Hemoencephalography: A New Form of Neurofeedback

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Introduction

Neurofeedback is a means of training brain functioning, either to ameliorate symptoms of a disorder or to improve performance.

The trainee is presented with some measure of brain activity, and tries to influence the signal in a desired direction. Figure 1 shows a graph obtained during a neurofeedback training session.

What specifically to we mean by activity and how do we measure it? In "traditional" neurofeedback we monitor the brain's electrical activity - called the electroencephalograph.
Hemoencephalography (HEG) is a more recent development which is based on a different way of quantifying brain activity.

The Physiological Basis of HEG

One way to quantify brain activity is in terms of *metabolic activity* or *metabolic rate*. In fact this concept has widespread applicability in the field of neuroimaging. Metabolism is a cellular process in which "fuel" in the form of glucose or sugar is "burned" to release energy for use by the cell. The process consumes oxygen and creates carbon dioxide. Metabolic rate is the rate at which energy is used up.

When the brain is engaged in some mental task such as mental arithmetic, we expect that those regions of the brain directly involved in the task will use energy at a faster rate than other regions.

The human brain is extremely metabolically active. Although the brain makes up just 2% of body weight, it accounts for 20% of the body's oxygen consumption and 25% of glucose consumption.[1] In order to meet this energy demand, brain tissue has an extremely dense network of blood vessels and capillaries.

How do we measure metabolic rate? We can measure it indirectly, in a number of ways. Some of these ways rely on a phenomenon known as *neurovascular coupling*.

Neurovascular Coupling

Metabolic activity depends upon a supply of glucose and oxygen, which arrive via the bloodstream. Neurovascular coupling is a mechanism for matching blood flow to metabolic demand in the brain. This means that whenever there is a localised increase in neural activity (which happens when the brain engages in some specific mental task) there is a rapid localised increase in cerebral blood flow. A consequence of this response is that the blood in the active region becomes more oxygenated (i.e. the concentration of oxygen increases).

The process is managed by cells called astrocytes - these are a common type of glial cell or support cell in the brain.

Figure 1: Graph showing gains in the HEG signal over a typical 15 minute training session.

Brain Scanning

There are two broad classes of brain scanners - those that reveal structure and those that look at activity. Here we're concerned with the latter. These scanners indirectly measure metabolic activity. Typically they're used in research to try to infer which regions of the brain are involved in particular tasks.

PET[2] & SPECT[3] measure the relative rates at which glucose (the brain's fuel) is used up. Glucose which has been tagged with radioactive atoms is injected into the subject's bloodstream. The fate of this glucose is tracked by measuring the radiation it emits. Relatively more of it is delivered to the more active regions of the brain.

Functional MRI or fMRI[4] detects the localised increases in blood oxygenation mentioned above. This increase in oxygenation level changes the magnetic properties of the blood, and this change can be detected when the brain is subjected to a strong magnetic field.

HEG

Like fMRI, HEG also detects changes in brain activation by detecting changes in blood oxygenation.

Let's summarise the process:

- A mental task activates neurons in some particular region of the brain.
- These neurons consume relatively more energy
- This demand for energy is met by a localised increase in blood flow.
- The local oxygenation level of the blood increases.

There are actually two forms of HEG, each form having its own sensor. They measure different aspects of the one process (metabolic activation), and hence have a similar range of appication and achieve similar results.

Near Infra-Red HEG

Near infra-red (NIR) HEG is historically the first form. It was invented by Dr Hershel Toomim. He adapted a method called Infra-red Spectroscopy. His original contribution was to realise that the signal he was measuring could be consciously influenced and hence was useful in a context of biofeedback training.

The NIR device shines a light source into the head, most typically at the forehead (in part because hair obstructs the signal). The light is a mixture of red and infra-red wavelengths. A proportion of this light is bounced back out by a physical process called scattering. The device then measures this scattered light.

This is possible because the scalp, skull and brain matter (both grey and white) are relatively translucent to light of this wavelength. Blood, however, is not. Furthermore, the proportions of the light absorbed and scattered by blood depend on its level of oxygenation. This means that as the local oxygenation level of blood increases in response to neural activation, the signal from the device changes. Thus the device can detect changes in the brain's activation level.

