HEG Neurofeedback

Optimizing brain function by controlling blood flow

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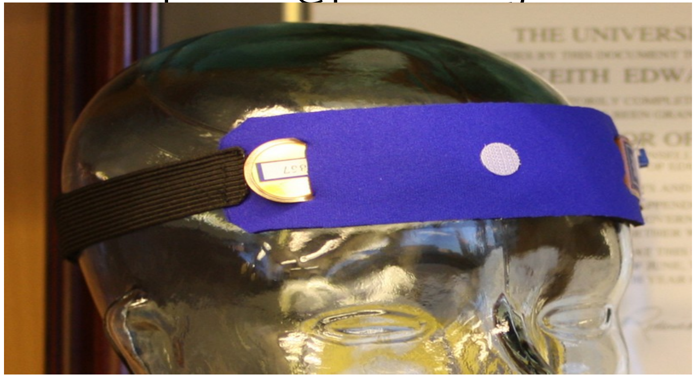

But first...

Creatine in Vegetarian Undergrads

Oral creatine monohydrate supplementation improves brain performance: a double-blind, placebo-controlled, cross-over trial

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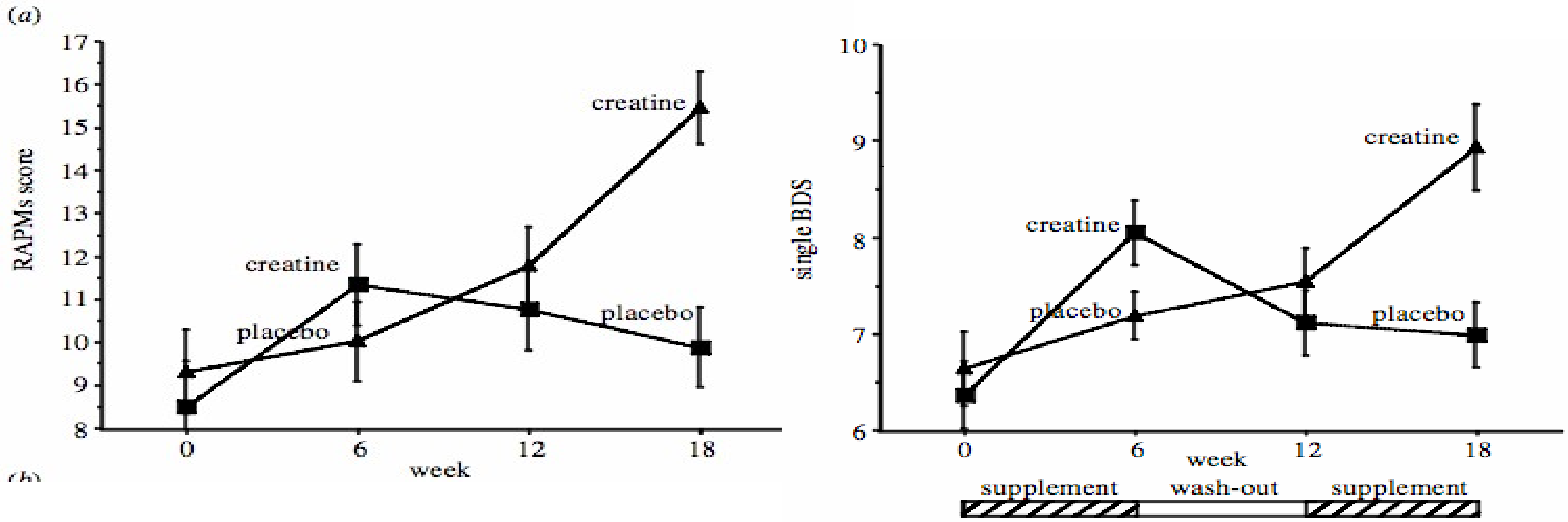
Creatine supplementation is in widespread use to enhance sports–fitness performance, and has been trialled successfully in the treatment of neurological, neuromuscular and atherosclerotic disease. Creatine plays a pivotal role in brain energy homeostasis, being a temporal and spatial buffer for cytosolic and mitochondrial pools of the cellular energy currency, adenosine triphosphate and its regulator, adenosine diphosphate. In this work, we tested the hypothesis that oral creatine supplementation ($5\ \mathrm{g\ d^{-1}}$ for six weeks) would enhance intelligence test scores and working memory performance in 45 young adult, vegetarian subjects in a double-blind, placebo-controlled, cross-over design. Creatine supplementation had a significant positive effect ($p < 0.0001$) on both working memory (backward digit span) and intelligence (Raven's Advanced Progressive Matrices), both tasks that require speed of processing. These findings underline a dynamic and significant role of brain energy capacity in influencing brain performance.

