complex, nonlinear system, to be exquisitely sensitive to the initial conditions (orientation), such that the simple act of releasing can lead to any of an infinite number of possible outcomes, with a wide range of observable behaviors. Moreover, the opportunity arises for an extremely skillful and differentiated, efficient response, with a minimum amount of energy expenditure. At an extreme, a complex system can have a wide range of possible basins, separated by bifurcation points, which are stable, yet optimally poised for action (Figure 4). These points are stable, yet provide an infinite opportunity for refinement of position, orientation, and the moment of release. At such times, the brain is not necessary in action, yet it contains within it the potential for highly specific and refined action, when such action occurs. Setting up the brain for optimal performance thus consists of exploring and maintaining the most efficient synaptic relationships mediating the setup of neuronal pools.

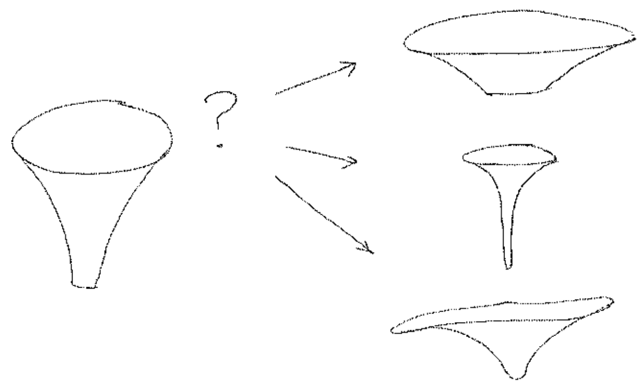

FIGURE 4

Figure 4. In a nonlinear, chaotic system, the basin that represents the system can change at any time, and can take on many possible forms. This variability is at the heart of the ability of the chaotic system to change and adapt its response characteristics.

What does this mean to a runner, a swimmer, a diver, a golfer, a skiier, or anyone interested in peak performance? It means that one key, being "in the zone," is to set up the initial conditions that correspond to the position and orientation of coins ready to roll down a set of basins that are themselves determined by the current state of the brain system. When in an optimal state of being poised for action, only a minimal amount of inertia must be overcome, for the system to fall into action. Thus, when an optimally tuned action is carried out, the system is really moving spontaneously from a state of high potential energy into one in which that energy is manifested in thought and action, in a spontaneous fashion.

The brain builds on a repertoire of experiences which are stored, possibly at the synaptic level, and made available through the process of both conscious and unconscious repetition. The bifurcation points are the points of synaptic organization, and by developing control of the bifurcation points, and the orientation therein, the brain learns to prepare for optimal action. The information is maintained and stored both at a latent, synaptic (unconscious) level, and at a manifest, active (conscious) level, comprising the decision to execute the transformation of energies, and the choice of pathways.

Walter Freeman has conducted studies on the cortex that demonstrate that the brain translates sensory information into perceptual meaning through state transitions that are determined by the chaotic dynamics of neuronal populations. These dynamics provide a substrate of neural plasticity, such that an organism can orient itself in preparation for to respond to sensory input. This orientation takes the form of patterned activity that provides a "ground state" for the perceptual (and motor) apparatus (Skarda and Freeman 1987, Freeman 1994a, 1994b).

An example of a simple linear system, which does not reorient itself, might be a brain tissue preparation resting in a laboratory container under controlled conditions, such as used for studies of cell responses to induced stimulation. In such cases, very repeatable and predictable responses can be observed, because the properties of the brain tissue can be well controlled, and there are no unknown inputs to the tissue from other parts of the brain. In a real-brain situation, however, there will be uncontrolled changes in the system due to changes in brain and blood chemistry, and the effects of signals arriving from other parts of the brain. Thus, although at the lowest level, the behavior of individual neuronal pools may be understood as a relatively simple phenomenon, the activity of an intact brain is considerably complicated by the presence of additional influences and changes, over which we not only have no control, but which we cannot even measure.