Dr Toomim found a very good correlation between his device and fMRI, which also relies upon changes in blood oxygenation.[5]

The device can't give absolute measurements of activity. The signal is affected by factors such as skull thickness - so we can't compare one person to another. But it can detect changes happening over a short time scale, which is all we need in order to be able to train activation.

The current generation of NIR HEG sensor only detects activity in the brain's outer layer - the cortex. It is possible that future developments may allow training of structures much deeper in the brain.

Passive Infra-Red HEG

Passive Infra-Red or PIR HEG is conceptually much simpler. It was invented by Dr Jeffrey Carmen, who adapted a technique called thermoscopy. The sensor detects light (or electromagnetic radiation) of a particular wavelength - a small band within the infra-red (IR) part of the spectrum. This IR radiation is essentially heat being radiated by the brain. The sources are firstly local metabolic activity (sugar being burned for energy release) and secondly, local blood flow. This heat is detected in other forms of thermal imaging - in fact thermal cameras have been used to assess the effects of HEG training - see figure 2.

Comparison with EEG Neurofeedback

Compared to EEG neurofeedback HEG has these advantages:

- The signal is much simpler to interpret: it either increases or decreases in magnitude (corresponding to increases and decreases in brain activation, respectively).
- The signal is more stable (EEG measures tend to fluctuate rapidly and seemingly quite randomly)

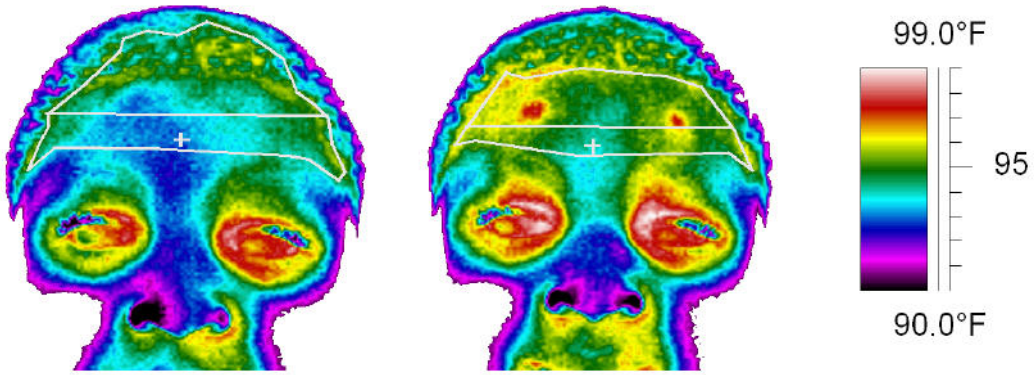

Figure 2: Images taken with a thermal camera, before (left) and after (right) a single session of HEG training. The subject has AD/HD. Note the increase in temperature seen over the whole forehead. Images courtesy of Dr. Robert Coben.

- The signal is much less subject to contamination by artefact.
- Dr Toomim claims that clinical benefits are achieved more rapidly.[6]

Training HEG

In HEG neurofeedback, the trainee tries to increase the signal, which is equivalent to activating the region of the brain under the sensor. To achieve this (at least for the forehead placement) the trainee looks for:

- an intensely alert or awake state of mind
- a firm intention or desire that the signal increase, but at the same time
- a relaxed, open, emotionally positive state - not getting too hooked into getting results because frustration tends to lead to deactivation.

Applications of HEG Neurofeedback

HEG is still a new neurofeedback modality and much work needs to be done in researching the applications. Here I'll consider three areas where HEG is already proving itself:

- ADD
- Depression
- Migraine

The Prefrontal Cortex

One thing that links these disorders is the possibility of dysregulation of the Prefrontal Cortex (PFC).

The PFC is the region of the cortex (outer layer of brain) behind the forehead, and also above the eyeballs (on the underside of the brain). The PFC is a particularly important part of the brain, most highly evolved in humans, and sometimes described as the brain's executive control centre[7]. It plays a central role in purposive behaviour - making decisions, formulating and carrying out plans and intentions, and sticking to them in the face of distracting stimuli. It coordinates the brain resources needed to carry out these intentions, and evaluates actions in terms of their success or failure in meeting objectives.

