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Open Source, Low Cost, Scalable fNIRS/HEG Whitepaper

Contents

Abstract:

This whitepaper is to cover what I've learned from functional Near Infrared Spectroscopy (fNIRS) and Hemoencephalography (HEG) biofeedback as well as my development progress on open source low cost tools for anyone to jump into this space and benefit from it either for education or home therapy. These are important emerging imaging and therapeutic technologies as they offer a low cost and low abstraction method to work with live or recorded information from the brain. This is paired with a type of brain blood flow training for biofeedback therapy that allows users to increase their baseline brain perfusion in their prefrontal cortex and beyond. This field promises even more interesting monitoring methods and psychiatric tools akin to functional Magnetic Resonance Imaging (fMRI) with the use of tomography (DOT), laser interferometry (OCT), and deep learning feature decoders to understand brain activity. Our goal is to carve a path for open source efforts in this area by developing low cost tools and free software through reproducing different public domain hardware and experiments. We are sharing working and tested plans free, and hardware low cost.

Acronyms:

fNIRS - Functional Near Infrared Spectroscopy
HEG - Hemoencephalography
EEG - Electroencephalography
HbO2 - Oxygenated Hemoglobin
Hb - Deoxygenated Hemoglobin
SpO2 - Pulsatile Oxygen Saturation
CBF - Cerebral Blood Flow
DOT - Diffuse Optical Tomography
fMRI - Functional Magnetic Resonance Imaging
OCT - Optical Coherence Tomography

fNIRS overview:

Here will give a brief overview of the essential concepts of Functional Near Infrared Spectroscopy (fNIRS) and brain blood flow biofeedback. The Hemoencephalography (HEG) device is simply a single sensor fNIRS device with red and infrared wavelengths standard to pulse oximetry, and 3 cm spacing for depth readings. Alternatively it has been done with thermocouples to just measure IR radiation off your forehead, while photodiodes also include optical wavelengths. You can view the original patent 5995857 by Hershel Toomim and Bob Marsh, now public domain, online.

fNIRS is the application of near infrared light, and more generally optical wavelengths, for the purpose of imaging the surface of the brain and monitoring Cerebral Blood Flow (CBF). It is much cheaper but not as complete as a functional Magnetic Resonance Imaging (fMRI) scan with tracer injections, though it can still elucidate a ton of useful structural and functional data about the brain. The skull is highly translucent and even lends itself well for optical imaging of the brain. This is accomplished by placing LED or laser emitters with specific wavelengths at specific distances from photosensors on the scalp or forehead and flashing them repeatedly while reading the response on the photodiode. Your pulse for example is plainly visible by this method and blood oxygen can be calculated.

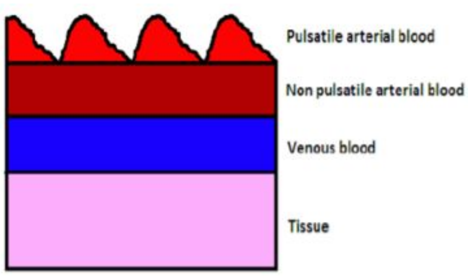


Figure 4. Light absorption diagram

The pulse oximeter analyzes the light absorption of two wavelengths from the pulsatile-added volume of oxygenated arterial blood (AC/DC) and calculates the absorption ratio using the following equation.

Equation 1:

$$\frac{(AC_{660})/(DC_{660})}{(AC_{940})/(DC_{940})}$$

We borrow typical methods from pulse oximetry, with a unique sensor shape to achieve depth readings.

Redder = More O2

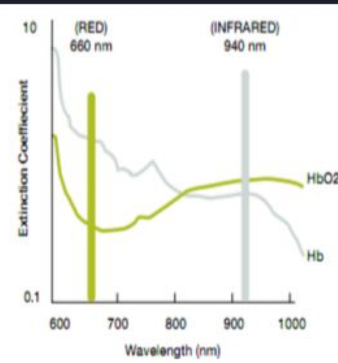
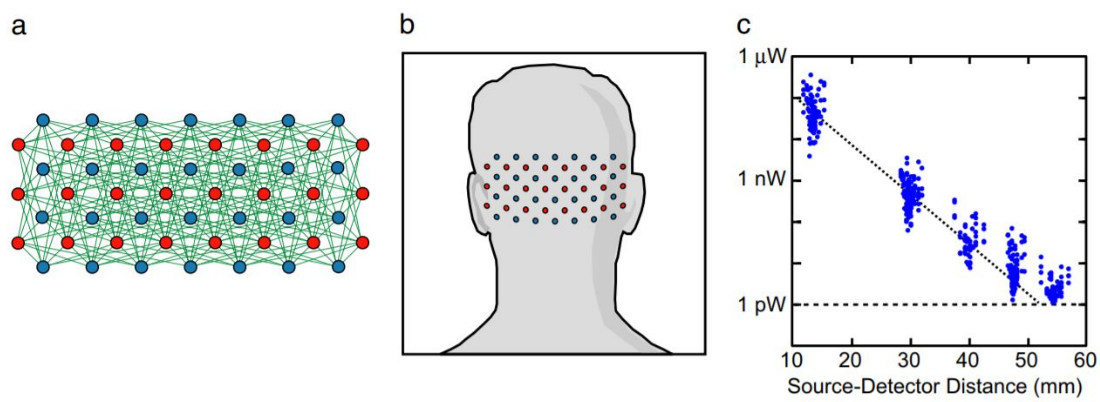


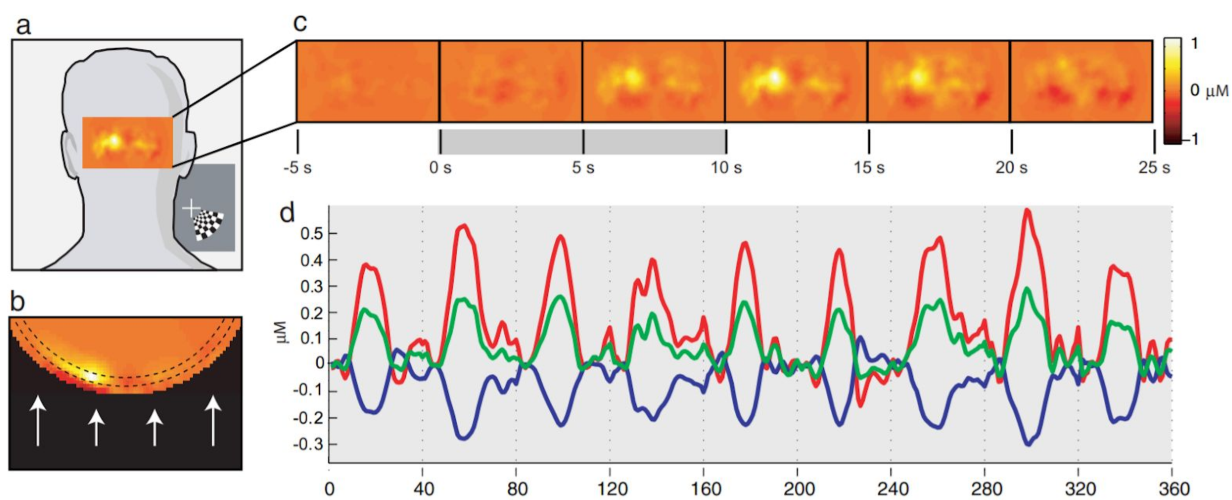
Figure 3. Hemoglobin light absorption graph

A photodetector in the sensor perceives the non-absorbed light from the LEDs. This signal is inverted using an inverting operational amplifier (OpAmp) and the result is a signal like the one in Figure 4. This signal represents the light that has been absorbed by the finger and is divided in a DC component and an AC component. The DC component represents the light absorption of the tissue, venous blood, and non-pulsatile arterial blood. The AC component represents the pulsatile arterial blood.

Optical wavelengths between Green - usually Red or Far Red - and Near-Infrared are generally chosen, one above 810nm and one below as Hb and HbO2 have opposing absorption indexes above and below that point, and are identical at that point. This creates a relationship that can be used to empirically calculate oxygen saturation and monitor blood flow. Pulse oximeters are probably the most universal application of fNIRS used for skin surface or fingertip pulse and pulsatile oxygen (SpO2) measurement.

