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BIOFEEDBACK, BEHAVIOR THERAPY, PSYCHOTHERAPY
migraines, tension headaches, pain disorders, impulse control disorders
stress management for chronic diseases
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Passive Infrared Hemoencephalography (pIR HEG)

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DEFINITIONS:

BIOFEEDBACK refers to the process of "feeding back" physiological signals from the body with the intent of teaching the person how to control these signals. BIOFEEDBACK has a long and respected history, assisting people in the management of troublesome physiological and/or emotional conditions.

NEUROFEEDBACK refers to a special type of biofeedback. It uses physiological signals that originate within the brain (brain waves), as opposed to signals that originate from other sites such as cardiac activity or skeletal muscle activity.

HEMOENCEPHALOGRAPHY refers to a special type of neurofeedback. It uses physiological signals from the brain, but these signals are based on blood flow dynamics rather than electrical activity. This has the distinct advantage of being free from electrical artifacts that can distort brain wave based neurofeedback.

PASSIVE INFRARED HEMOENCEPHALOGRAPHY refers to a variant of that technique. It utilizes physiological signals from the brain, but these signals are based on thermal output, arising from changes in blood flow dynamics and cellular metabolism.

My interest in Hemoencephalography (HEG) started early in 1998, after becoming aware of Hershel Toomim's Near Infrared Spectrophotometry (NIRS) HEG system. The reason for my immediate interest was that 70% of my practice represents work with migraine patients. Although the precise etiology of migraine headaches has yet to be determined, there is universal agreement that the cerebrovascular system is intimately involved in the migraine process (Bednarzcyk, Remier, Weikert, Nelson and Reed, 1998; Moskowitz, 1998).

Prior to becoming aware of Hershel Toomim's system, I had been experimenting with passive infrared technology in an attempt to both monitor migraine activity and to directly train control over the associated abnormal cerebrovascular behavior. I was able to effectively monitor the activity, but

never had success at all implementing voluntary control. Hershel Toomim's development of NIRS HEG was the first effective implementation of direct voluntary cerebrovascular control.

I had been for several years, successfully using passive infrared technology for peripheral thermal biofeedback. The main advantages of this process were:

1. Extreme speed of response. This does not seem critical once the initial phase of learning occurs, but at the very beginning of the learning curve, an extremely rapid sensor response time can be very beneficial.

2. Variable measurement surface area. This is extremely difficult to achieve with physical contact temperature sensors.

3. No requirement for a physical connection to the body. This is a critical issue with disorders such as Reflex Sympathetic Dystrophy (RSD) and sometimes with both primary and secondary Reynaud symptoms, in which intense pain and of vasospasms may be generated by physical contact.

Hershel Toomim's discovery prompted me to take another look at the passive infrared technology I was already using. His early implementation of the NIRS HEG system was largely directed to the prefrontal cortex. I had never tried to do passive infrared based feedback at that site. When I tried other locations on the head, the pain would often get worse during a migraine, or sometimes it would even seem to initiate migraine activity during a non-migraine period.

Based on Hershel Toomim's pioneering work I started experimenting with the passive infrared process on the forehead area. My initial attempts were not overly successful there either, but neither did they produce the negative effects I had previously observed. With further refinements, my initial attempts evolved into a system that appears to have strong clinical efficacy.

The signal acquisition in my system represents a conversion of infrared (IR) signals produced by the brain and its vascular system, into a temperature equivalent. It appears to be a very sensitive and very useful system for measuring and feeding back changes in regional thermal output of the brain. Its main usefulness is in "exercising" brain function.

This mechanism has been intensively studied in the rat brain by Shevelev (1992), and the human brain (Shevelev, 1998). He found a high degree of correlation between localization of thermal output and localization of conditioned neural responses in the living rat brain. He determined the relative contribution of increased thermal output to be predominantly a function of local cerebral blood flow increases with a smaller but significant contribution coming from local metabolic activity.