Keywords: creatine; oral supplementation; intelligence; memory; brain bioenergetics

Rae et al., 2003

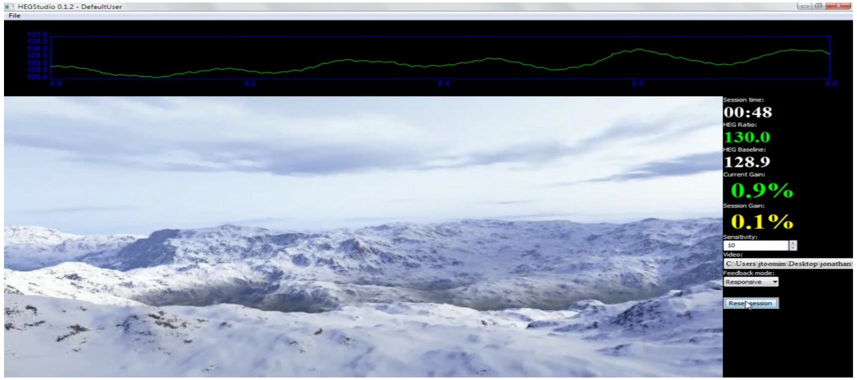
Creatine in Vegetarian Undergrads



Rae et al., 2003

Short version: NIRS Neurofeedback

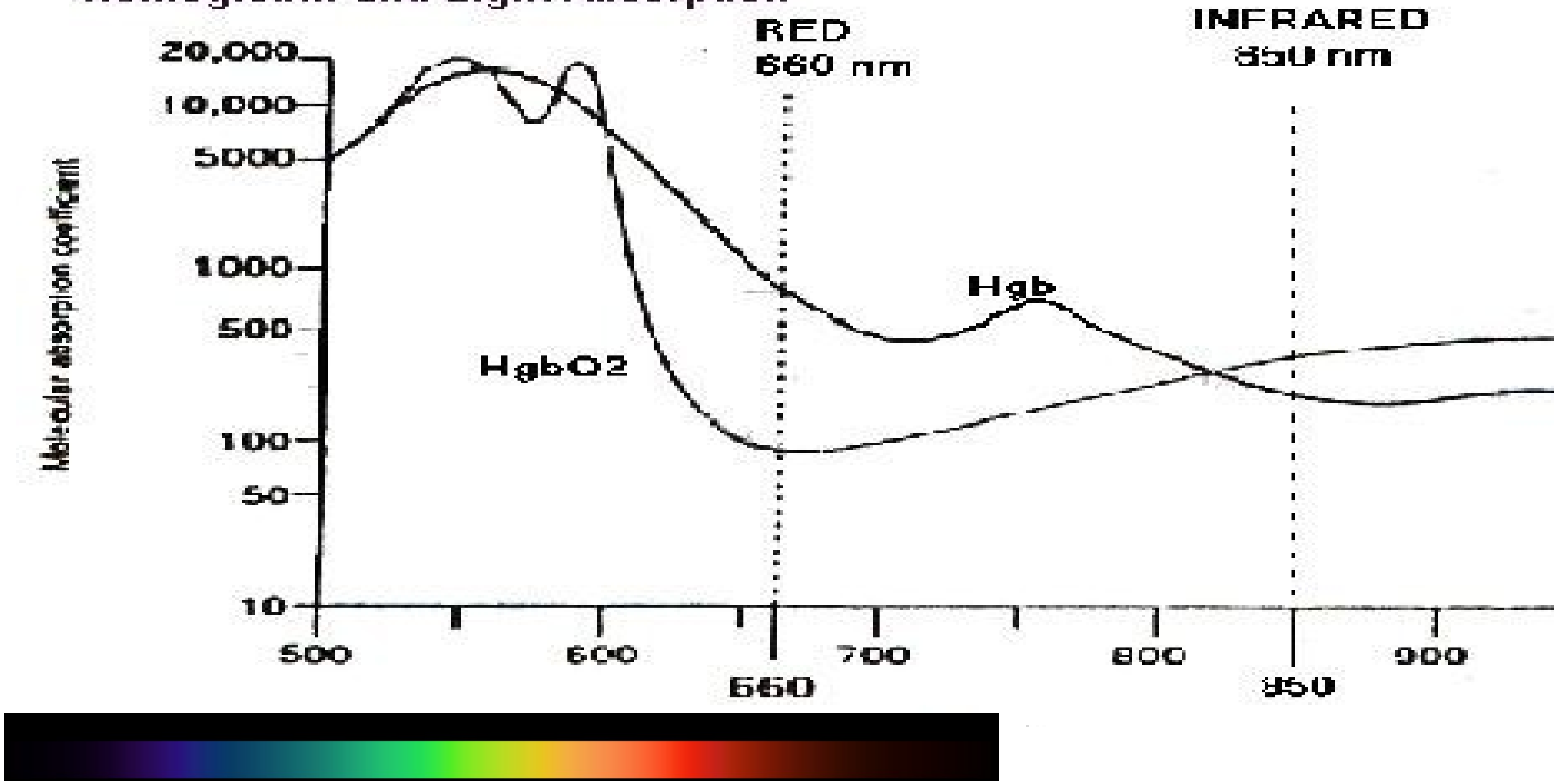
(Hemoencephalography, or HEG)