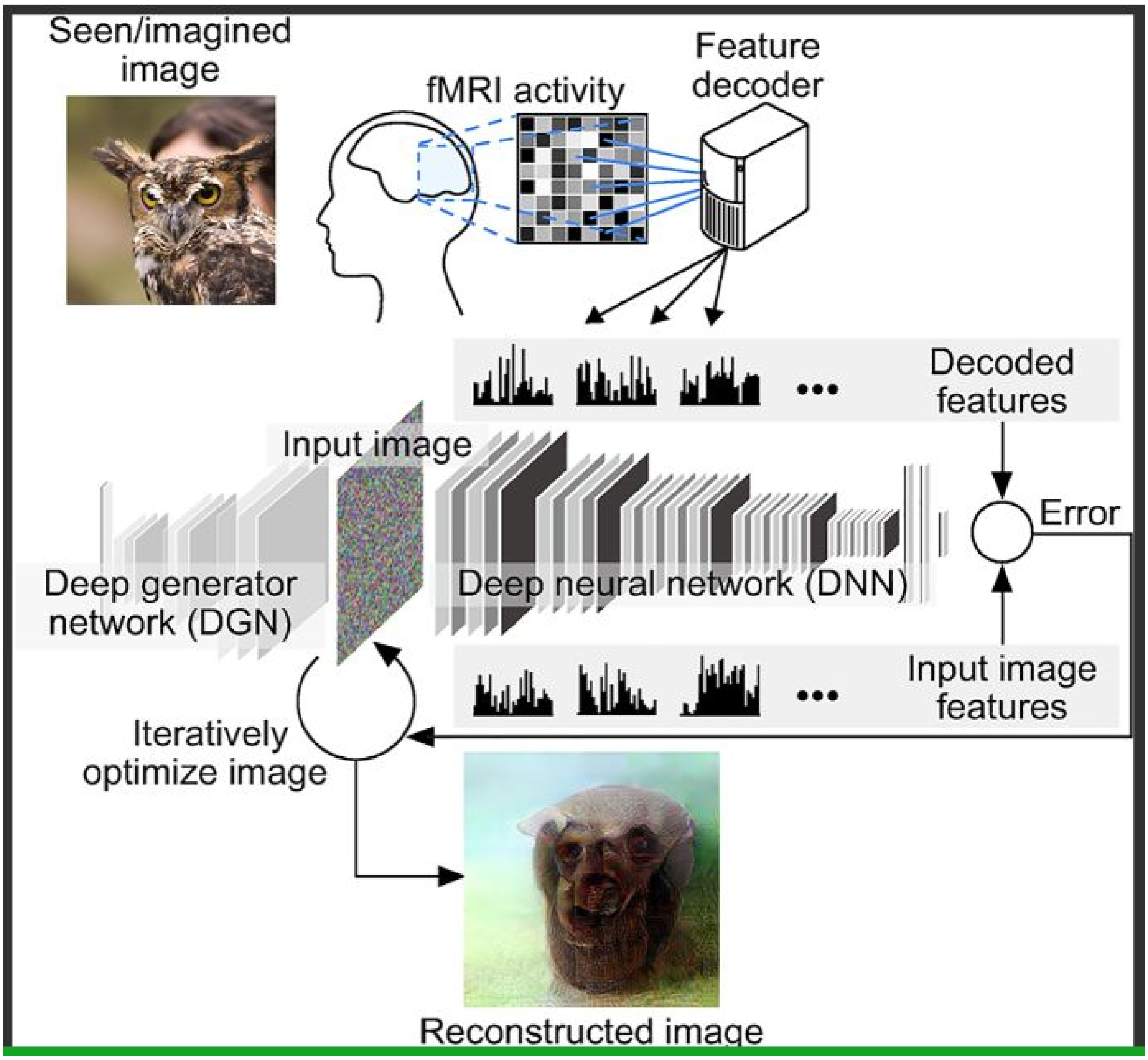
This goes much further however, some optical wavelengths have deeper penetration than others, peaking apparently at [1064nm](#) in the Near-Infrared spectrum. Photodiode and emitter pairs can even be densely arrayed to enable image reconstruction, and the curvature of the skull allows estimation of light paths between source and sensor pairs to perform 2D or 3D reconstruction using techniques similarly seen in geological surveying or electrical tomography. With mapping techniques especially demonstrated by a little-known piece of tech called Diffuse Optical Tomography (DOT), we can begin to functionally image the brain and spatially monitor metabolic and blood flow activity.





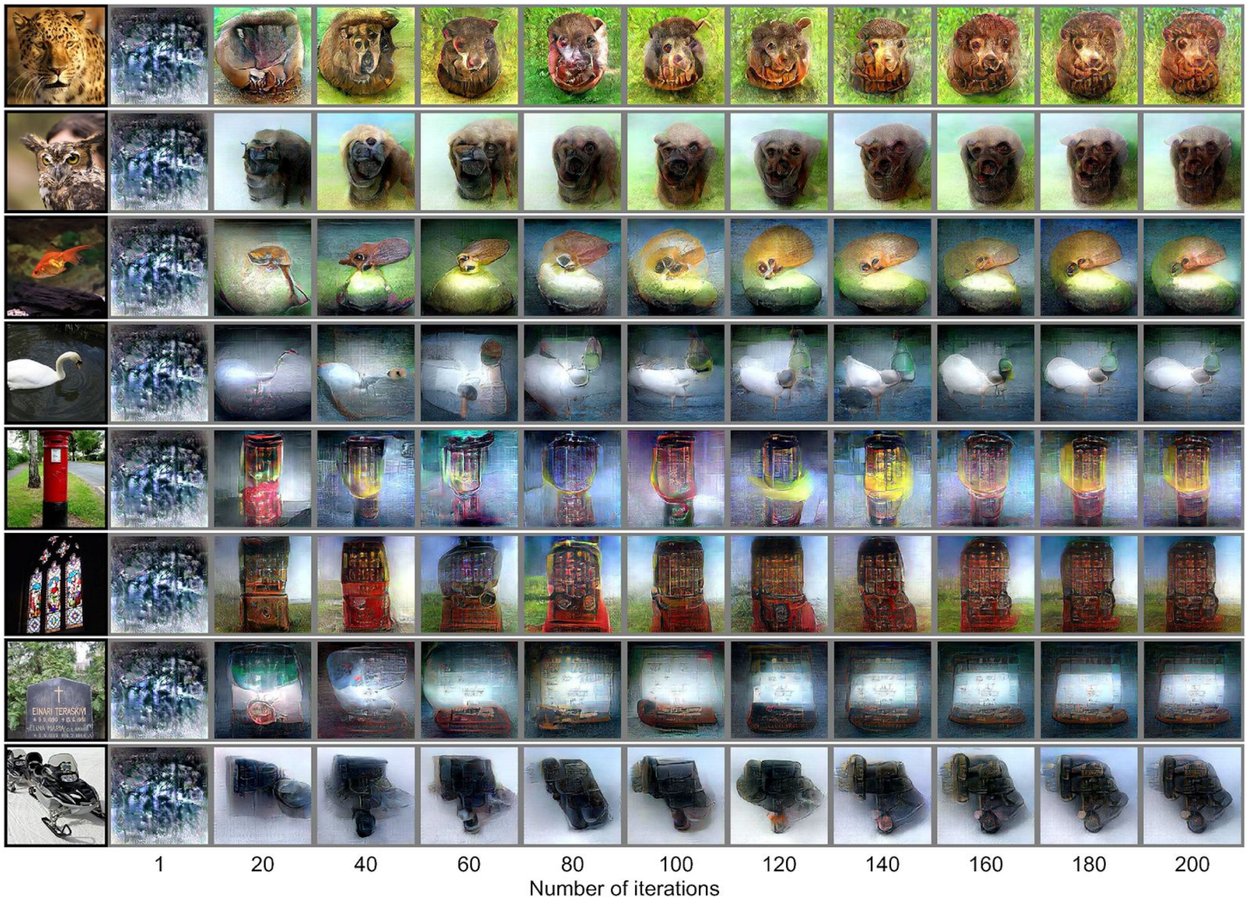
Source: *[Retinotopic mapping of adult human visual cortex with high-density diffuse optical tomography](#)* *- Ben Zeff, Brian White, Hamid Deghani, Bradley Schlagger, Joseph Culver (2007)*

In the above image you can clearly see the two hemispheres of the visual cortex activating using only 28 sensors and 24 emitter pairs in the near-infrared range. My favorite study involving fMRI data made deep learning-assisted reconstructions of images and videos from visual cortex activation patterns as seen in the next image, which ideally can be accomplished using fNIRS. In the next image you can see how deep learning of fMRI activity gets vaguely close to what the person was looking at, and that's spooky enough. There are other impressive studies out there involving similar data for doing video reconstruction from the visual cortex.