In terms of the specific signal components, some of the IR signal originating from brain tissue passes directly through the skull and surface tissues and radiates directly into the environment in much the same way the beam from a flashlight would pass through a piece of translucent plastic. Second, some of the signal is absorbed by the skull and surface tissue as heat, which then gets re-radiated as infrared. The pIR HEG system measures a complex composite of these two signals. Since it measures wavelengths longer than visible light, the intensity of light in the room has no effect on the signal.

The process of passive infrared Hemoencephalography (pIR HEG) seems similar in response characteristics and effects to the NIRS HEG system. Reports from clinicians who have used both suggest similarities, especially similar responses to cognitive focus. As focus increases so does the signal.

There are two tentative observations that may represent differences between the two systems, when they are both compared at frontal locations. One difference that has been noted anecdotally is the effect of emotions. Consistently, if a person starts to feel frustrated, this is followed by a reduced frontal thermal output on the pIR HEG system. It is unclear if this has any effect on the NIRS HEG system. If there are effects, they may be less consistent. A second variable is sympathetic arousal which correlates with increased signal on the NIRS HEG system but appears to not impact the pIR HEG system, or sometimes may even decrease the signal output.

TECHNOLOGY:

Infrared light is not heat. It represents light waves that have been generated from an object. All objects that have temperatures above absolute zero generate infrared light. The intensity and frequency of the IR output represent a calculable variable from which assumptions can be made about the thermal output of the object from which the IR light is emitted.

Non-Contact Infrared measurement works in a manner more closely related to a camera than a thermometer (Omega Engineering, 1994). The pIR HEG system processes light through a lens, at frequencies below the visible spectrum. It responds to intensity and frequency changes. In a manner
similar to a camera, the field of view (FOV) is processed by the instrument as a circle that increases in diameter as distance from the measured object increases. While distance does not have any practical effect on the measured intensity of the IR signal, if the angle becomes too wide, IR radiation from non-target sources will be included, representing artifact. In a camera, as the focal length of the lens changes, the angle of the FOV changes. The same is true of IR measurement. Sensors with different lens characteristics have FOV angles that vary from those of a telephoto lens to those of a wide angle lens.

Unlike a typical camera, the lens on an IR instrument measuring within the 7 to 14 micron band is always made of non glass material such as germanium or zinc, since glass becomes opaque at those frequencies.

In developing the system, several variables appeared to affect its clinical usefulness.

1. Field of View (FOV). I started out experimenting with a 7mm FOV. This allowed very precise targeting. It was actually potentially more precise than EEG electrodes, because in an EEG system each electrode needs a reference electrode placed at another location to complete the electrical circuit. This 7mm FOV may still turn out to be a very useful mechanism for measuring focal brain changes. Unfortunately, the very narrow FOV had two problems. It was very difficult for most people to produce voluntary changes, hence not very useful clinically. Also, the recorded signal was strongly affected by small variations in surface temperature, especially arteries that are close to the surface of the skin. I found that by increasing the FOV, it became progressively easier to voluntarily control the signal, and the measured signal was progressively less affected by minor surface temperature variations. After many design changes the current FOV is defined by a 32mm circle. This appears to be an optimal compromise. The FOV is center weighted roughly approximating a bell shaped curve. It is relatively resistant to minor surface irregularities but still small enough to allow some degree of localization. It also appears to be very easy to develop voluntary control.

2. Response Speed. This has been the subject of much past and current debate among biofeedback and neurofeedback professionals. I think it remains an unresolved issue. Response speed needs to be fast enough to allow the system to process the signal and feed it back to the individual so that voluntary control can develop. In general, faster is better, up to a point. My pIR HEG system has a sensor response time of 80 milliseconds (the time requires to reach .67 of full reading). The response to indicate the start of a temperature increase is much shorter, around 5 milliseconds. At those speeds the signal becomes too jumpy for the subject to process easily, so signal smoothing is used retain the responsiveness while making the signal less jumpy.