- Measures brain activity and blood O_2, like a pulse ox
- Provides subjects with real-time feedback on brain activity
- With practice and feedback, subjects learn to control their brain activity
- May be useful with ADHD, autism, stroke, TBI, migraine, and others
- May make your brain bigger, stronger, faster, better

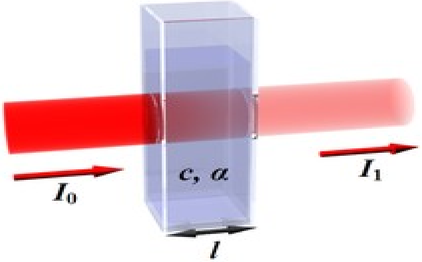
US Patent 5,995,857

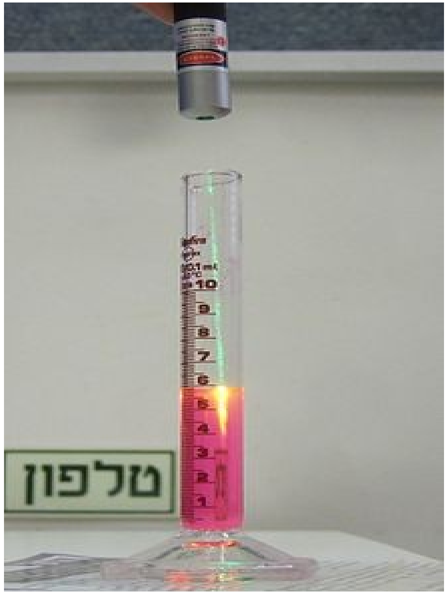
Hemoglobin and Light Absorption



Photoplethysmography

- Stuff absorbs light
- You can shine light through stuff
- If you look at how much gets through, that tells you how much stuff there is





Photoplethysmography

$$T = I / I_0 = 10^{-\alpha\ell} = 10^{\varepsilon\ell c}$$

This is the Beer-Lambert law.