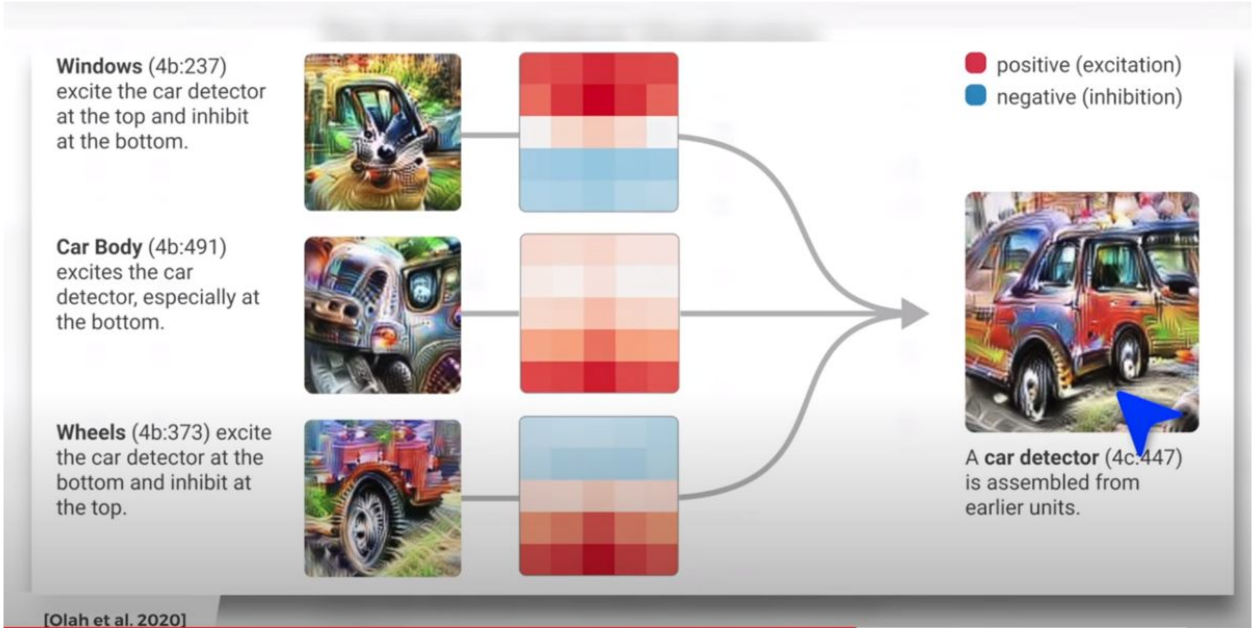
Source: *Deep image reconstruction from human brain activity - Guohua Shen, Tomoyasu Horikawa, Kei Majima, Yukiyasu Kamitani (2017)*

This deep image reconstruction technique gets more interesting the more you look:



Source: *Deep image reconstruction from human brain activity - Guohua Shen, Tomoyasu Horikawa, Kei Majima, Yukiyasu Kamitani (2017)*

Even rough information can lead to fairly accurate categorizations by deep learning networks, which are picking signal out of noise and comparing it to a learned image database. What is striking to me, when paying special attention to the church window reconstruction in the above image, is that the visual cortex may also blend that image with categorical archetypes encoded within the visual cortex. The church window gets painted onto an obelisk in a grassy field from the looks of it, and to me that suggests Jungian-like object archetypes existing within our sensory processing field when chunking visual input or any sensory input for that matter, likely for efficiency. It's a weird but not an original idea. This can be related to a recent publication looking at how convolutional neural networks (CNNs) encode different categories into its neurons by visualizing what those neuron ensembles actually encoded - where CNNs are heavily based off of the structure of the human visual cortex:



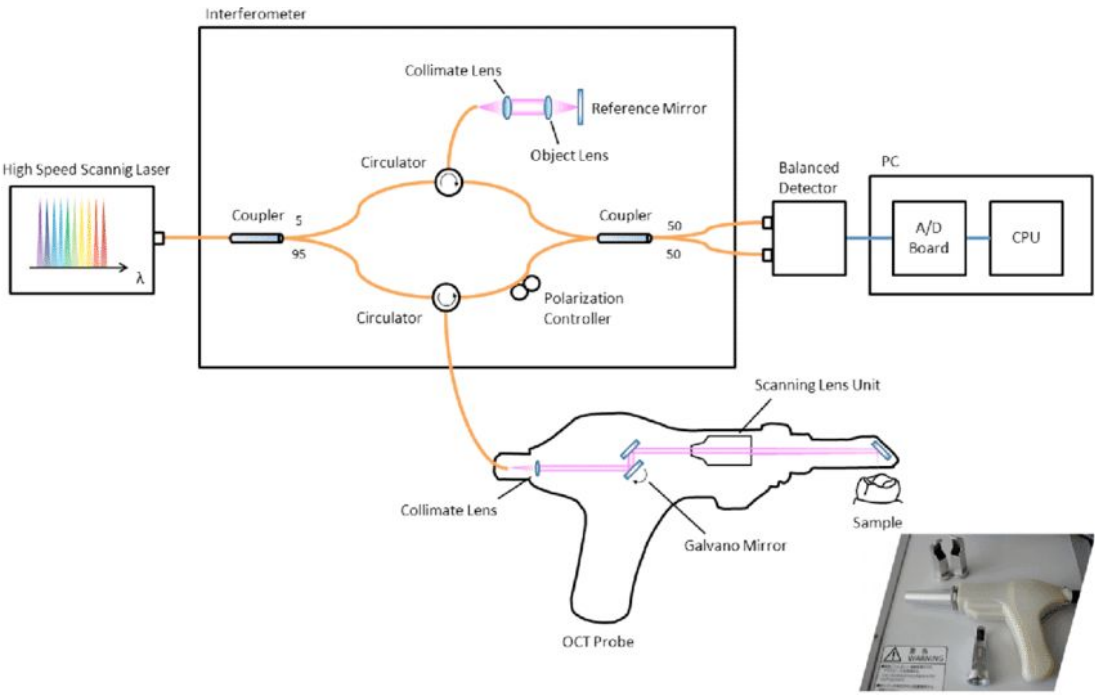
Source: *CNN Explainer: Learning Convolutional Neural Networks with Interactive Visualization. Wang, Zijie J., Robert Turko, Omar Shaikh, Haekyu Park, Nilaksh Das, Fred Hohman, Minsuk Kahng, and Duen Horng Chau. (2020)*

You can see how the different parts of the car get encoded as amalgams of different labeled feature sets that look like trippy fractal meta images, representing all of the different images exposed to the neural network during training. This all suggests a powerful imaging tool for gaining some much deeper insights into human visuospatial psychology and more by live decoding the brain's actual activity, though that's pretty far out, dude. Using machine learning decoding comes with a lot of potential confirmation bias problems, too.

"What we call 'reality,' consists of an elaborate papier-mâché construction of imagination and theory filled in between a few iron posts of observation." - Donald Hoffman in The Case Against Reality: Why Evolution Hid the Truth from our Eyes

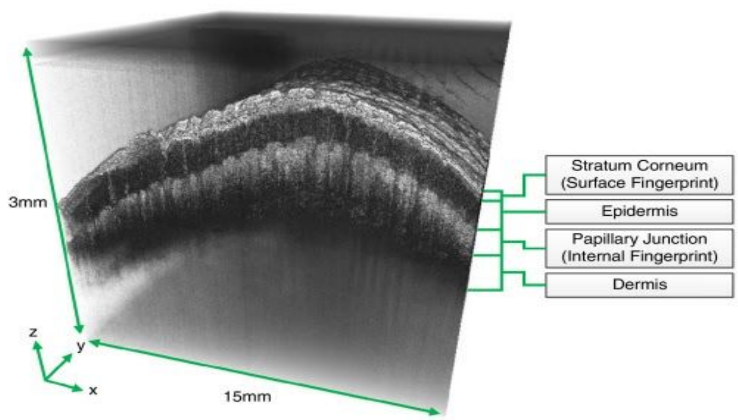
This is just what's possible with diffuse optical imaging or Fast Optical Signal spatial mapping by another name, and uses a lot of mathemagic to make it happen. It is also constrained by the speed of your processing and LED routines, and sensor array density. A commercial example of this is the NIRSIT device for frontal lobe monitoring with around 200 overlapping sensors on the forehead. So what about modern laser scanning tech? This leads to even more interesting but much more difficult infrared imaging featuring interferometry. This is best demonstrated using Optical Coherence

Tomography (OCT), where you apply the similar fNIRS principles to microscopy and get freaky with mirrors, beam splitters. and interferograms.



Source: *[Assessment of natural enamel lesions with optical coherence tomography in comparison with microfocus X-ray computed tomography](#)* - *Espigaras et. al. (2015)*

OCT provides another level of optical imaging and is currently only used for microscopic applications, requiring very high coherence lasers and lenses and other expensive optical equipment. This is able to perform miracles like high res 3D fingerprint detection or 3D angiography to image dense capillary networks, and more. A couple main applications are in eye clinics to look for issues in your cornea layers or experimentally in high security zones for extra fingerprint verification.



Source: *[Automated spoof-detection for fingerprints using optical coherence tomography](#)* - *Luke Nicholas Darlow, Leandra Webb, Natasha Botha (2016)*

And who said modern science isn't cool enough? This of course comes on the heels of massively improved manufacturing techniques and computer technology which can handle the high resolution and high processing speeds required for this 3D microscopy. What if you can scale this up, however, to effectively create a much higher resolution DOT image that is halfway in-between the high resolution microscopy and the rough 28 sensor DOT image (which still highlights brain hemispheres and some gyrations as seen above)? This has many engineering challenges associated, but it probably can be done. This would improve resolution especially at deeper layers, and can be enhanced even further with the use of dynamic focus and more tricks from RF and astronomy.