3. Feedback Modality. I have developed a personal preference for a non abrasive, green, digital numeric display for feedback. I use these displays in all of my systems, regardless of the modality being measured. This may have something to do with my own idiosyncratic preferences, but I like both the smoothness and precision of the visual displays, and clinically they are as powerful as anything else I have ever used. Also, I have a suspicion that this type of display permits a type of brain data logging that is unavailable with analog types of feedback. The addition of threshold based control of a VCR and/or DVD player provides operant reinforcement of desired brain behaviors and deinforcement of undesired brain behaviors. Under normal training conditions, the movie will play when the individual is relaxed with a clear mental focus, but will stop when his/her mind wanders or frustration rises.

4. Resolution. My early attempts at developing the pIR HEG system used two different levels of resolution. One had a resolution of .1 degree Fahrenheit, the other .01 degree Fahrenheit. The main advantage of the .1 degree unit was that it was commercially available and therefore was very cheap. My hope was that I would be able to use it as an inexpensive home training device. It worked fine electrically but not clinically. Even after developing considerable skill on the higher resolution unit, only 50% of those people have been able to switch over to the .1 degree unit. Most of those people who were able to make the switch found it more difficult and less satisfying because of the relatively reduced sensitivity.

THE CURRENT SYSTEM:

The current system works within the 7 to 14 micron wavelengths of infrared light. The cutoff is very sharp, so it is completely insensitive to visible light. This is “far infrared” which has a longer wavelength than the IR pickup of most infrared cameras and infrared security systems. The instrument readings don’t change regardless of whether the room is dark or brightly lit. Since no electrical signals are being measured, eye movements and muscle tension have no effect. The FOV of the lens is 32mm. When placed on the forehead, it picks up temperature changes in the prefrontal cortex. As stated previously, It is probable that the source of IR measured by this system originates from both cellular metabolism and from capillaries and veins that pick up additional thermal output form the working brain.

CLINICAL OBSERVATIONS:

This is a very new system. As of this writing (10/2001), the system, having gone through multiple refinements, is still less than three years old. So far the preliminary data comes from my own clinical observations and those of other clinicians using the system. Since the system has been evolving, early data may not be completely comparable to later data. The data presented here reflects my

own observations from my own cases. Although I have attempted to be as objective as possible, this information should be viewed with appropriate scientific skepticism.

MIGRAINE: This is my main interest area. Among most migraine researchers, the pathophysiology of this mechanism is still considered to be a two stage process (Diamond, 1994). The first stage includes constriction of blood vessels in the head, and for still unclear reasons this correlates positively with constriction of blood vessels in the fingers. During this stage, there is no pain. The second stage is a rebound dilation of cerebral blood vessels that correlates with and probably causes the perceived pain. Researchers generally consider the second stage a “lock up” that requires heavy duty drugs to reverse.
There is now general agreement that the basic migraine mechanism is neurological rather than vascular, but that the pain is probably generated from excessively dilated blood vessels. This is supported by the repeated observation that the pounding that accompanies most migraine headaches corresponds to that person’s pulse.

I have been treating migraines for over 20 years relying mostly on peripheral thermal training. I have been quite successful at this and have built my practice around this population. Most of the folks I see have not done well on medication and represent some of the more difficult cases. Peripheral training is not difficult, but using it to manage migraine activity requires long hours of practice, along with rather constant monitoring of finger temperature during migraine free periods to prevent slipping into one. This is a very well established prophylactic practice and works well if a person can detect the physiological changes that occur when the first stage begins. However, it is a virtually useless process once the second (headache) stage begins.

When I started experimenting with my pIR HEG system, I noticed that migraine control developed much more quickly than with peripheral training. Typically migraines start to respond within 4 to 6 sessions. At first I used both modalities simultaneously, but now rely more heavily on pIR HEG because of its speed of response and also the apparently increased effectiveness. There is another wrinkle. Some of my patients have reported being able to abort the headache stage of migraine by using HEG, by trying to increase the frontal signal.