The second factor determining the nature of an intrinsic brain rhythm is the driving rhythm that is arriving via. the RAS. For each afferent volley, there will be a cortical response that may be manifested in the EEG. In our analogy, the participant has a large sack of coins at the ready, to be deposited into the funnel in succession, producing sustained, complex responses. Coins arrive at the hand without effort, and the maximal use of brain energy is to orient the coins, and to release them at the appropriate times.
An important issue is where these "coins" arrive from, and what determines their amount and nature. Clearly, the production and release of coins corresponds to that facet of brain activity that actually produces the "spins" of activity in the preconfigured neuronal masses. This is likely to be an aspect that is to some extent genetic, being neuroanatomic and neurophysiological in nature, but it may likely be a learned activity, as well. Can we train brains to produce and "play" coins in an optimal way?

We are more concerned with the efficient orientation and tranformation of energy than with the introduction of large amounts of energy. The RAS is one of the potential sources of this energy. However, there are other sources of energy, both external an internal, and the critical action of the RAS is to orient and time the release of "coins," resulting in the transformation of energy into desired thought and energy. This results in the ability to detect, utilize, and transform energy into thoughts and actions. The organism is responsive to energy, whether or internally or externally generated.

There are two important steps here. One is in the production of basins, with their accompanying bifurcation points, comprising readiness. The other is the orientation and release of coins in an optimal manner, producing maximally directed and efficient transformation of the latent energy into connected, kinetic energy manifested and directed by conscious (cortical) thought and action. This results in the refinement and focus of energy. For example, at one extreme, if the coin is aimed directly toward the center of the funnel, it will fall directly into the bottom, perhaps producing little observable, or useful action, as it does so.

THE IMPORTANCE OF NEURONAL POOLING: THE CONCENSUS OF THE CLOCKS

Because of the nature of the neuronal pooling mechanism and the properties of the individual neurons, the brain is generally not capable of recruiting a large mass of neurons at a high frequency. This is because to do so would require the existence of large numbers of high-speed pathways that simply do not exist. Fast rhythms such as beta, are observed to occur in relatively localized brain areas. On the other hand, the brain is very capable of generating large-amplitude, low-frequency activity. Delta, theta, and low-frequency alpha waves are often seen to occur over large brain areas, evidence by widespread EEG synchronization, visible at many brain locations, for these rhythms.

In the application of peak performance, this model leads to a picture of a fit and agile brain, in distinction to one that is less so, in terms of the ability to pool and unpool neuronal masses in an optimal way. The neuroscientist William H. Calvin has developed a theory (Calvin, 1989) that explains the ability of the brain to develop critical timing, as well as planning and decision making, by pooling large numbers of neurons into a single task. A maximally fit brain is able to pool large numbers of neurons into tasks such as accurate throwing, by using what we call "concensus firing" to achieve extreme accuracy.

As an example of how pooled behavior can produce peak performance, Calvin uses the analogy of a large number of clocks. Suppose I can produce clocks with an accuracy to only plus or minus one minute, but that I can produce any number of such clocks. If I wish to be alarmed at precisely 6:00 AM and I set one such clock to wake me, I will receive an alarm at any time between 5:59 and 6:01 AM. If, however, I set 100 of these clocks, and arrange an alarm to go off when the 50th of them has gone off, then I will be accurate, statistically, to within plus or minus 1/100 of a minute, which is better than one second. If I use 1000 or 1000000 clocks, I can achieve corresponding accuracy, with no upper limit on the number of clocks I can use. The device that counts the clocks' individual alarms, and provides a final decision, is a "concensus" mechanism, as is any neuronal mechanism that combines many cells' activity into a merged information pool.

Similarly, the human cerebral cortex contains millions of cells, each with its own intrinsic response speed and accuracy which, as we know, is on the order of 1/100 of a second, or ten milliseconds. However, human performance is well in excess of that that could be handled by a small number of such elements. For example, to accurately throw a rock 16 meters, requires a timing accuracy of less than 0.2 milliseconds, which is more than 50 times the accuracy of a single neuron. By pooling the activity of thousands of neurons into functional pools, in a dynamical fashion in which "concensus" firing is controlled on a moment-to-moment basis, the brain turns itself into a finely tuned information processor, that is tuned and refined continuously, according to the rules of chaotic dynamics (Figure 5).