HEG Biofeedback Overview

First, familiarize yourself with various Cerebral Blood Flow (CBF) studies in this informal list, which demonstrate how different physical and psychological stresses, not to mention aging, have significant impacts on CBF. This helps stage an argument for why therapies targeting this process may be so significant to improving overall wellbeing:

Perfusion MRI to study CBF under psychological stress - Wang et. al.
https://www.pnas.org/content/102/49/17804.short

Cerebral Blood Flow changes in socially phobic people during stressful speaking tasks - Tillfors et. al.
https://ajp.psychiatryonline.org/doi/full/10.1176/appi.ajp.158.8.1220

CBF changes in cops with PTSD - Lindauer et. al.
https://www.sciencedirect.com/science/article/abs/pii/S0006322304008546

Cerebral Hypoperfusion in migraine patients - Woods et. al.
https://www.nejm.org/doi/full/10.1056/NEJM199412223312505

Cerebral Hypoperfusion and the onset of dementia - Ruitenberg et. al.
https://onlinelibrary.wiley.com/doi/abs/10.1002/ana.20493

Cerebral Hypoperfusion in children with dysphasia and ADD - Lou et. al.
https://jamanetwork.com/journals/jamaneurology/article-abstract/583298

Cerebral Hypoperfusion accelerates Alzheimer's - Okamoto et. al.
https://link.springer.com/article/10.1007/s00401-011-0925-9

Effects of Aging on Cerebral Blood Flow - Ances et. al.
https://onlinelibrary.wiley.com/doi/full/10.1002/hbm.20574

Sympathetic nervous system effects on CBF - Seifert et. al.
https://www.ncbi.nlm.nih.gov/pubmed/21963551

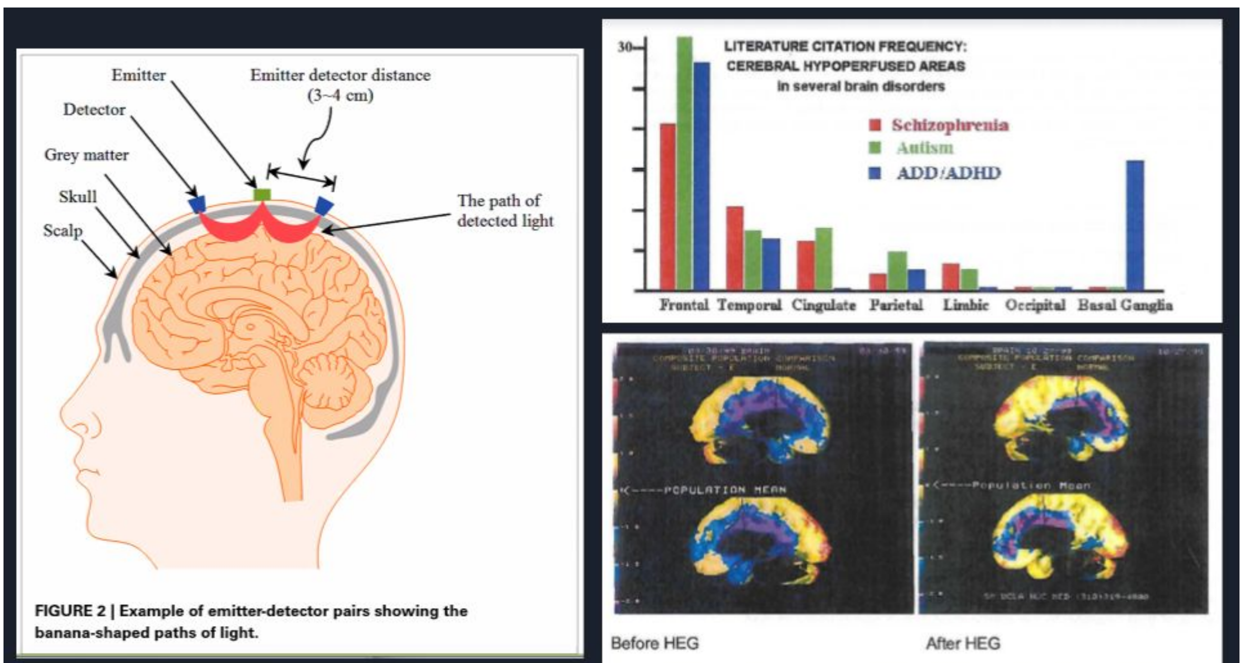
Cognitive training to improve resting Cerebral Blood Flow in the PFC in adults - Mozolic et. al.
https://www.frontiersin.org/articles/10.3389/neuro.09.016.2010/full

Exercise increases CBF, NIRS study - Ide and Secher
https://www.sciencedirect.com/science/article/pii/S030100829900057X

CBF changes with volitional breathing - Colebatch et. al.
https://physoc.onlinelibrary.wiley.com/doi/abs/10.1113/jphysiol.1991.sp018824

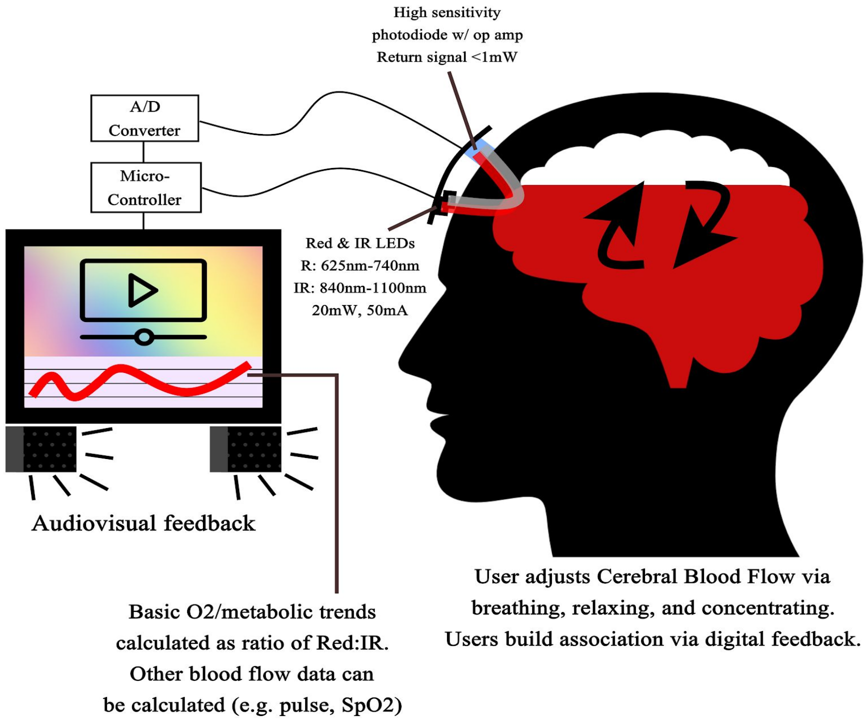
Tasty-looking food increases cerebral blood flow - Koyama et. al.
https://www.tandfonline.com/doi/abs/10.3109/09637486.2015.1118618

What makes the HEG device special and rather unorthodox is that it's a purposefully stripped down tool meant to capture general rises and falls in blood oxygen and the corresponding metabolic action in the targeted area of your brain. Breathing patterns for example are fairly clear, as well as when the user is paying attention or stressed out. These are all clearly marked by slow or even rapid changes in blood oxygen content in the prefrontal cortex. Increased activity corresponds with increased regional CBF when neurons draw on capillaries to meet their energy demands to fire. Compared to EEG the results are immediately apparent without any complex information processing required and happens slowly enough to be quite visible to the naked eye. This allows users to perform a type of brain exercise by breathing and paying attention to their thought patterns and seeing how prefrontal cortex oxygen saturation changes. Remember this is the same tech used for that cool imaging in the last section, just totally stripped down to remove any abstraction.

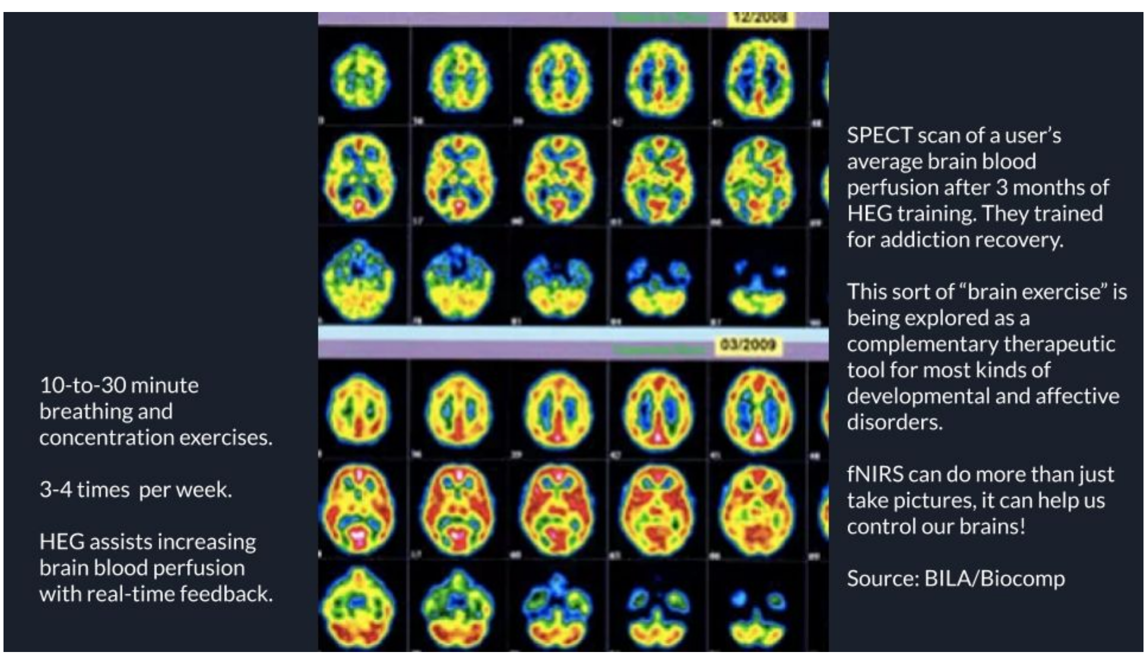


The User's goal with HEG is to improve their brain's energy use i.e. its physical fitness. Src: Toomim & Carmen