This is important because it flies in the face of conventional wisdom. This leaves the question as to why some people can shut off the headache by raising the display reading. Increases in the feedback signal from a central frontal location appear to reflect increased activity in the prefrontal cortex. At this point in time my hypothesis is that this increases the intensity of some naturally occurring negative feedback loops that proceed to deactivate the migraine. Typically when migraine headaches are stopped in this manner, there is no rebound later that day or the next day.

The apparent effectiveness of this pIR HEG system when placed on the forehead, seems to have more to do with the executive functions of the prefrontal cortex than its direct effects on the vascular system. There has been a great deal written about the functions of this part of the brain (Schore, 1994). It is part of what makes us human. It also plays an active role in regulation of other portions of the brain. It helps regulate attention, emotional tone, general arousal, and maybe other functions yet to be discovered. Exercising the prefrontal cortex seems to improve many autoregulation functions of the brain. It may be this improvement in autoregulation that accounts for the improvement in headache activity.

There are other effects as well. Whether they are viewed as side effects or serendipitous effects depends on perspective. Most migraine sufferers are women. Women tend to multitask much better than men, and have a tendency mentally to keep track of multiple things at once. This is a benefit when multitasking is needed, and sometimes an annoyance when trying to focus on only one thing.

Most of the women who have used this system for migraines have also reported that their thoughts have become more focused, and they like the feeling of the increased focus. Sometimes this change is temporary, sometimes it appears to be permanent.

My observations to date suggest that about 90% of the people I have seen for migraine headaches show some improvement. Of those, some are now completely headache free and some are not. The majority lie somewhere in the middle with significant improvement but with occasional lapses in control.

ADHD: pIR HEG, by its very nature requires a relaxed mental focus. It doesn't require having a diagnosis of an attentional disorder to benefit from learning how to concentrate more effectively. Children and adults diagnosed with severe ADHD symptoms sometimes completely normalize after the first few minutes using this system. I discovered this watching the changes with dual diagnosis (migraine and ADHD) individuals. Here the normalization of attention was unanticipated. It has had such a powerful effect that I now also use this as the first line of intervention for primary attentional problems.

The fact that the normalization is so dramatic is not always clinically useful, since the duration of this effect is very variable. With some children and adults, after just a few sessions, attentional patterns stay normalized. In these instances, there is probably a learning effect in that the person learned some selective control skills over patterns of attention. However, with others, it requires many hours of practice. Some people have not responded at all. Some normalize for hours or days after a session but then return to baseline. There are wide variations. Most people improve focused attention. However only some maintain the improvement in what appears to be a permanent manner.

For severe ADHD, this is probably not as good an alternative as medication. However, if medication side effects are troublesome, it can be a reasonable alternative.

DEPRESSION: Depression is a frequent component of migraine (Mitsikostas, D., Thomas, A., 1999). The etiology is unclear but may have something to do with the hypothesized common link of reduced serotonin levels. Both sexes have reported spontaneous elimination of depression while being treated for migraines with the pIR HEG system, with a placement in the center of the forehead.

This past year, I have experimented with sensor location over the left eye when depression has been present. This was in response to research over the past few years on the correlation between hypo activation of the left prefrontal cortex and the presence of depression. I have found that this placement may be more specific for depression, but at this point this observation is in its very early stages.

Regardless of placement in the center of the forehead or over the left eye, only about 50% of the people with depression found that the depression changed even though the migraine activity improved. The effect seems to be independent of gender or age. I have subsequently tried the system on people whose primary symptom was depression, and the 50% figure still seems to hold, although a left prefrontal placement may be somewhat more effective. The effect seems either dramatic or non-existent It may have something to do with varying etiology. At this stage all I can say is that only about 50% of the people with depression seem to notice any improvement, but that the improvement when noted is significant. As a related observation, often when I try the left prefrontal placement, children will giggle by the end of the session, and adults while not giggling will often smile. Both do this spontaneously without having any idea why they are exhibiting this behavior.