For instance, suppose one day it is time for your evening meal. You'll formulate a plan for meeting that need - you decide to cook a meal, and then decide what to cook. The PFC is responsible for formulating the steps needed to meet this goal - e.g. first get the pans and utensils out. The PFC accesses the knowledge you need - for example your memory of where you keep your pans. Suppose the phone rings while you're cooking - you decide to answer it, but hold your intentions in mind so that you can come back to cooking when you're finished on the phone.

The PFC is also strongly linked to motivation and emotion (these are of course connected). You can keep to a long-term plan (e.g. gaining a degree) by somehow holding in mind the good feelings connected to achieving that goal.

The PFC has the ability to inhibit other structures in the brain connected to emotions, enabling you to for example override a fear of heights when you need to climb a ladder.

Emotions are connected decision-making - it seems that the PFC arrives at decisions by in some way "imagining" the feelings that would result from each option.[8]

The PFC is especially relevant to social emotions because our ability to imagine what other people are thinking and feeling depends upon the PFC.

ADD

The behaviours described in the preceding section are just those that people with ADD find difficult - in short their problems are distractibility, impulsiveness, disorganisation, short attention span and quite commonly emotional difficulties too.

ADD is a real neurological disorder, and typically results in dysregulation of the PFC. The root of the problem may lie in other parts of the attention system (which includes many areas in the brain) - for example the dopamine pathway that acts something like the PFC's power supply. PFC function seems to be relatively easily dysregulated since it is at the top of the brain's organisational tree.

Brain scanning studies have shown difficient activty in the PFC of ADD sufferers, and is sometimes seen to deactivate further during tasks requiring concentrated attention, for which you would normally see an increase in PFC activity.

Though still a new form of therapy, HEG neurofeedback is showing promising results for ADD.

Depression

Depressed people typically suffer from diminished energy and motivation and poor focus. Some experience emotional flatness, others strongly painful emotions. All these symptoms can be linked to dysregulation in the PFC.

Training increased activity in the PFC can be a good idea for depression, firstly because it's often under-active[9], and secondly since it plays a role in regulating other emotional centres in the brain. As with ADD, the PFC dysregulation may be contingent upon problems somewhere else in the brain, but that need not undermine the potential benefit of training PFC activation.

Migraine

Dr Jeffrey Carmen developed PIR HEG specifically to treat migraine, with encouraging results. He treated 100 migraineurs with PIR HEG over a four-year period.[10] Over 90% of subjects who completed at least 6 sessions reported significant improvement in migraines. 'Significant improvement' was the point at which it became difficult to identify headaches as migraines - i.e substantially reduced pain levels. Typically both pain levels and frequency of migraine improved. (24 people dropped out of therapy before 6 sessions for various reasons including financial.) 61% experienced significant improvement after six sessions or less.

The underlying neuropathology of migraine remains unknown. Dr Carmen's theory for the efficacy of PIR HEG is that training strengthens the PFC's inhibitory control over some part of the brain stem thought to generate migraines.

Notes

1 See http://www.acnp.org/G4/GN401000064/CH064.HTML

2 PET is an acronym of Positron Emission Tomography.

3 SPECT is an acronym of Single Photon Emission Computed Tomography.

4 fMRI stands for functional Magnetic Resonance Imaging.

5 Source: course notes in training delivered by Dr Ernesto Korenman.

6 See Toomim's paper, 'HEG Talk 1: A Conceptual Introduction to HEG' available online at: www.biocompresearch.org/articles.htm

7 Elkhonon Goldberg's book 'The Executive Brain' (2001) is devoted to the topic.

8 Antonio Damasio explores this idea in his books, especially 'Descartes' Error' (1994).

9 See Amen (2003), for example

10 Dr Carmen describes his results in a paper, 'Passive Infrared Hemoencephalography: Four Years and 100 Migraines', originally published in the Journal of Neurotherapy and also published in Tinius (2004).

Bibliography

Amen, D. (2003) 'Healing Anxiety and Depression', Putnam

Damasio, A. (1994) 'Descartes' Error', Putnam

Goldberg, E. (2001) 'The Executive Brain: Frontal Lobes and the Civilized Mind', Oxford University Press

Tinnius, T. (Ed.) (2004) 'New Developments in Blood Flow Hemoencephalography', The Haworth Press