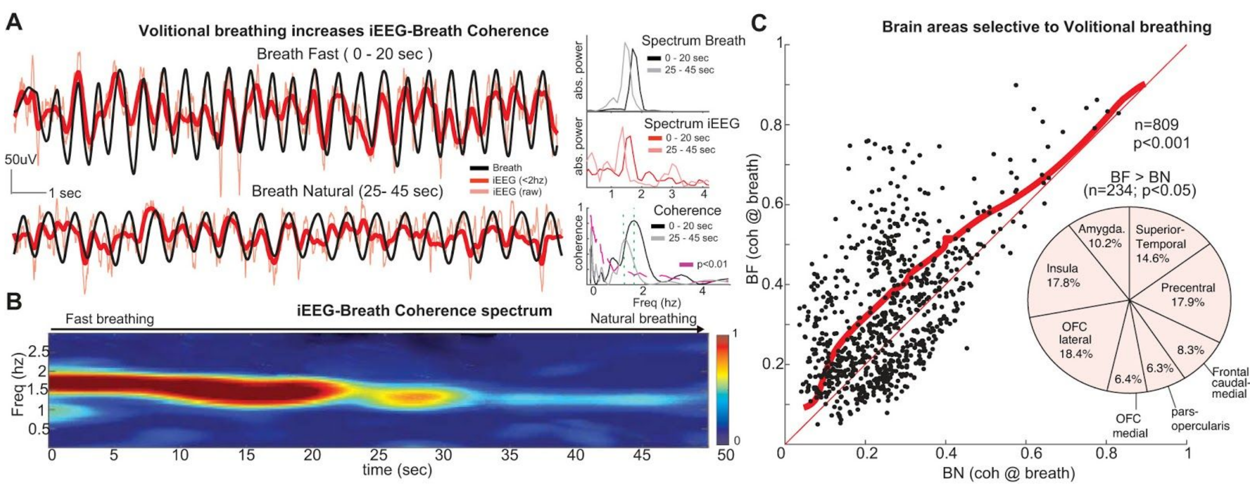
The Biofeedback Institute of LA had a few hundred SPECT scans performed on dozens of patients over several month periods while training with their HEG device several times per week. BILA noted how often issues like hypofrontality, i.e. reduced frontal lobe metabolism, show up in so many studies of mental disorders, and this therapy offered a direct remediation method quite unique to this technology. They recorded and reported fairly dramatic increases in average perfusion in the brain by population mean (see bottom right in the image above) after several months of HEG training.



To begin to explain the breathing exercise's effects, we need to talk about volitional breathing. Volitional breathing, i.e. controlled breathing, is a time-tested tactic to redirect oneself in the moment as well as strengthen one's overall sense of clarity and presence. It's obvious that optimal breathing patterns will enable better oxygen delivery and therefore bodily functioning, and different breathing styles can stress or relax the body in interesting ways as practiced by a lot of yogis or notably by [Wim Hof]. Oh but there's more to this story.



A 2018 study with implantable EEG in a seizure patient found that the anterior cingulate cortex (ACC) would oscillate in correspondence with controlled breathing patterns then stop cohering nearly as much when automatically breathing. This shows that the ACC among many others is quite involved when controlling and paying attention to our breath, and this networks with the rest of our frontal lobe as well as plays important roles in regulating the limbic system - notably the amygdala. A 2018 mouse brain study in Nature magazine discovered that stimulating the ACC reduced instinctual fear responses due to its direct connection to the amygdala and other related areas for fear (same with the olfactory bulb). Lack of activity in the ACC conversely increased instinctual fear response. This helps demonstrate how the frontal cortex plays a role in inhibiting instinctive reactions, which is a well known idea. However, this corresponds with regions of the brain that we now know we have direct influence on via controlled breathing, with several other networks probed in the volitional breathing study also correlating to either *controlling* breathing and/or being *aware* of breathing.



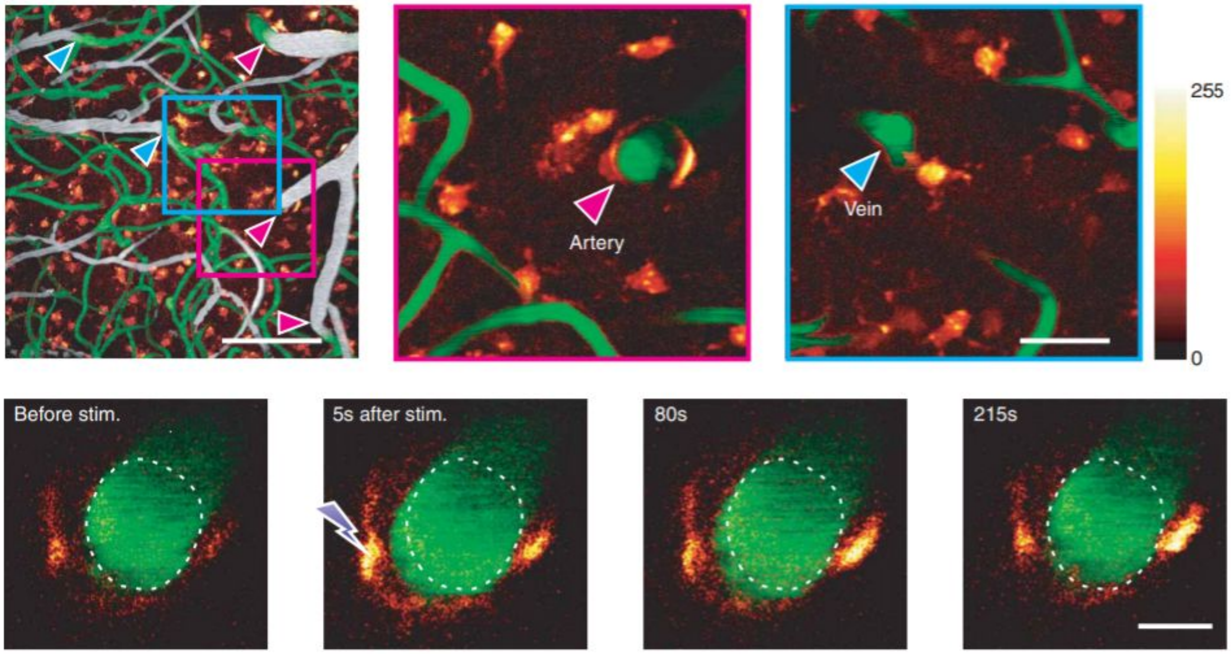
Source: *Breathing above the brainstem: volitional control and attentional modulation in humans - Jose Herrero, Simon Khuvis, Erin Yeagle, Moran Cerf, Ashesh Mehta (2018)*

Now let's talk about energy use for a minute and how stimulating the neocortex enables healthier cortical growth. This may help us understand why a direct brain stimulation method via controlled breathing may be so significant and help explain why it's been such a long held practice. This is also how we can begin to establish the idea of "brain exercise" as a real thing and something with a lot of nuance and potential benefits along with technologically-assisted psychotherapy.

The brain directs energy where it needs. It's like a water balloon with limited blood supply and it's squeezing itself in different places to direct that blood supply to the most-needed areas so that they can operate, recover, and self-clean. Your brain also eats at least a steady 20% of the body's resting state calories or about 300 calories/day - making it the most high demand organ in your body when compared to body mass. Young children's brains have been hypothesized to burn as high as 2/3rds of the body's energy with all of the major growth the brain undergoes, making it that much more sensitive to changes in the developmental environment.

Human brain vascular system. Source: Carnegie Science Center in Pennsylvania

High demand means high vascularization i.e. density of blood flow networks - a process managed by our glial and endothelial cells. Without that process, brain cells can't grow, heal, or fire on demand, while the demand also encourages more vascularization by signaling capillaries to grow into the networks as part of the reinforcement process. Astrocytes - which make metabolites and neurotransmitters for neurons, manage hundreds of thousands of synaptic clefts each, and help perform vasodilation - can be stimulated with diaphragmatic breathing (a tried and true stress and anxiety relief technique) to regulate regional blood supply like a baroreceptor, and are another fundamental yet underrepresented part of the brain's processing. Exercise and stimulation also induces astrocyte plasticity along with neuroplasticity and angiogenesis to meet the new demands on the neurons as they form new connections and modify old ones. It all happens all at once as a complex system, and the non-neuronal cell structures might still be doing much more to contribute to consciousness and memory beyond maintaining homeostasis. What we can take away, however, is that we have the full ability to influence this whole system through exercise, especially with our breath.



Astrocytes stimulated (orange) to induce arterial vasodilation (green). Source: *Astrocyte-mediated control of cerebral blood flow* - *Takano et. al. (2006)*

These different cellular phenomena in the brain demonstrate a clear and verifiable precedent for how breathing and increasing blood flow via exercise can have real structural and functional changes in many key areas of the brain, related to all kinds of mental processes and psychiatric issues. It shows how intense the cellular processes really are for just building the infrastructure that supports your biological neural network, and how it must adapt at every step of the way to keep up with your learning and living.