T = light transmission ratio

I = intensity of light passed through

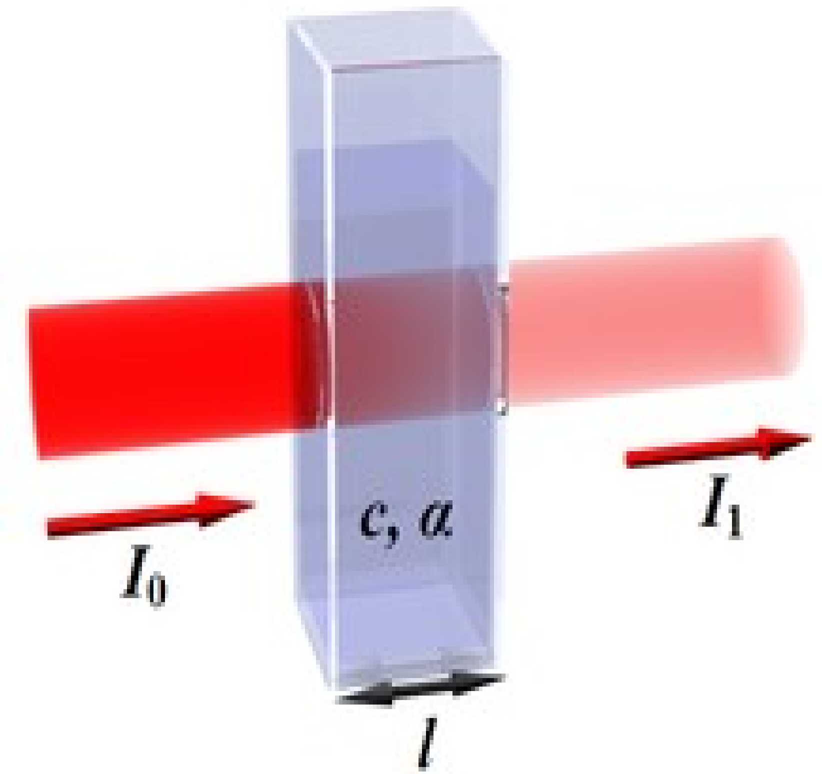
I_0 = intensity of incident light

α = absorption coefficient

ε = molar extinction coefficient of molecule

c = concentration of molecule

ℓ = path length



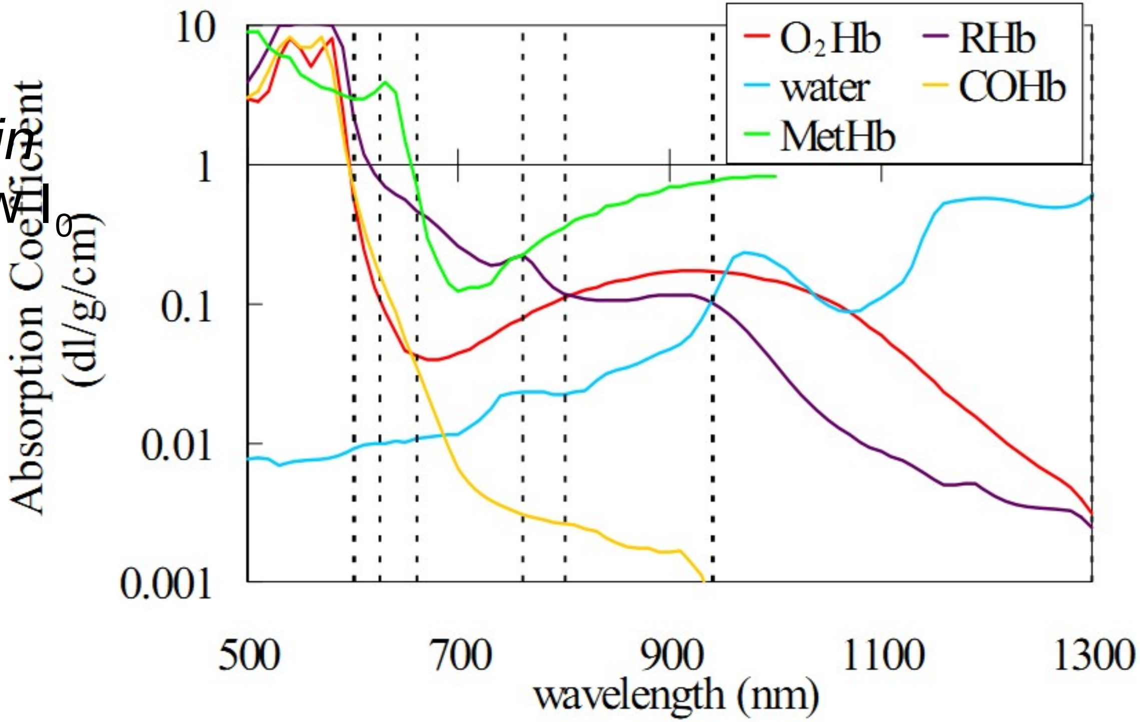
Photoplethysmography

$$T = I / I_0 = 10^{-\alpha\ell} = 10^{\varepsilon\ell c}$$

We want to know *c*.

Calibration to get absolute values *in vivo* is difficult, since we don't know I_0 or ℓ.