Many people with depression who have not had positive responses to this process have benefited significantly from taking antidepressant medication. With depression as with ADHD, medication may be a better first choice, unless there is a particular reason for needing to avoid it.

MEDICATION EFFECTS: The interaction between all forms of biofeedback and various medications is well established. The direction of effects has not always been clear, but with psychotropic medications in particular, progress with biofeedback may mean that medication will need to be reduced. The medication interactions with pIR HEG seem a little more precise. People currently taking antidepressants, especially SSRI's, will sometimes show effects as if they were taking too much of that medication. Under those conditions, sometimes a reduction in conscience mediated behavior is seen. Reducing the medication takes care of the problem. The same holds true for attentional disorders. The same dosage of a stimulant that used to work well may become functionally too high, producing overly quiet behavior.

pIR HEG RESPONSE PATTERNS: After monitoring hundreds of hours of work with this instrument, it has become apparent that the amount of signal increase during a session is not very significant. What appears to be significant is the amount of time spent working in the range at which further increases are a bit difficult. Based on this observation, the goal for each session is to reach that level at which further increases become difficult, and then maintain that level of difficulty.

What is not well known at this point is the range of effects that the process has on underlying brain function. Preliminary observations during full 10-20 clinical EEG recordings suggest that there is almost complete suppression of lower frequencies from about 12 Hz down, and this suppression occurs within 4 or 5 minutes of initiating prefrontal pIR HEG. There is also strong correlation with peripheral physiological measures. This suppression tends to occur throughout the brain, not just frontally.

As the number of minutes spent working on the pIR HEG system increases, the following tend to happen. Skin conductance decreases in magnitude and increases in stability. Peripheral thermal readings increase but in a binary manner. Nothing happens initially and then at some point there is a sudden increase in bilateral finger temperature. These observations are suggestive of normalized neural systems, possibly the tightening of negative feedback loops.

SUMMARY:

The pIR HEG system that I have developed over the past two years is still very much in its early stages. My own observations and those of other clinicians using the system suggest that it has very strong effects on behaviors and physiological responses that correlate with poor autoregulation. This is especially true for those behaviors linked to the prefrontal cortex. There may be other applications as well, that have not yet been considered.

A bonus seems to be the rapid learning curve. Even young children need only a few minutes to learn the initial stages of the control process. There are limits though, and children younger than six as well as mentally retarded adults who function below that level, seem to have difficulty understanding the concepts involved. I have worked with both groups and with much effort can make the process work. However it is very difficult and would not usually be a first choice.

As more data comes in from others using this system, and as we review comparative data between the NIRS HEG and pIR HEG systems, the knowledge base for this new technology will develop. My initial impression is that both systems when applied frontally may be roughly equivalent in function to frontal EEG neurofeedback, especially when EEG neurofeedback is used to train reductions in slower frequencies.

There is one main difference between EEG systems and HEG systems. This difference is most apparent with prefrontal cortical recordings. When recording EEG signals, there are two significant sources of signal artifact. EMG artifacts arise from excessive muscle contraction of scalp and facial muscles. Perhaps more potentially troublesome are eye movement artifacts which can be very large. Both sources can contaminate the EEG signal. This is not a big problem for clinical EEG recordings because these artifacts can be noted when the recording is analyzed. It can be a big problem when these signals are processed electronically and then automatically fed back to the subject for the purpose of the development of improved neural control systems. The reason for this is that even with sophisticated software, it is still difficult to eliminate these signals from the processed signal that is fed back to the subject. The NIRS HEG and pIR HEG systems are completely free from this sort of artifact contamination because they do not measure electrical activity. The absence of eye and muscle artifacts makes HEG a nice choice when working in that region of the brain.

My impression, based on repeatable response patterns across multiple individuals is that the pIR HEG system has powerful effects. However, with any new concept, there is always the potential for a placebo effect creeping into the picture. I have been acutely aware of this and have tried to minimize the possibility, but remain aware of its potential. Only time and research will tell how much of a potential problem this may be.

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