Breathing exercise specifically has several well-mapped and interesting relationships to mental processing via breathing's specific coupling with many different important brain systems. This is likely due to its big role in keeping us alive, sensing, and communicating. It's just like how all of the other functions we perform are now being found to have specific networks in our brain, and we can stimulate those networks to grow and reinforce by performing and practicing those functions along with practicing good health. This also offers a way to interact with and remediate many of the involuntary CBF changes cited in the studies at the beginning of this section and in countless others not highlighted. The brain is like a muscle in that sense, and must "fire together to wire together." This exercise can also increase uptake of different types of learning and memorization as a priming method.

With this all in mind, what I suggest is simply that we have a very interesting and universal way to better understand and reinforce many systems in our brain. It offers the opportunity to reinforce our mind-body connection very pragmatically, and just with simple controlled breathing exercises. It's nothing new, but I am attempting to link it with clinical evidence down to the cellular level so there is much less doubt about this reality and more dignity for its practitioners. However, with a clearer holistic model developed as more related physiological studies come out, we ought to be able to use this as a kind of old-school but valid deep brain stimulation. We can likely learn to very specifically regulate activity in different parts of the brain associated with different mental processes - places otherwise out of reach - with the aid of different breathing techniques to see how functional, morphological, and psychological changes may occur in response. The point is to better understand how we may provide people more relief from mental illnesses and a chance to excel in themselves by more noninvasive, non-pharmacological means so that there are more options and more prevention (of which there are few). This can and should be done with the assistance of low cost monitoring technology like fNIRS for maintaining objectivity as well as introducing new ways to interact with ourselves directly or indirectly.

With regards to the self-interaction allowed by technology, not all of this is conscious and our body is able to interact with much more complex sensory information to inform itself than we may initially realize due to our limited top-down awareness. A great 2015 TED talk with David Eagleman highlights his contributions on measuring information throughput via vibrations on the skin (akin to how we read braille). His team found that within days a deaf person could learn to interpret vibrations on a vest, corresponding to audio inputs encoded in specific vibratory patterns, and could interpret spoken words very easily without lip reading. What we can extrapolate from this is that our bodies are processing and encoding much more information and are capable of internalizing all kinds of abstract models for language and self-regulation. This helps indicate that biofeedback - or adding some extra sensors to better indicate our physiological states - has real implications at both the conscious and unconscious levels. Taking this further, our bodies use all of the sensory input it can get to help regulate its internal processing and form new communication pathways to itself and the external world in tandem via reinforcement learning. We are like cybernetic octopuses disguised as apes or something.

Bringing this back down a peg, dozens of case studies over the past two and a half decades indicate repeatable, predictable responses to HEG biofeedback across hundreds of users either considered healthy or with different major symptom profiles like PTSD and ADHD. The next section contains a list of case studies (most of the ones I can find on the internet) and show positive results across the board. I did not have to cherry pick.

List of HEG Case Studies

Here is an informal list of links to many widely varied case studies across many institutions and describe many testable treatment protocols for using the HEG effectively:

Intentional Increase of Cerebral Blood Oxygenation Using Hemoencephalography (HEG): An Efficient Brain Exercise Therapy - Toomim et. al.
https://www.tandfonline.com/doi/abs/10.1300/J184v08n03_02?src=recsys

Effects of HEG training at three prefrontal locations - Sherrill
https://www.tandfonline.com/doi/abs/10.1300/J184v08n03_05?src=recsys

HEG Neurofeedback Mechanism of Action (ASD focused) - Shoshev
https://www.researchgate.net/profile/Mitko_Shoshev/publication/323699457_Hemoencephalography_neurofeedback_-_mechanism_of_action/links/5ab8b34045851515f59f8fc9/Hemoencephalography-neurofeedback-mechanism-of-action.pdf

Clinical Usefulness of HEG - Serra Sala et. al
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4869785/

Passive Infrared HEG: 4 years and 100 migraines - Carmen
https://www.tandfonline.com/doi/abs/10.1300/J184v08n03_03

HEG Case studies - Toomim and Carmen
https://www.brainchanger.co/wp-content/uploads/2018/07/heg_case_studies.pdf

HEG A New Therapy for ADHD: Case Report - Mize
https://www.tandfonline.com/doi/abs/10.1300/J184v08n03_06

Evaluation of PFC activation and emotional processing with HEG - Gallart
https://www.tandfonline.com/doi/abs/10.1080/10874208.2012.705754

Passive Infrared HEG - Carmen
https://www.eeginfo-neurofeedback.se/fileadmin/images/was_ist_neurofeedback/literatur/pIR_HEG_article_10_25_01.pdf

HEG for Dyslexia - Pecyna
https://link.springer.com/chapter/10.1007/978-94-007-6627-3_26

HEG for Schizophrenia vs Healthy participants - Gomes et. al.
https://www.sciencedirect.com/science/article/abs/pii/S0920996417305200

HEG for Migraines without aura - Walker and Lyle
http://www.neuroregulation.org/article/view/16213

HEG training for improving brain function with EEG comparisons - Bartosinski et. al.
http://82.139.152.144/index.php/pjas/article/download/133/110

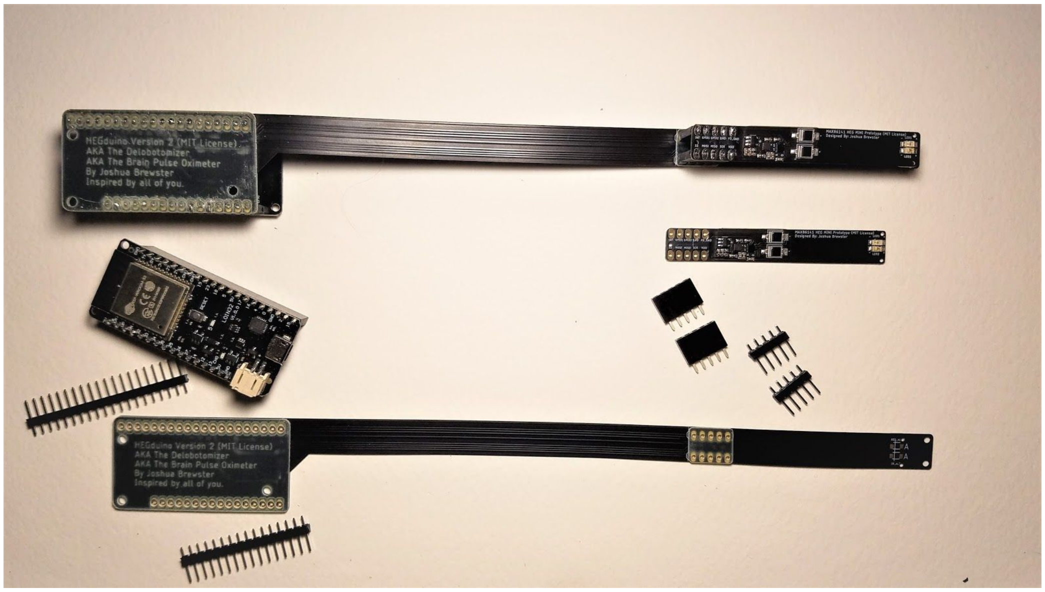
HEG training for children with and without ADHD - HEG and QEEG comparisons - Castro et. al.
https://www.sciencedirect.com/science/article/abs/pii/S0924933814778095

HEG training with EEG data compared - Sherrill
https://www.tandfonline.com/doi/abs/10.1300/J184v08n03_05

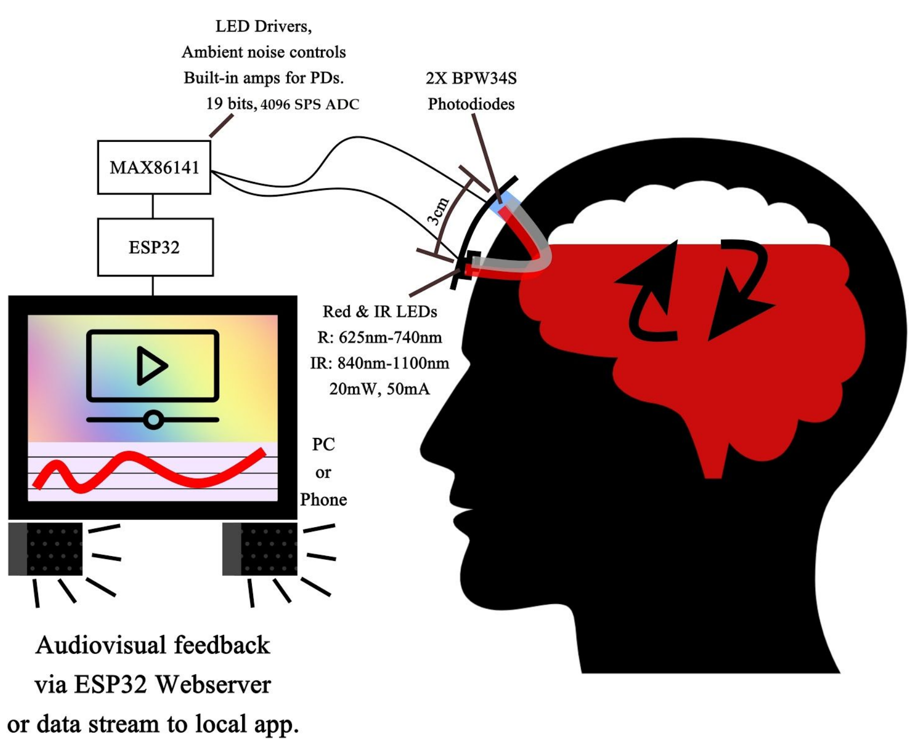
37 Migraine patients studied with EEG + HEG + Skin temperature - Stokes and Lappin
https://link.springer.com/article/10.1186/1744-9081-6-9