ε is easy, though: ----->



I_0 = intensity of incident light

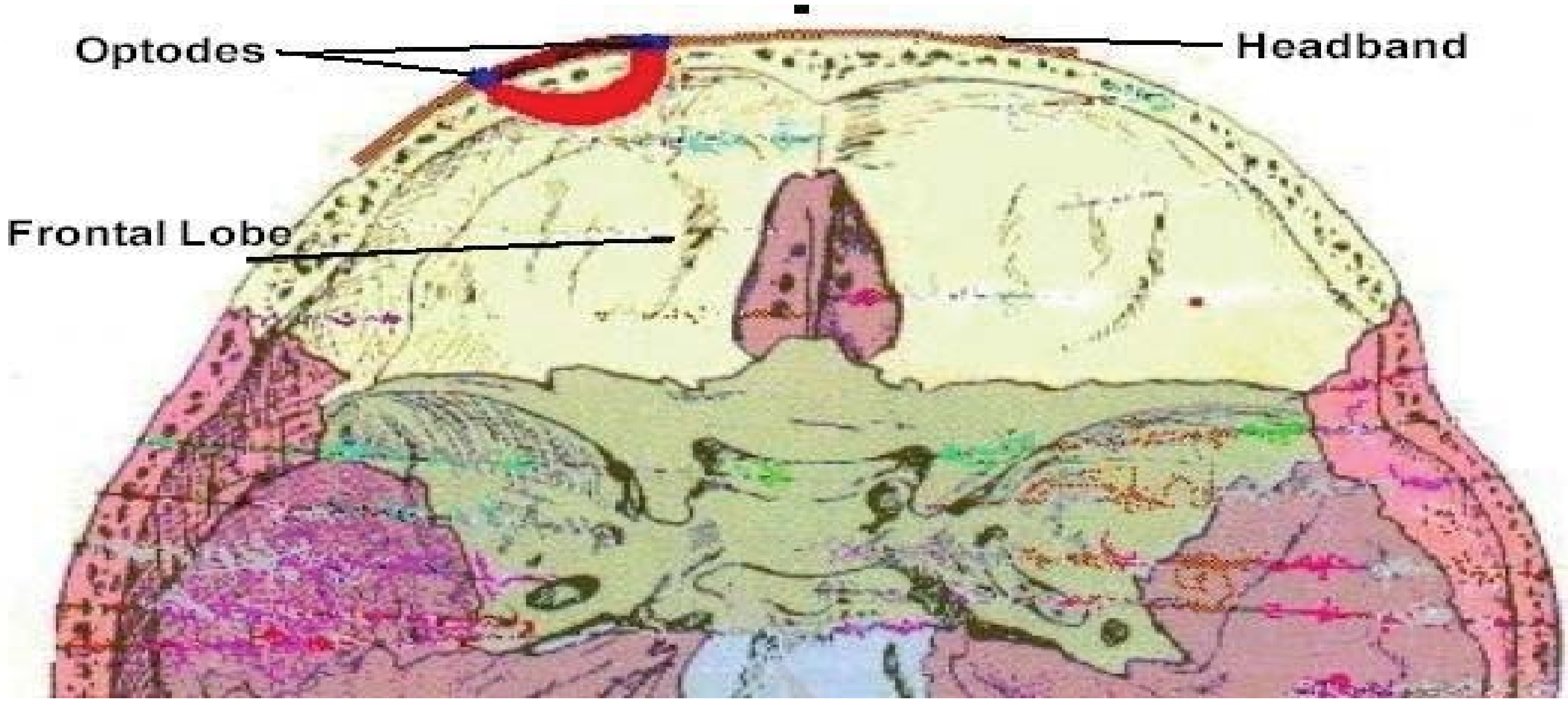
ε = molar extinction coefficient of molecule

c = concentration of molecule

ℓ = path length

Photoplethysmography

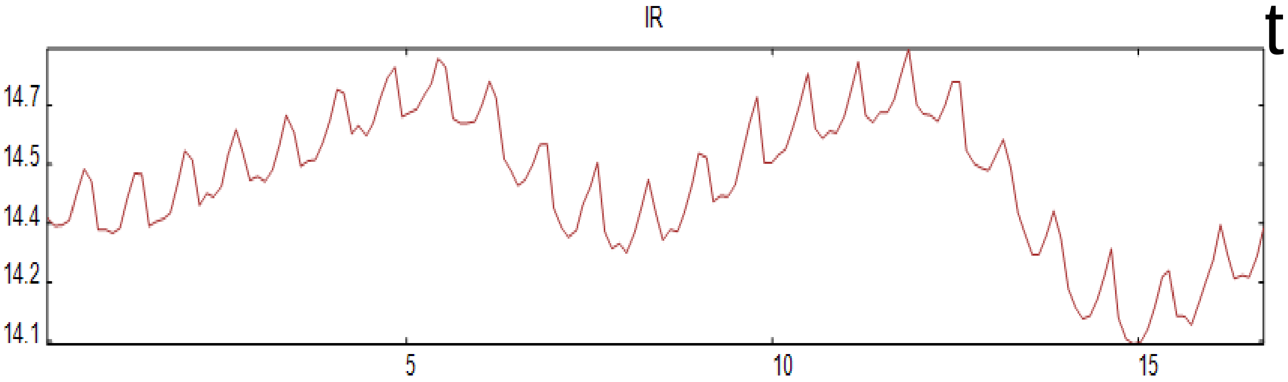
- Scattering attenuates light—not all of the light leaves in the right place.
- Scattering also increases the path length. Most photons don't take a straight-line path.

