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Mastering Our Brain's Electrical Rhythm

Les Fehmi, Ph.D., and Jim Robbins

Les Fehmi, a pioneering researcher and practitioner of neurofeedback, and Jim Robbins, Author of *A Symphony in the Brain: The Evolution of the New Brain Wave Biofeedback*, argue that voluntary control over the Brain's electrical rhythms enables us to train ourselves to prevent or heal stress-related disorders and attention disorders. In addition, we may find a way to gain some of the benefits of meditation practice by means that are distinctively Western.

This is not your everyday account of neuroscience research. It is about a nearly forgotten corner of that field: harnessing the brain's electrical rhythms. Biofeedback or, more precisely, neurofeedback, is a technique that uses an electroencephalograph (EEG) machine and a system of rewards to teach people to increase their conscious control over the electrical rhythms generated in the brain – a process called operant conditioning. This was an active field of research in the 1960s and 1970s, but it began to slip from scientific favor when equipment manufacturers made wildly speculative claims for their biofeedback devices and the media joined in with characterizations of neurofeedback as a path to instant bliss-a panacea for the ills of the modern world. A writer in the *New York Times Magazine* (September 12, 1971) suggested that "The children of the future may look back on us as little more than Neanderthal men, crude creatures who were unable to control our feelings, our physiology, and unable to play upon the instrument of the brain."

These days, study of the brain's "spark," its electrical properties, is thoroughly subordinated to research on its "soup," the neurochemicals. Unfortunately, when EEG biofeedback was jettisoned from mainstream science, the baby went out with the bathwater. But quite apart from any particular applications, the operant conditioning of brain waves is a real phenomenon.

A handful of researchers at the University of California at Los Angeles, the Langley Porter Neuropsychiatric Institute in San Francisco, the University of Chicago, the University of Tennessee, and Northwestern University – and hundreds of practitioners – continued to study operant conditioning of cortical (cerebral cortex) rhythms. Despite an almost complete lack of research finding, neurofeedback has evolved over several decades into a powerful treatment for an impressive list of stress-related ills. For the past 28 years, I personally have used brain-wave training to treat patients for an array of psychological and physical disorders.[1]* My clinical observations suggest that neurofeedback can be used to treat anxiety,[2] depression, chronic pain, sleep disorders, attention disorders, and other disorders caused or aggravated by chronic stress. It is also an effective treatment for some mild closed-head injuries. It can reduce or eliminate the need for medication, an important benefit when a medicine has debilitating or unacceptable side effects.

* First person references are to Dr. Fehmi.

THE BRAIN AS GENERATOR

The human brain is a wondrous marriage of electricity and chemistry. Neurons are microscopic power sources that build up an electrical charge by chemical means (like a battery), then briefly reverse the voltage over and over again. In this way, electrical potentials can shoot dong the neuron's major extension –the axon– and be translated into chemicals that cross the synapse, the tiny gap between neurons, to produce electrical potentials in the receiving dendrites of the next neuron. In that neuron, the process can begin again, so that the electrical potential can keep moving. Neurons fire these action potentials in unison to accomplish whatever task the brain is doing. The number of times a cell builds up a charge and reverses it determines the frequency of the cortical rhythms in the brain. The cortical rhythm is the sum of the brain's action and dendrite potentials.

The discovery in the late 19th century that the brain generates electricity is credited to Richard Caton, who detected it by means o f a crude device called a reflecting galvanometer. A wire and coil that vibrated when electricity was detected was hooked to a small mirror upon which a narrow beam of light was directed. The stronger the electrical signal that went through the coil and wire, the more the mirror tipped and the higher on the wall the reflected beam of light rose. Caton attached the other end of the wire to the brains of monkeys and cats. When he presented them with a stimulus such as food, there was a corresponding electrical spike from the brain and the light shone higher on the wall.