HEG Alpha

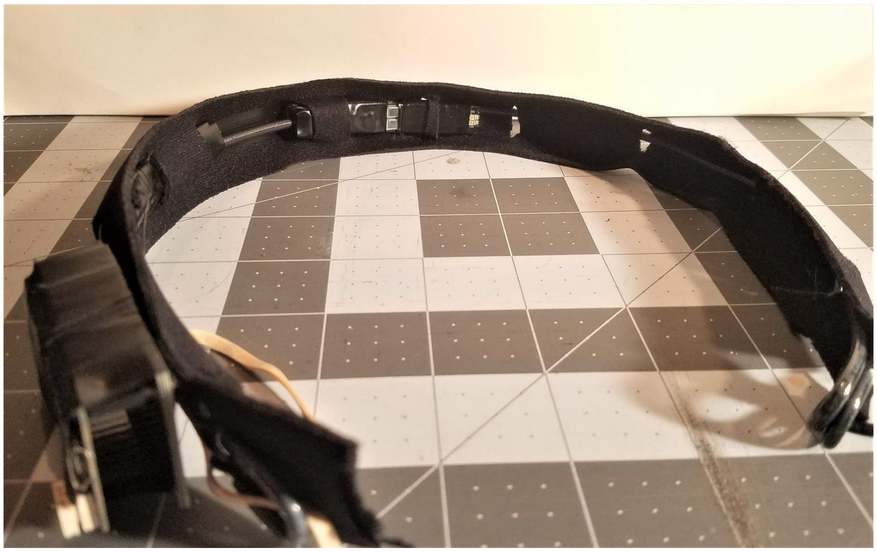
So where are we at right now? There are many emerging fNIRS technologies on the market of varying complexity and an even more variable cost, though it is dropping on average like all commercial technologies. I myself have produced a single sensor fNIRS HEG board, first as a cheap off-the-shelf kit and now a more competent and state of the art design using the MAX86141 with a modular and flexible breakout board style. It can be either a foldable fingertip pulse oximeter or fNIRS sensor. These are currently available at https://hegalpha.com as developer kits and come with a simple but functional headband to make it a wearable biofeedback device. The original kit was launched successfully on Crowd Supply and picked up by OpenBCI for their shop. We have sold hundreds without much budget for advertising or flashy designs due to its highly practical purpose.



The Delobotomizer kit features an ESP32 to drive the MAX86141, enabling Bluetooth, WiFi, and Serial USB data transmission and lightweight onboard software via a web server to deliver a robust HTML5 interface. This was developed over the last year and a half with the help of Brain Trainer (from Georgia) and John Chibuk (BlueberryX in Toronto) at certain phases while I helped them prototype their own designs. My own version is available open source under the MIT license or as a purchasable developer kit to support my continuing public domain work.

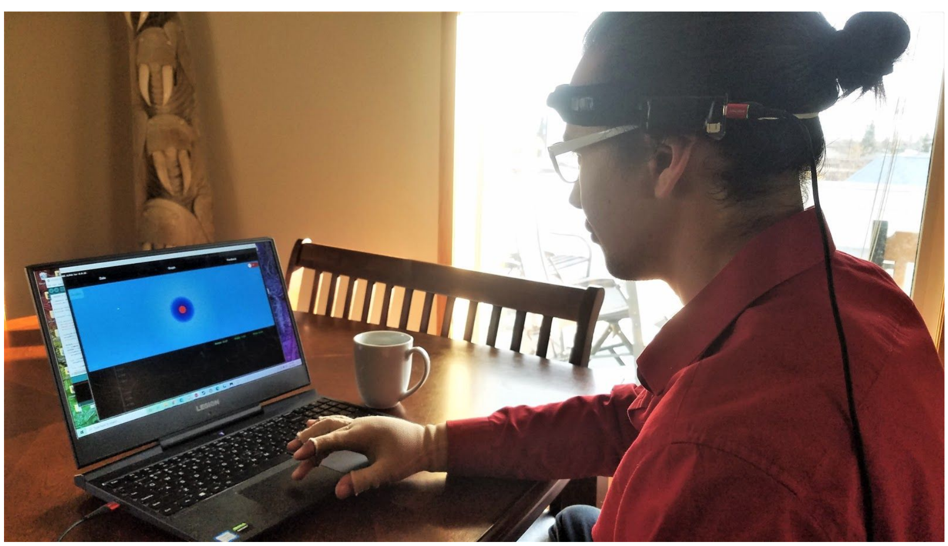


The MAX86141 is a dual channel 4096sps 19 bit ADC with built in amps and LED drivers to manage photodiodes and up to 6 LEDs. The MAX86141 also has its own automatic data buffering system and some nice hardware noise reduction algorithms to sweeten the deal, all for about $5 in a barely visible BGA package (see if you can spot it above). We used the highest sensitivity photodiodes we could find - the BPW-34S and bright, fast-pulsing ~650nm and ~950nm LEDs, standard wavelengths for pulse oximetry using [common SpO2 algorithms](#).

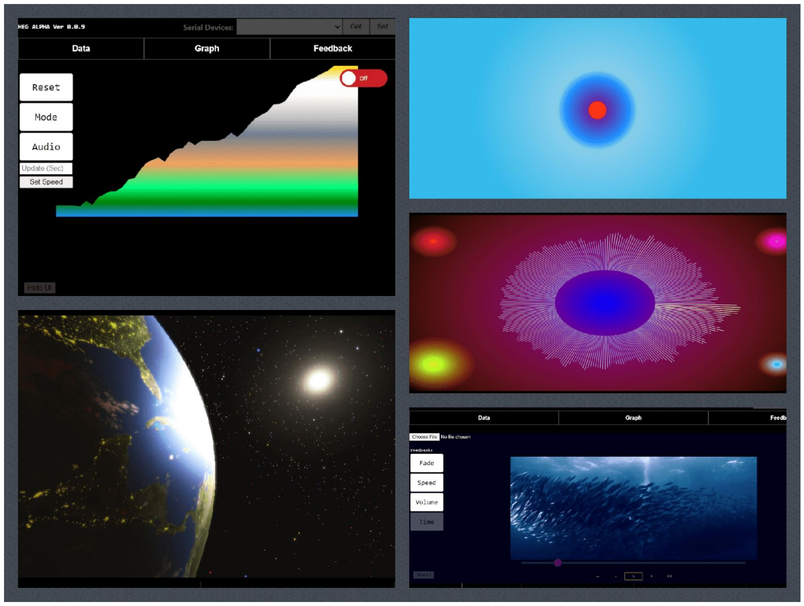


HEGduino: The Delobotomizer, a homemade wearable dev kit.

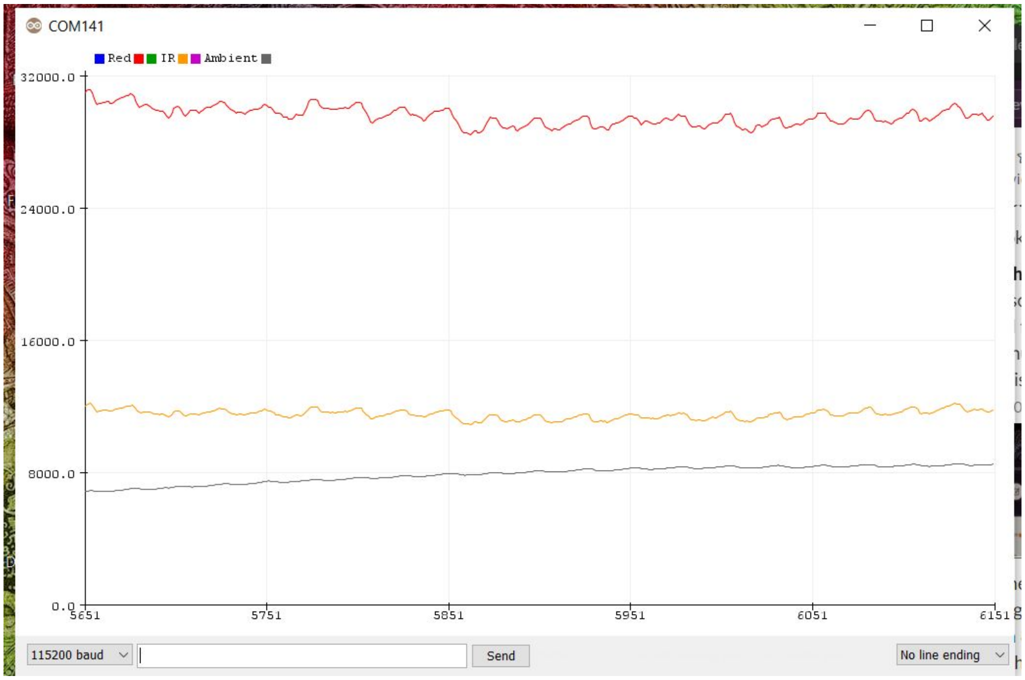
Users wear this device on their heads with a simple headset and interact with our streamlined cross-platform javascript software. At the time of writing this exists as either the on-board HTML5 app or a Chrome extension which enables USB or Bluetooth connectivity via virtual COM port.