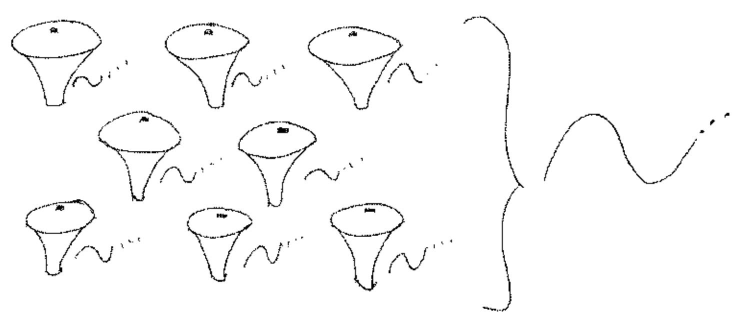

FIGURE 5

Figure 5. A system with many elements operating in parallel can be thought of as containing many basins. The pooled behavior of these elements provides a stability, accuracy, and speed that far exceed the abilities of any one element.

A "fit" brain is thus one that is able to quickly pool neurons into a specific task, and to unpool them, when they are no longer needed. The mechanism of such pooling and unpooling is likely to involve the postsynaptic activity of collateral neurons that are able to modulate the response of neurons to afferent activity, thus bringing them into the pool (excitatory), or taking them out of the pool (inhibitory). The ability of the brain to perform this modulation can be enhanced by improving the efficacy of these modulating influences, perhaps by increasing synaptic area, increasing the number of synaptic vesicles, increasing the efficiency of neurotransmitter uptake and removal, or in any other way making the collaterals more effective in their pooling and unpooling action on their target neurons.

THE TRANSITION INTO CHAOS

The transition from this linear model to a nonlinear model that takes advantage of the concepts of chaos theory lies in the introduction of key concepts such as extreme sensitivity to initial conditions, unpredictability of responses, and changes in the nature of the response, based on the current state. These would be conceptually modeled as, for examples, changes in the properties of the spring, changes in the mass, or other nonideal conditions over which we have no control, and which we may not even know exist. However, the recognition that the brain is in nonlinear and chaotic does not necessarily compromise the value of these simple concepts. Rather, these simple concepts can still be applied, particularly in the interpretation of EEG trajectory data and its possible value in the application of brain stimulation, and in the development of a rationale for brain fitness training.

A chaotic system has an infinitely large family of basins, that come and go in a dynamic fashion, while a linear system has a single, fixed set of basins. Thus, the possibilities an any moment of time for a linear system are fixed and predetermined, while those for a chaotic system are dynamically changing, and can be changed by learning, or by the behavior of the system itself. Thus, a chaotic system can facilitate the entrance into a set of states, which are present in a latent fashion, corresponding to a state of consciousness consistent with the potential of the system (Figure 6).

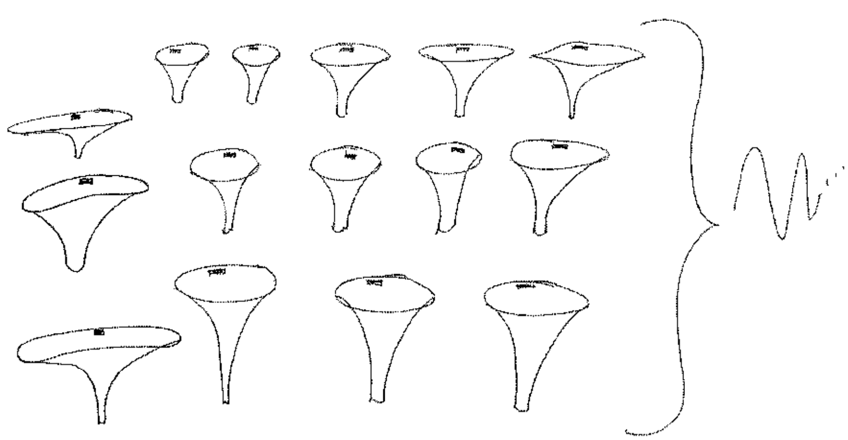

FIGURE 6

Figure 6. If the system is chaotic, the basins can be diverse and varied, and undergo constant change and adaptation. When the system is poised for peak action, the basins are perfectly formed, and the coins are optimally positioned and aligned. At any moment, the system can release coins, providing for accurate and efficient, yet effortless action.