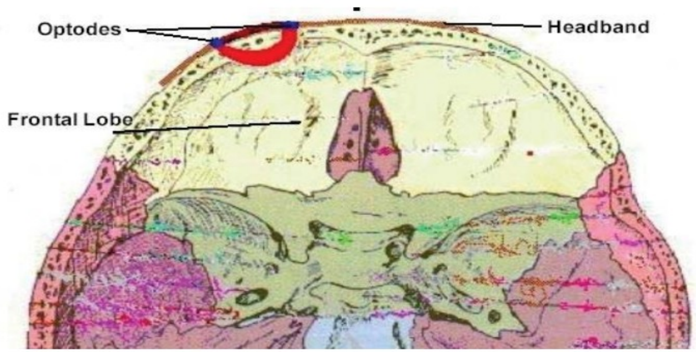

Optodes
Headband
Frontal Lobe

Photoplethysmography

- But it's easy to get simple measurements of relative change
  - Great for measuring heart rate
  - Also shows blood volume/pressure changes

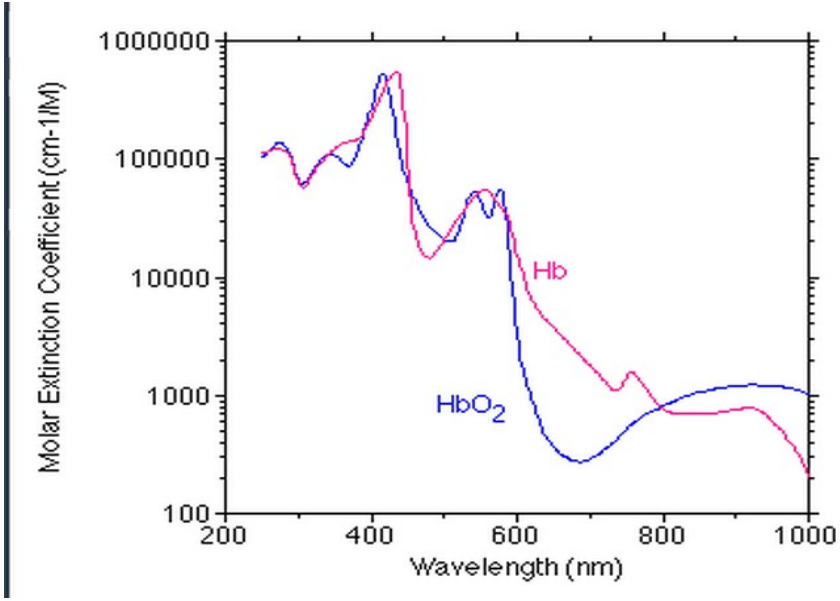
t

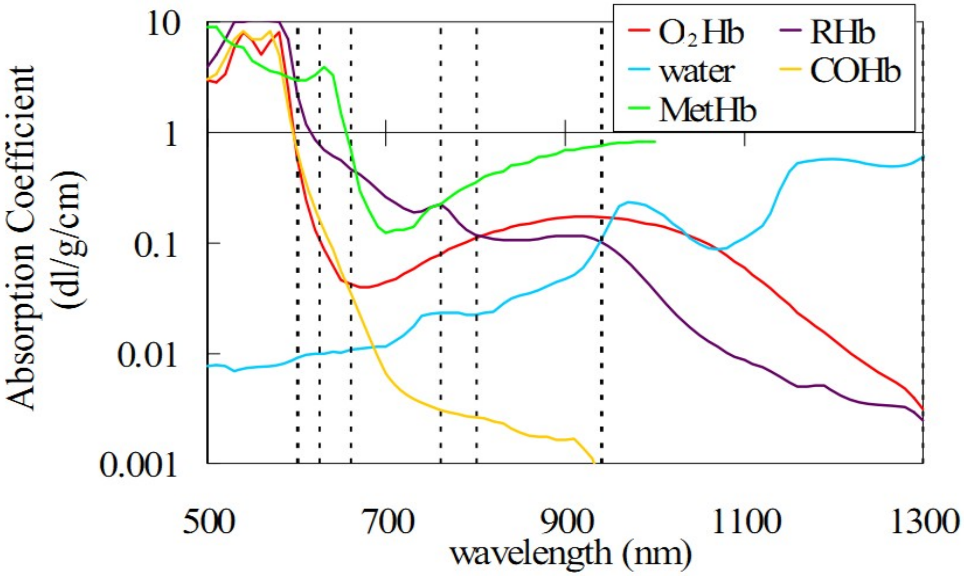