Hans Berger recorded the first human electroencephalogram (EEG) across the top of his son's scalp in the 1920s, reporting his work in 1929. Understanding that the brain is governed by electrical impulses, Wilder Penfield, ;in Oxford-trained neuro-surgeon in Montreal, set out in the 1920s to create the first map of the brain's functions. At the beginning of necessary brain surgery, when a patient's skull was open and the patient was anesthetized locally but was conscious, Penfield inserted electrodes into the cortex and watched how the patient responded to tiny amounts of electrical current. When the electrode was inserted into the speech area of one man, for example, he emitted a long vowel cry. The instant the current was withdrawn, the cry stopped. Penfield's work, still respected and used today, made him a legend in brain science.

Experiments of this kind became a discipline called electronic stimulation of the brain, or ESB. A famed ESB expert, Yale psychology professor Jose Delgado, M.D., showed in the 1950s and 1960s that running electrical current into specific parts of the brain could evoke specific responses. He sent a small amount of electricity into a cat's amygdala, the almond-sized mass that governs the fear response, and the otherwise friendly animal instantly started hissing and spitting. As soon as the juice was turned off, the cat returned to a calm state. The flamboyant Delgado made headlines when he climbed into a ring with a charging bull with an electrode implanted in its brain and stopped it dead in its tracks with a remote-contolled shot of electricity. Delgado envisioned a utopian society in which people had electrical transmitters in their brains that they could use to dial up joy and pleasure at will, something he called a "psychocivilization." Electrical stimulation of the human brain is used to this day, for example in implanted pacemakers intended to treat epilepsy.

Neurofeedback comes into the picture when we realize that changes in the brain's electrical voltage are not just spontaneous or automatic, nor are they necessarily driven by an external sensory source; they can also be consciously self-generated. Scientists used to believe that autonomic responses such as the heart rate or brain-wave generation were beyond our conscious control. Then, in the 1950s and early 1960s, Neal Miller at Yale University trained a mouse to raise or lower its heart rate by 20 percent by rewarding the animal with a jolt to its brain's pleasure center every time it changed its heart rate in the desired direction. Later he taught humans with tachycardia, or abnormally fast heartbeats, to slow the beat-they were rewarded not with a shock but a pleasant musical tone.

Joseph Kamiya, a psychologist at the University of Chicago and later at the Langley Porter Neuropsychiatric Institute, performed the first experiment establishing that brain waves could be operantly conditioned. In fact, he found it surprisingly simple to teach people to recognize, and later reproduce, a particular frequency (alpha) on command if it was pointed out to them when they generated it. Many scientists replicated his work. At UCLA in the 1970s and 1980s, M. Barry Sterman demonstrated that operant conditioning of brain activity is an effective intervention for epilepsy in cats and humans.[3]

Scientists hypothesize that neurofeedback works by teaching people to gain conscious control over their brains' primary wave generator, the thalamocortex. If they are rewarded with a tone or a light when they are producing a specific range of frequencies in a specific brain locale, people can learn to increase and decrease this activity at will.

How much control is possible? Research has shown that very fine control can be achieved. J. V. Basmajian, a neuroanatomist at Queen's University in Canada, taught people to control small clusters of motor-unit cells in the brain that govern a specific muscle. He inserted an electrode into the base of the thumb, in and near cells that were linked by nerves to the brain, and then amplified the intercepted electrical activity from the brain over a loudspeaker. Each activation of the thumb's motor-unit cells by the brain produced an audible click on the speaker. In less than half an hour, the research subjects could turn the cells on and off voluntarily. After a few sessions, they could make' a sound like galloping horses or play a drum roll on request, without visibly moving their muscles. They were firing a select group of muscle cells by self-controlled brain activation.[4]

THE POWER OF ALPHA WAVES

Research has not established conclusively whether learning to control the frequency, amplitude, and synchrony of brain waves can permanently alter the brain. I believe that it can. One of the critical discoveries of the past decade is that our brains are far more plastic than we ever imagined. The handful of controlled studies on this subject, and years of clinical observation, support the idea that brain activity-and the brain's structure-may be changed by operant conditioning, with a resulting increase in the flexibility of attention. Just as learning a new task permanently alters neural circuits, so too does conditioning via EEG biofeedback, another kind of learning.