The chaotic brain, in a state of inaction, but with the neuronal pools poised for action, can be said to have maximal potential energy. In an ideal state, the pool contains a large amount of pure potential energy, and is optimally prepared for peak performance. It is this state, characterized by high dimensionality, yet minimal action, that constitutes the rest state of being "in the zone," ready to react to either internal or external stimulation, to produce a focused, directed, well-controlled response to any subsequent input.

TOWARDS A CLINICALLY USEFUL MODEL

The predominant method for clinically describing brain function has historically been derived from studying pathologic brain states. This approach has been exceedingly helpful and necessary when diagnosing pathologic entities such as tumors and distinct structural abnormalities. This linear model of brain organization and function relates to many medical therapeutic procedures and treatments. However it is inadequate for describing human behavior and more complex functions of the brain.

A behaviorally specific diagnostic system does not acknowledge the reality that the whole a person is infinitely more complex than the simple sum of its behavioral and structural parts.

In their corridors and offices, clinicians acknowledge the complexity of people and their interactions. But in their attempts to communicate this to each other many still continue to rely on a reductionistic, linear perspective. Perhaps clinicians still use this linear model because at the present time there is not a more acceptable coherent model available that has any meaning for relating to therapeutic approaches and treatment.

We think it is important to begin to explore other conceptual models of brain function, a model that more accurately reflects how the human being relates to their own physiology as well as to the world around them---a model that helps us become healthier as we become more sensitive and responsive to our bodies and our environment.

Individuals in the EEG Biofeedback field such as Siegfried Othmer, Ph.D., and M. Barry Sterman, Ph.D., are attempting to provide a more basic model of function which has clinical relevance and which deals with states of arousal, and the organization and regulation of the nervous system. We are suggesting that a starting point for this model lies within the theory of chaos or complexification as described by authors such as John L. Casti (1994), James Gleick (1987) and Michael Heffernan (1996). This model is based on a "nonlinear," "chaotic" approach which we believe is a more accurate description of who we are and how we relate to our world.

Using a chaotic nonlinear model may provide us with greater understanding of some of the innovative approaches used by clinicians such as Len Ochs Ph.D. and Prof. Dr. Niels Birbaumer. We are particularly interested in a model that can help us understand how we can optimize the potential of anyone interested in peak performance. As utilized in peak performance training, this model derived from nonlinear chaos theory could consist of two stages: Primary and Secondary Synaptic Training.

APPLICATIONS IN TRAINING - STAGE ONE: PRIMARY SYNAPTIC TRAINING

The objective of this stage of training is to increase the potential energy of groups of neurons, preparing them to release energy in a flexible, efficient and sensitive manner. Such properties are particularly important when these small neuronal pools are called upon to transform their potential energy into kinetic energy as members of larger neuronal pools. Primary training would typically be carried out with alpha or low-frequency training, to produce a desired, controlled state of neuronal rest. But in fact, primary training can be conducted with no frequency-specific content at all. Dan Maust has, for example, explored using wideband filters (4-32 Hz analog) in an amplitude reduction paradigm, to stabilize and normalize EEG patterns in a variety of conditions.

If localized training is used, then specific populations can be developed. However, widespread training of global populations is also possible For example, Steve Wall uses a protocol that includes frontal-occipital training as part of the initial alpha training. Len Ochs, on the other hand, uses a protocol that includes an initial phase of training individual sites to reduce EEG amplitude, and moving from site to site as training progresses.