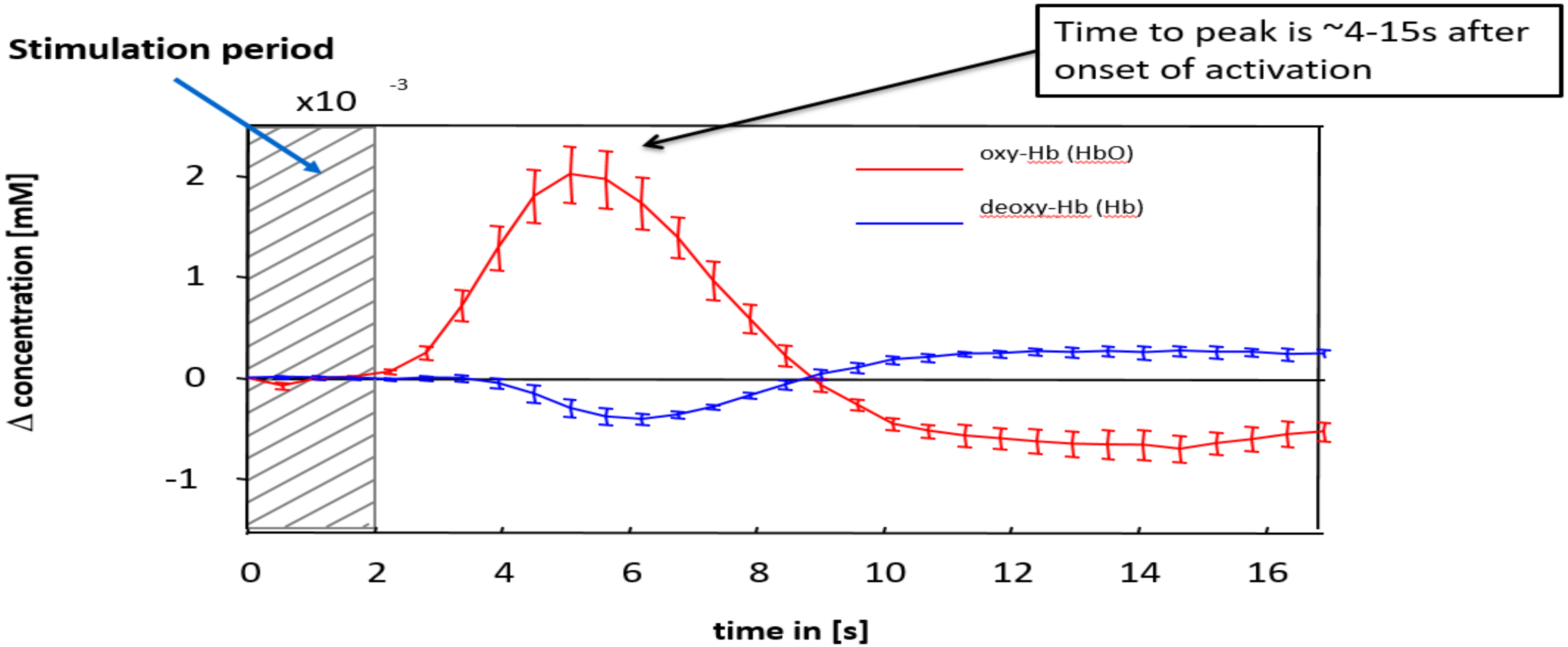
Oximetry techniques

The Beer-Lambert unknowns can be cancelled out by using ratiometric techniques



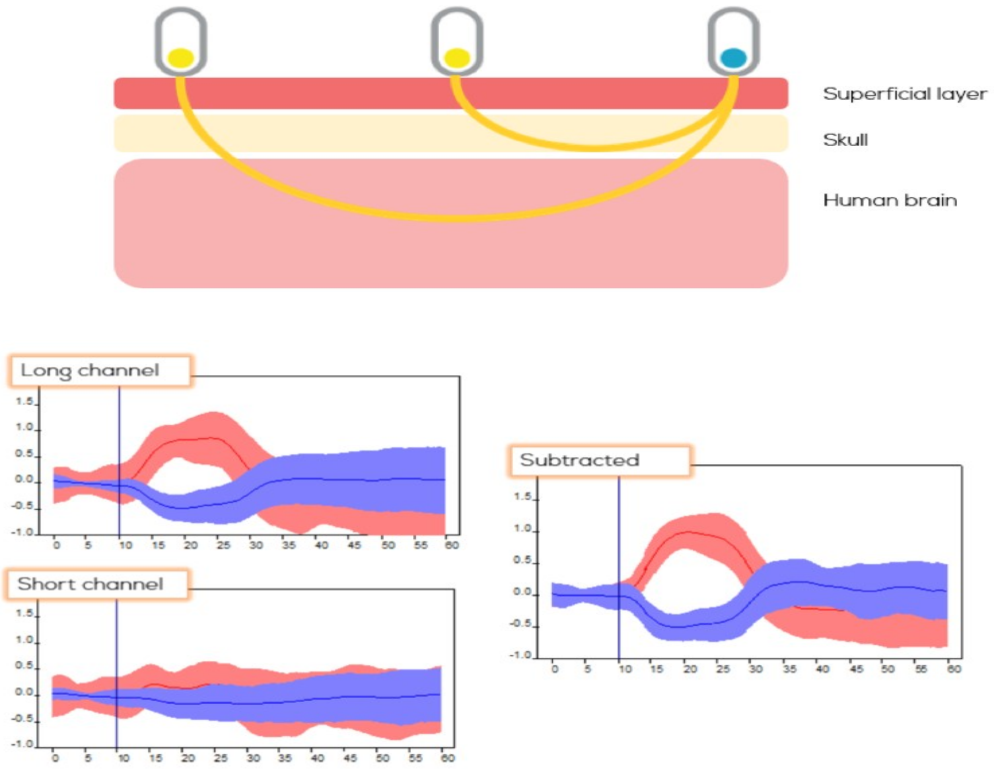


Blood flows where it is needed

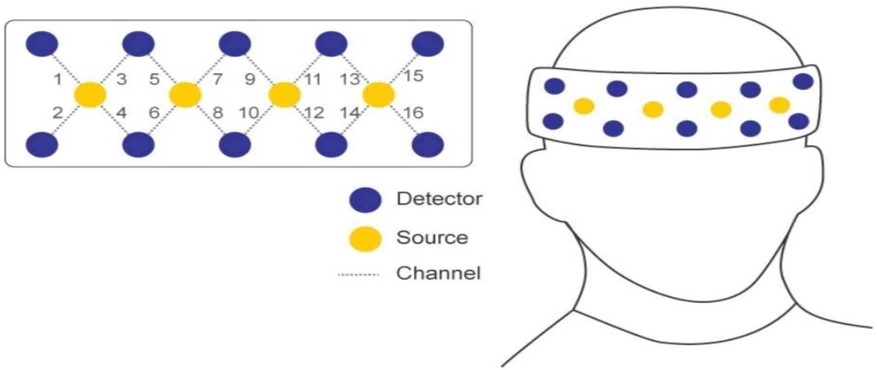


Kohl M ,.. , Dirnagl U. Phys. Med. Bio. 2000
http://www.ncbi.nlm.nih.gov/pubmed/11131197