The human brain operates along a spectrum from 1 Hertz (a frequency of one cycle per second, abbreviated as Hz.) up to as much as 100 Hz, although most commonly we record up to about 40 Hz. Brain wave frequencies are clustered into four basic categories associated with different mental functions and named with letters of the Greek alphabet:

Delta, from 1 Hz to 4 Hz, is associated with sleep.

Theta, from 4 Hz to 8 Hz, is associated with hypnogagic and hypnopompic states (states between sleep and wakefulness).

Alpha, from 8 Hz to 13 Hz, is associated with a deeply relaxed, yet waking state.

Beta, from 13 Hz to 40 Hz, is the frequency range in which we operate in our day-to-day waking state.

Neurofeedback, which gives a person information about the amplitude and frequency of his brain waves at a particular moment, can be used in many ways. Let me explain.

My journey began in the 1960s at UCLA's Brain Research Institute, where I was a doctoral student working with Donald B. Lindsley, a pioneer of physiological psychology. Studying visual processing in macaque monkeys, we realized that the nerve and brain activity being triggered in them must be coded in their brains in the form of synchronous cell firing. The speed at which information processing occurred was possible only if the cell firings were traveling in parallel from region to region of the central nervous system, instead of in a series from point to point.[5] In other words, I realized that the brain was most efficiently processing and conducting information when the neurons worked simultaneously – in synchrony. Recent research has shed light on the idea that alpha frequencies are generally where the brain is most synchronous – that is, where the most neurons are being simultaneously excited. I hypothesized, therefore, that conscious control of alpha might be a key to enhancing brain function.

In the early 1960s, Kamiya's successful conditioning of college students to recognize and produce alpha frequencies further piqued my curiosity. Using biofeedback instrumentation I designed, I became my own first subject. One saline sensor was placed over the midline between my occipital lobes, while reference and ground sensors were clipped to my cars. In the course of a dozen sessions, I sought to produce alpha waves. I tried everything imaginable: meditation, visual imagery, music, colored lights, incense, negative ions, and muscle relaxation – all to little avail.

Exasperated and disappointed, I gave up. Fortunately, I was still attached to the instrument. At the moment of my mental surrender, the pen and ink EEG scratched high-amplitude alpha waves across the strip of paper. I had stumbled into the state of aware effortlessness, without daydreaming or sleep, which is associated with alpha.

After practicing in this alpha-abundant state for over a week, I observed surprising changes in myself. My whole body, and some particularly tense muscles in my face and neck, relaxed, yet I felt alert, centered, and poised. My sleep improved. I experienced an unusual mental sharpness and clarity. Colors seemed more vibrant and rich. My rather compulsive personality style softened. Most unusual of all, it seemed that the scope of my vision opened; when I looked around, I took in more with less effort. This was important to what would come later.

Synchrony, heightened in an alpha state, relates directly to amplitude and power. In the February 23, 2001, issue of the journal Science, two researchers at the National Institute of Mental Health, Robert Desimore and Pascal Fries, reported that synchronous neuronal firing may be a fundamental mechanism for boosting the volume of brain signals that represent important stimuli. In effect, they said, synchrony is the brain's way of encouraging more voices in the choir, which helps important signals to stand out from the "noise."

Synchrony, in other words, is necessary for optimal information processing in the brain, something animals understand instinctively. While grooming and at rest, monkeys and other animals produce more synchrony. When neurofeedback conditions the whole brain into synchrony, that synchrony moves the brain cells and the physiological systems they govern toward homeostasis, or better, more flexible physiological regulation.

SYNCHRONY MULTIPLIED BY FIVE

If training one part of the brain could produce these effects, what would happen if the lesson of synchrony were applied to the whole brain – for example, if five locations over the cortex were trained to produce alpha simultaneously, and in phase? That would mean that the brain's electrical waves were reaching their peaks and then their troughs at the same time, a uniform hum across the whole brain. This pattern is called rhythmic entrainment, and it can be very powerful. Soldiers marching in step over a bridge must break their cadence or risk bringing the bridge down. I sometimes refer to the goal of neurofeedback, as I practice it, as entraining cortical rhythms.