Ochs focuses on such small neuron groups in his unique clinical approach to neurofeedback called EEG-Driven Pica-photic Stimulation (EDS) (4). He evaluates and trains these pools at each of the cortical sites identified in the 10-20 model. The object is to decrease amplitude as well as variability (which he describes as hyper-reactivity to the EDS stimulus) at each of the EEG sensor sites. Ochs does this by pushing and pulling the dominant frequency at each site in both a positive and negative direction using a subthreshold visual stimulus. He works in a defined order, starting the training at sites he ranks as having the lowest amplitude and least variability (the easiest to work with) and moving to those with the highest amplitude and variability.

By decreasing amplitude and variability Ochs believes these small neuronal pools become more receptive to, and more able to discriminate aspects of, external stimuli. As a result they are not as hyper-sensitive or as hyper-reactive to the stimuli. We believe that by using the subthreshold stimulus he may be training an essential aspect of a nonlinear chaotic system by tuning the system to be exquisitely sensitive to initial conditions.

Ochs also utilizes a desensitization procedure for people he feels might benefit from a higher intensity of light. With this process of increasing the ability of the small neuronal pools to tolerate increased energy, Ochs may be helping remediate pathologic conditions or other situations that require the pool to respond and utilize high energy in order to function efficiently. At times Ochs also presents subliminal light stimuli 180 degrees out of phase to the left and right eye respectively. He observes that this seems to facilitate a "letting go" of the small neuronal pools' habituated responses.

This is also consistent with what David Siever, CET, (5) reports when he presents visual stimuli first to one eye and then to the other. Both procedures using relatively simple stimuli follow usual cortical pathways but they are delivered in an unusual manner which forces the brain to let go of its habituated interpretation.

This procedure is really not unlike the underlying assumptions of a Zen koan in which you must let go of your attachments to a habituated way of seeing and experiencing the world in order to grasp the koan's meaning. Ochs' method results in greater flexibility; Siever's method and Zen koans result in a move to a different state of consciousness and perception. All of them achieve an increase in the organisms ability to evaluate and participate in the reality of the present moment. This provides for a richer and more complex experience of life.

The high amplitude EEG that Ochs is working to decrease may well represent the brain's response to a traumatic or stressful circumstance stimulated internally or externally. This condition may have become habituated over time into a high "idle state" of the cortex that results in a less efficient use of energy and less sensitivity to external stimuli (although this state may have been appropriate at one point in time in response to a stimulus requiring such a high idle state). Both of these qualities described by Ochs--increased amplitude and increased variability---really represent a constriction of the ability of that nerve pool to evaluate and discriminate the stimulus which results in a linearity or lack of sensitivity and responsiveness of the system.

The use of alpha/theta training, or of a general EEG reduction training method reflects the goals at hand. Alpha training might be likened to a mantra, in which the brain is trained into an idle, but active, state, characterized by a particular cycle of action and relaxation, producing the 10 Hz rhythm. To do this, brain cells are acting in a synchronous fashion. EEG reduction, on the other hand, encourages brain cells to act in an unsynchronized fashion, or to be altogether inactive. This is more like the silence in the void, rather than a mantra; it is devoid of content, but represents being poised in a pure sense, enabling a potentially infinite range of possible outcomes.

What we really want this small group of neurons to do is to be able to respond to stimuli with greater degrees of freedom appropriate to the nature and intensity of each stimuli. We would then find it to be rapidly available to participate as a member of larger pools. This model from this frame of reference i.e. the small neuronal pools and their increasing ability to respond more effectively and efficiently to complex situations, represents an increase in their dimensionality.

The observation that an increase in linearity or the inability to have large, varied repertoires of responses to internal and external stimuli may well be directly correlated to what we perceive as pathologic states, pathology being defined as the organism's inability to effectively and efficiently participate in the complex reality of the present moment.

The result of this first stage of training would thus allow a larger number of sites to be available to participate in large neuronal pools, in a more sensitive and efficient manner. It would also stabilize their rest states, and make the brain more able to enter a "recovery" phase, between actions. It would also have the effect of reducing uncontrolled, paroxysmal activity, including seizures.