A user interacting with the software. His brain blood flow creates changes to the different visuals on-screen to help with self-guided biofeedback. Guided exercises and more sophisticated conditioning tools can be developed, while the current visualizations are all passive - which are more ideal for casual sessions.

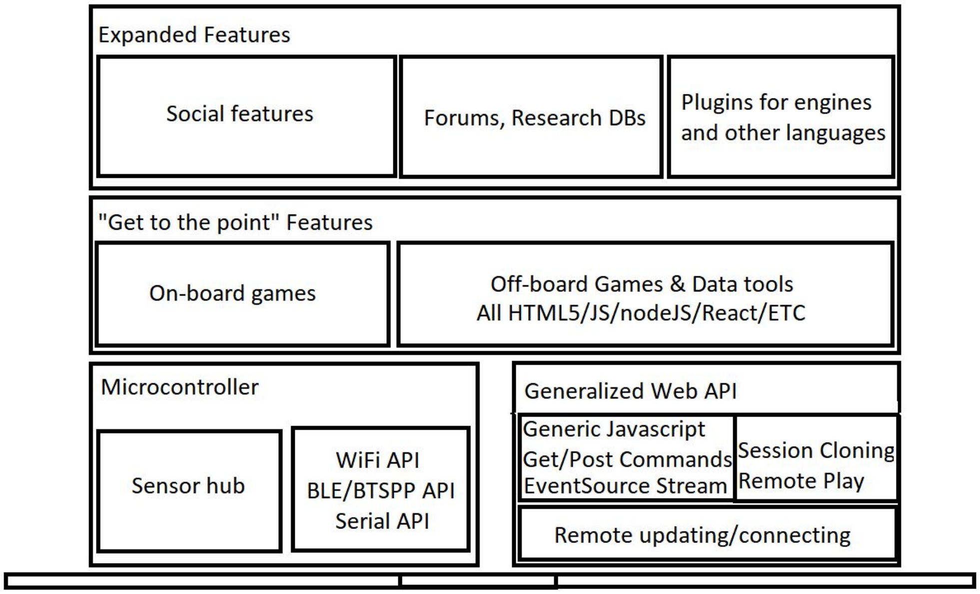


The interface contains different 2D, 3D, audio, and video feedback options. These are coded entirely modularly via classes with a homogenized format so the API is easy to learn and more features are fairly trivial to plug in or develop on top of. With vanilla HTML5/CSS/JS as the base, it can also be plugged into phone apps or websites to offer robust cross-platform accessibility or remote play. This is now being demonstrated with a Progressive Web App implementation which will provide cross platform access and will be downloadable from a single link on the web.



Data off the forehead with the Delobotomizer (I just like saying it) at 3cm spacing and 29.4us 124mA LED pulses, averaging 32 samples for each pulse at 2048sps. This was not a great controlled test but this was shoving as hard as I could into my scalp to minimize scalp signal. You can see pulse amplitudes even in the ambient light, and even the blood pressure waveforms in the Red and Infrared. While you can see that the Red signal is double the IR, at times it is the other way around depending on location and your physical state. There are rapid, dramatic changes visible even with a 1 sensor signal. This is all done in Arduino since it's a piece of cake to work with.

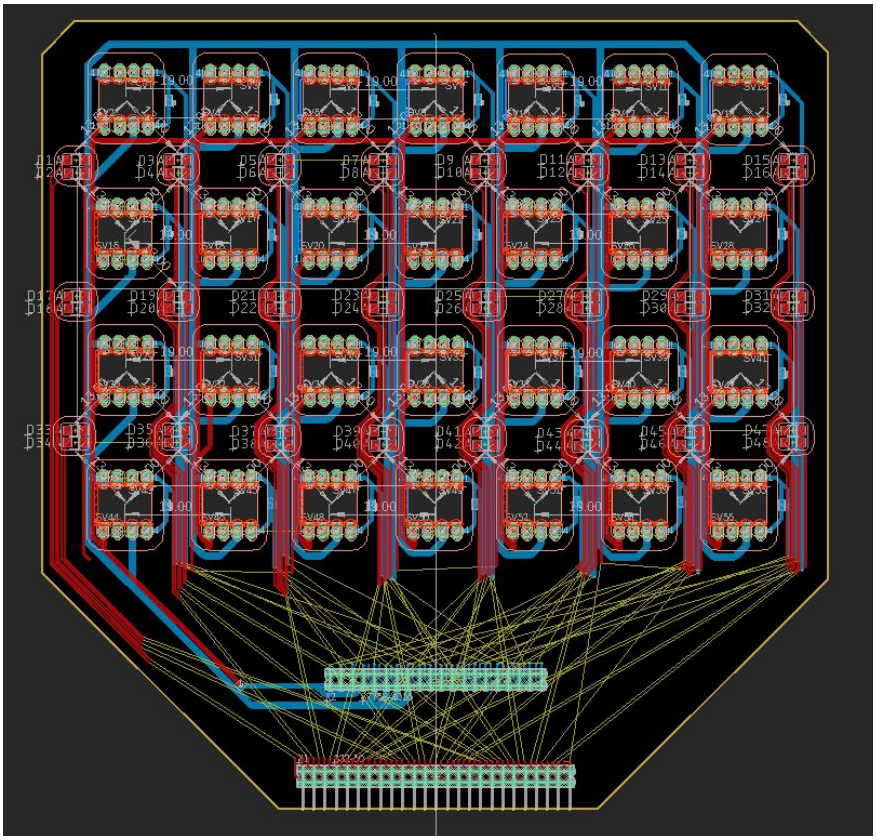
The goal with the software was to make the beginnings of an open and relevantly formatted BCI software API and simple game engine (including easy and lightweight plugins like ThreeJS). Each class contains default instantiations of the contained visual features so it's easier to build a UI and then modify it with CSS. Everything is handled with document fragments for creating highly performant webapps. Web and game engines have also improved dramatically with many standard communication protocols now on hand to interact with hardware streams, and the ESP32 on the HEG allows a wide variety of ways to connect to different local or remote interfaces. The more generic and reusable we make this API, the easier it is to build a professional feature set in less time on any platform (or all platforms). My goal is to be able to offer comparable software to the professional ones by this method, for free, and make it a robust and performant BCI platform as well as a launchpad for future, better iterations. This is all in a format that is not likely to become obsolete in the near future - rather even more feature-rich with Web 3.0 and the recent addition of great GPU tools like compute shading.



HEG IOT PLATFORM

Here's a rough idea of the modular software stack. It's like a RESTful API so nothing gets wasted on the front or backend plus it prioritizes better information throughput and cleaner coding. The idea is to eventually integrate this all into a hosted web server to provide an interesting (but optional) online front end for general home BCI just to improve accessibility and make more use of the online connectivity potential between clients. A native phone application is also planned. You can see demos here: https://hegalomania.netlify.app and here: https://heg-alpha.netlify.app where one is a React port of the interface.

We are informally partnered with the FreeEEG32 project and intend to lump EEG features into our API, and we are developing our own <$50 flexible DOT sensor set (MIT license) to plug into the <$200 FreeEEG32 board (AGPL license). This DOT set mimics the visual cortex fNIRS array back in the fNIRS overview. With the FreeEEG32 as the A/D converter and extra boards tied together as LED drivers for the 24 LED pairs on the device this will be the lowest cost and most enthusiast-friendly DOT headset to date, and the goal is to work up to repeating the image reconstruction study also cited in the fNIRS overview and see if we can begin to parse what our visual cortex is seeing.



We are trying to work our way through this weird and wonderful realm of light based sensing and brains. We are developing low cost biofeedback tools and graduating ourselves to imaging, without leaving any stone unturned along the way so that we are continually putting out practical tools for common use and articulating important ideas as best we can. We're exploring the associated mathematics and doing as much ourselves as possible so we can safely open source it for free and low cost use, as enabling more and more inquiry and collaboration for this fascinating space is a most important goal.

Other interesting open source fNIRS projects to check out:
ninjaNIRS: https://openfnirs.org
OpenNIRS: https://opennirs.org

This will hopefully carry over into a wider coordinated effort with a lot more people involved as we explore new frontiers. Get in touch and let me know your ideas/efforts if you want to collaborate at https://hegalpha.com.

Citations from Hyperlinks

This section is to highlight all of the studies and articles in the embedded links throughout the paper (click on them if you are viewing on a computer). Check all of them out, there are more than 60 links throughout this article, and you haven't really learned anything if you haven't looked further beyond my paper as they contain tons of detailed information and images.

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