Working with research volunteers, I sampled eight lobes with five saline sensors secured to the scalp at places above the brain's midline prefrontal, the midline occipital lobe, the midline motor areas, and both temporal lobes. Placements of sensors on the midline between the lobes helped monitor bilateral synchrony; and feedback was provided to condition in-phase synchrony. The effects were far more powerful than training one site alone. People who underwent the five-channel training had experiences similar to mine – enhanced sensory experiences, a feeling of well-being, and a profound kind o f relaxation--but often could achieve some of these effects after a single training session. Sometimes these effects lasted for days. Usually the effects of a series of sessions lasted months, years, or indefinitely.

How the cortical electrical information is sampled (for example, where the sensors are placed on the scalp) is critical to brain-wave training. In the early days, many failures by researchers to replicate biofeedback studies were caused by poor research design. One common error, bi-polar placement of sensors, actually cancels out the observable in-phase synchronous activity for which the subject is supposed to be being trained.[6] Unfortunately, the distinction was lost on researchers. Because of these and other problems, it became virtually impossible to get funding for neurofeedback research and difficult to get research results published.

HOW TO IMAGINE NOTHING

Searching for ways to help people produce phase-synchronous alpha, I monitored their EEGs while I varied the imagery and relaxation exercises. I asked them to imagine a series of sensory images-a waterfall or a sunset-designed to induce relaxation. Here another clue revealed itself. Out of 20 images, only 2 produced immediate alpha amplitude increases: "Can you imagine the space between your eyes?" and "Can you imagine the space between your cars?"

Imagining space became a simple, effective tool for helping people get into alpha more quickly. With light and sound feedback to reinforce them when they achieved alpha synchrony, they listened to an audiotape of questions that required them to imagine the space around them, inside their heads, or occupied by their bodies. As they imagined space, their EEG moved into phase-synchronous alpha. We set for them the goal of listening to the taped questions about space in a way that produced maximum light and sound feedback. We then asked them to listen the same way during home practice. This basic protocol (much-simplified in this description) has worked in my clinic for three decades.

Imagining an object can create desynchronized brain waves, but when space is imagined there is nothing for the brain to grip, nothing to struggle to make sense of. Profound relaxation results because tension is released. I later learned that this use of space is similar to the techniques that some Eastern religions use in meditation. The EEGs of veteran meditators display a phase-synchronous alpha pattern across the whole head during meditation; and some longtime meditators describe an opening of their focus as the result of this practice. But while I believe that phase-synchronous training has effects similar to some types of meditation, it is not the same. Imagery protocols with light and sound neurofeedback are a faster, Western scientific way to achieve some of the same benefits. Moreover, it does not require adherence to a specific path or belief; it is a physiological process that everyone can access.

ATTENTION THAT IS STUCK IN "FIGHT OR FLIGHT"

Remember when I explained that after many hours of alpha training, my vision seemed to change and open? If I looked at a landscape, I took in more of what I was looking at, with less effort. Many of my students and clinic participants have noticed the same phenomena. What I came to understand is that we modern humans pay attention very narrowly. This is an emergency mode of paying attention. We can speculate that, in our evolutionary past, if we were walking in the forest and heard a twig snap, we would instantly narrow our focus. Our heart rate, adrenaline production, and other physiological indicators would shoot up, preparing us to fight or flee. After we discovered the source of the sound, and if it was not threatening, we would gradually return to a more open kind of attention.

Modern society and its almost continuous concerns demand narrow, objective focus. We teach our children to watch out for cars, to focus on their schoolwork, to pay close attention to what they are doing. We do not teach them, for the most part, that they should relax and open their focus, at least some of the time, while they are learning or performing. With the constant exhortation to focus a narrow beam of attention on the world, it becomes habitual early in life. So we spend our whole lives stuck in this mode of attention, without realizing it until our focus opens.

What is more, we pay attention with our whole body. Living in narrow focus, our heart rate, respiration, blood pressure, and other systems stay in overdrive. Eventually we either get so revved up that we become chronically anxious and irritable, perhaps unable to sleep, or our bodies start to burn out. To keep pace, we drink too much coffee to maintain narrow focus, then use alcohol or prescription drugs to relax. Chronic narrow focus is akin to keeping a hand constantly clenched; after a while the muscles stiffen and we lose control of them.