APPLICATIONS IN TRAINING - STAGE TWO: SECONDARY SYNAPTIC TRAINING

The second stage of peak performance training relates to the ability of neuronal pools to respond in a more flexible and non-habituated manner to more complex stimuli and tasks. Again, training can be either at a localized or at a global level. However, training is more likely to be task-specific, and to be targed at specific brain areas where secondary training is directed toward a particular goal. The same issues of increasing potential energy of the neuronal pools and increasing the efficiency of transforming this potential energy to kinetic energy are present. Various approaches to effectively train larger pools of neurons that are perhaps more specifically task related are yet to be discovered and adopted for peak performance training.

Secondary synaptic training builds on the substrate provided by primary training. Once the brain can reach an organized state of high potential energy, the release of that energy becomes the focus of secondary training. Such training will involve higher EEG frequencies, such as SMR and beta, which are indicators of brain organization suited to application in a wide range of cognitive and behavioral tasks.

Dr. Neils Birbaumer has described and demonstrated an approach to training larger pools of neurons that he believes represents both an excitation and inhibition of attentional systems in cortical and subcortical structures (6). In research supported by the German Research Society, Birbaumer has shown that "slow cortical potentials indicate a state of excitation or inhibition of large cortical neuron pools. Negative slow brain potentials of several seconds duration indicate depolarization of the underlying cortical network, positivity reflects reduction of facilitation. Therefore, Birbaumer says, "it can be concluded that self-regulation of slow cortical potentials involves excitation and inhibition of attentional systems in cortical and subcortical structures." Prof. Dr. Birbaumer has utilized biofeedback of slow cortical potentials in the treatment of epilepsy, severe motor paralysis and aphasia.

In a peak performance model we may be able to identify larger neuron pools, perhaps defined in "real time" while the individual is engaged in those tasks or analogous tasks defined in virtual space. Once we have defined these larger pools we could begin to train them using models developed by Ochs, Birbaumer or models yet to be described.

Secondary synaptic training will generally be organized toward the specific goals at hand. For example, a golfer might focus on occipital and premotor/motor training, while a protocol designed to enhance learning might involve frontal and occipital training, in an altogether different plan. Secondary training will tend to focus on higher frequencies, including SMR and beta. One emphasis would be to facilitate the shifting from a relaxed (potential energy) state to a concentration (kinetic energy) state, with control, and with fluidity. By re-entering the primary conditioned state quickly and effortlessly, after exercising a secondary synaptic activity, the brain will minimize the effects of the recovery phase, and approach optimal performance.

In the design of secondary synaptic training paradigms, tasks can be broken down into neuroanatomic elements, and correlated with states of consciousness and cognitive processes. By training brain locations in specific ways, and with specific goals in mind, a protocol can lead to remediation or improvement in an identified functional area, by conditioning and preparing the various brain areas, and by developing the ability of these areas to interact, in an efficient and purposeful manner.

CONCLUSIONS

We have attempted to provide a simple, physically intuitive model for the phenomena inherent in the dynamics of the brain during the preparation for, and execution of, finely tuned thought and behavior. This model makes use of the concepts of energy, organization, chaotic dynamics, and the aggregate behavior of many diverse neuronal pools, in the production of mental and physical activity, as well as the EEG.

The breakdown into primary and secondary training has parallels in other areas. Dennis Campbell, for example, describes the development of individual peak mental performance according to a progression of states that starts with calming the mind (solitude, sensory deprivation) , producing very low arousal states, following by stabilizing the mind (contemplation, mindfulness, reflection), all leading to a state of relaxed readiness, in preparation for activating the mind (engagement, performance), which is a high-arousal state. Thus, the chaotic model of brain dynamics is consistent with, and provides an underlying model for, the emerging cyclical models of concentration and relaxation, such as reported by Dr. Barry Sterman in studies of Air Force pilots.

The observed EEG signal trajectory may be thought of as a "window" into the current state of the brain, allowing us to attempt to understand its dynamics, to predict the effects of perturbations, and to develop a model of brain fitness suitable for applications in peak-performance, consciousness exploration, and the use of stimulation to alter brain states in an optimal way. A nonlinear chaotic model provides a starting point for each person to understand and experience the miracle of the complexity within each of us.

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