An extreme form of this can be seen in some children who grow up in an abusive environment. They are chronically hypervigilant and so narrowly focused on the possibility of harm that they have trouble with tasks such as reading. The scope of their visual focus is so small that they can see only one word at a time, and they must be taught to relax and broaden their focus so that they can learn to read.

Phase-synchronous alpha activity is an antidote to narrow focus, and thus a way to break its grip and reduce stress. Imagining space, while receiving feedback for brain wave synchrony, teaches people to access a form of attention in which the brain and body diffuse stress. The brain and central nervous system are the master control system for mind and body. Unresolved activity from chronic fight or flight responses – hyperactive nervous and glandular systems and tense muscles, for example – are dissolved.

Animals assume this state. Watch your dog or cat lying on the rug, eyes half open, seeming near sleep. The minute a morsel of food hits the bowl or there is a knock on the door, however, your pet springs up to investigate. This as yet uncommitted readiness to perform is what I call zero bias. It is an optimal attention in which people can throttle back and rejuvenate, instead of being in a chronic narrow state of hypervigilance. In this state, synchrony takes over and normalizes the nervous system. When something demands a narrow, object-oriented attention, we can flexibly zoom in with less effort. Ideally, we can stay in that mode of attention as long as it is needed, then return quickly to an open attention.

Although paying attention is essential to who we are, we seldom give it much thought, assuming that we are either paying attention or not. The truth is that we have an eclectic range of attentional styles within four basic types:

narrow: focus on something and exclude everything around it;

diffuse: encompassing awareness of all present sensory experience;

immersed: absorbed in experience;

objective: maintaining distance from experience.

One type is not superior to the others; each is appropriate to a particular situation. The goal should be flexibility, being ready to emphasize any type of attention that a situation demands. With advanced training, all styles of attention may be accessed simultaneously. To get a feel for the changes created almost immediately by a shift in attentional style, look at this printed page and continue reading, but also be aware of the space between your eyes and the page. Focus on the space behind and to the sides of the page . After a few minutes, your face and eye muscles may start to relax. Or sit still, and for 10 to 15 minutes, with your eyes closed, imagine space in, and between, various parts of your body, and space extending limitlessly in every direction.

Our style of attention both reflects and influences our brains' cortical rhythms. Phase-synchronous alpha waves, for example, appear to be inherently stable. Much of the anxiety, fear, and depression that we experience – and repress –was never meant to remain in our bodies for extended periods. The feelings were meant to be experienced as needed, and then to dissipate. But in a heightened state of arousal, brought on by narrow and exclusive focus, these feelings are either tormenting us (because they are spotlighted) or chronically blocked from our awareness – avoided or repressed.

Freud appears to have understood the role of attention in therapy. He asked patients to lie down in a darkened room facing away from him, which cultivated a style of attention that promoted free association . When someone's focus is opened, the unconscious also gradually opens and the contents become conscious. Freud wrote that he listened to his patients in a state of-"evenly hovering attention."

How we pay attention – and how our attention has been conditioned to react to situations and emotional stress – is at the root of more problems than we realize. Taking medication to mask emotions does not necessarily solve the problem, any more than disconnecting a warning light in your car gets at the cause of the mechanical problems the light is warning you about.

MANAGING OUR ATTENTION: CAN IT HEAL?

Fortunately, stress is beginning to get more attention from scientists. Bruce Perry, M.D., chief of psychiatry at Texas Children's Hospital and a research professor at Baylor College of Medicine, has studied abused and neglected children and believes that humans have an exquisitely sensitive stress response as a matter of survival. "The prime directive of the brain," he writes, "is to promote survival and procreation. The brain is 'overdetermined' to sense, process, store, perceive arid mobilize in response to threatening information from the external and internal environments."

There are, however, natural antidotes to this hyperactive stress response. Certain types of meditation tend to rhythmically entrain the brain and heal both body and mind. Music, chanting, and drumming are entrainment rituals that have served cultures for centuries. All stress antidotes, I believe, are effective because they help our attention become more diffuse and absorbed. The difference is that neurofeedback training tries to give people more direct control over that attentional shift. When people become aware of a more diffuse style of attention, they can locate where in their body their pain or other unpleasant experience is most intense: anxiety in their stomach or chest, for example. Resisting anxiety and pain takes energy. Diverting energy for resistance, energy a person needs to operate efficiently, can cause depression. But as anxiety is re-experienced in the diffuse style of attention, it can defuse or disappear. Depression lifts as the need for repression wanes and the system normalizes.

Migraine headaches, irritable bowel syndrome, anxiety, and insomnia appear as disparate symptoms but often they are manifestations of one problem, a stressed nervous system, and all these –and many more conditions – have been helped through attention training. We may ask how a single approach can be effective for disorders as varied as these, but often one medication is used for a similarly wide range of problems. For example, only a small fraction of prescriptions for the anticonvulsant Neurontin are prescribed for seizure; it is also prescribed for chronic rage, migraines, restless leg syndrome, bipolar affective disorder, chronic fatigue syndrome, chronic pain, ALS (Lou Gerhrig's disease), and tremors. If indeed it has such broad efficacy, it is probably because it stabilizes the brain. Certain forms of attention do exactly the same thing, while other forms destabilize the central nervous system.

Our ability to operantly condition brain activity says something fundamental about us. Perhaps the brain is not so inadequately designed or so frequently deficient as the array of chemicals now being prescribed by psychiatrists would suggest. Could the problems that we face largely be operator error-functional rather than biochemical or structural? If we know how to create the appropriate attentional environment, the brain can self-regulate to take care of many of its own problems without outside interference. On going return to homeostasis in the central nervous system is designed to be our normal state, but as a rule we do not know how to permit and maintain it. Changing the way we pay attention is one fundamental way to do that.

THE SPARK AND THE SOUP

For decades, research institutions and funding agencies have favored research on the brain's biochemistry, what scientists once dubbed the "soup." But brain chemistry is just part of the picture. The brain is not static, and the flow of neurotransmitters is not fixed. When we change the way we pay attention, we alter cortical rhythms – the spark – and in turn alter the chemical milieu – the soup – as well as the brain's structure.

Spark and soup are inseparable. We should start funding investigations into fundamental alternatives to the reigning orthodoxy of only brain chemistry. Medication has a role to play, but when we are dosing ourselves and our children with a growing number of antidepressants, stimulants, and anticonvulsants, many without long-term safety or efficacy data to support them, it is time to review our scientific premises. Meanwhile, before resorting to sending trial-and-error doses of medications into the unimaginably delicate neurocircuitry, I think the gentler and less risky approach of brainwave training is worth a try. It has few contraindications as a therapy, and the only requirement is motivated involvement.

Neurofeedback is a work in progress. There is much room for improvement. Brain-wave training has the potential to be a first line of treatment for many physical, neurological, and psychological problems, but research is needed to determine for whom it will work best and why, and to improve its efficacy. The approach to operant conditioning of the brain described here is one of many. Hundreds of professionals are treating various conditions with neurofeedback and getting excellent results – all with scant research funding.

There has been some renewal of research in the field of brainwave training. For example, John Gruzelier, Ph.D., a professor of psychology and head of the department of cognitive neuroscience and behavior at the Imperial College School of Medicine in London, is using low frequency neurofeedback training to teach musicians at the Royal College of Music enhanced control over mental and emotional processes as an aid to performance. Research on using brainwave training in connection with Tourette's syndrome, mild traumatic brain injuries, depression, and autism is taking place here in the United States.

Neurofeedback techniques are certainly not a panacea, but powerful and proven tools. Much clinical experience suggests that they can help patients become healthier by teaching them skills that effect long-term changes in the brain. It is to their detriment that formal research aimed at understanding the operant conditioning of the brain's electrical frequencies was abandoned. The time has come for scientists and clinicians to revisit the brain's spark.

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