What about skin?



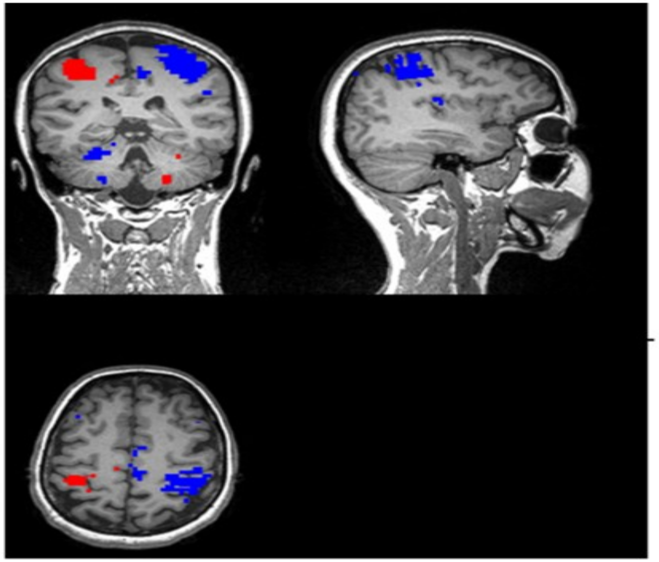
Improving spatial resolution



fMRI vs fNIRS

Finger tapping experiment

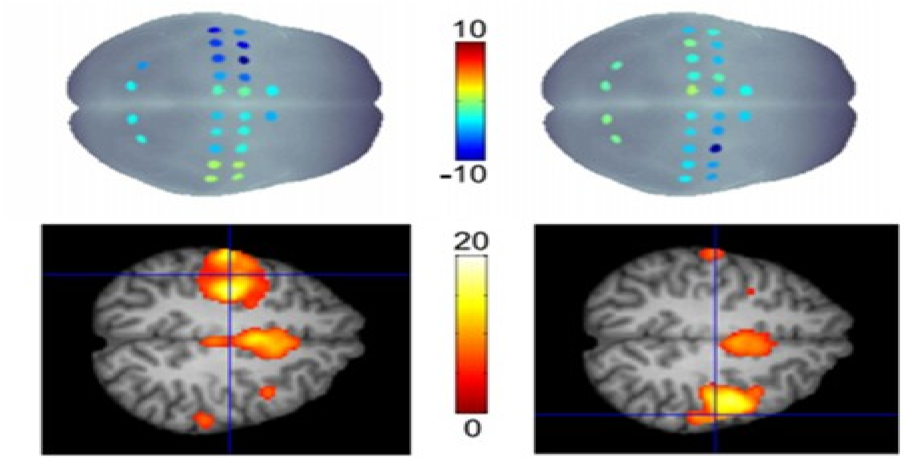
fMRI results



Blue: Left finger

Red: Right finger

fNIRS results



Right finger

Left finger

Improving spatial resolution further

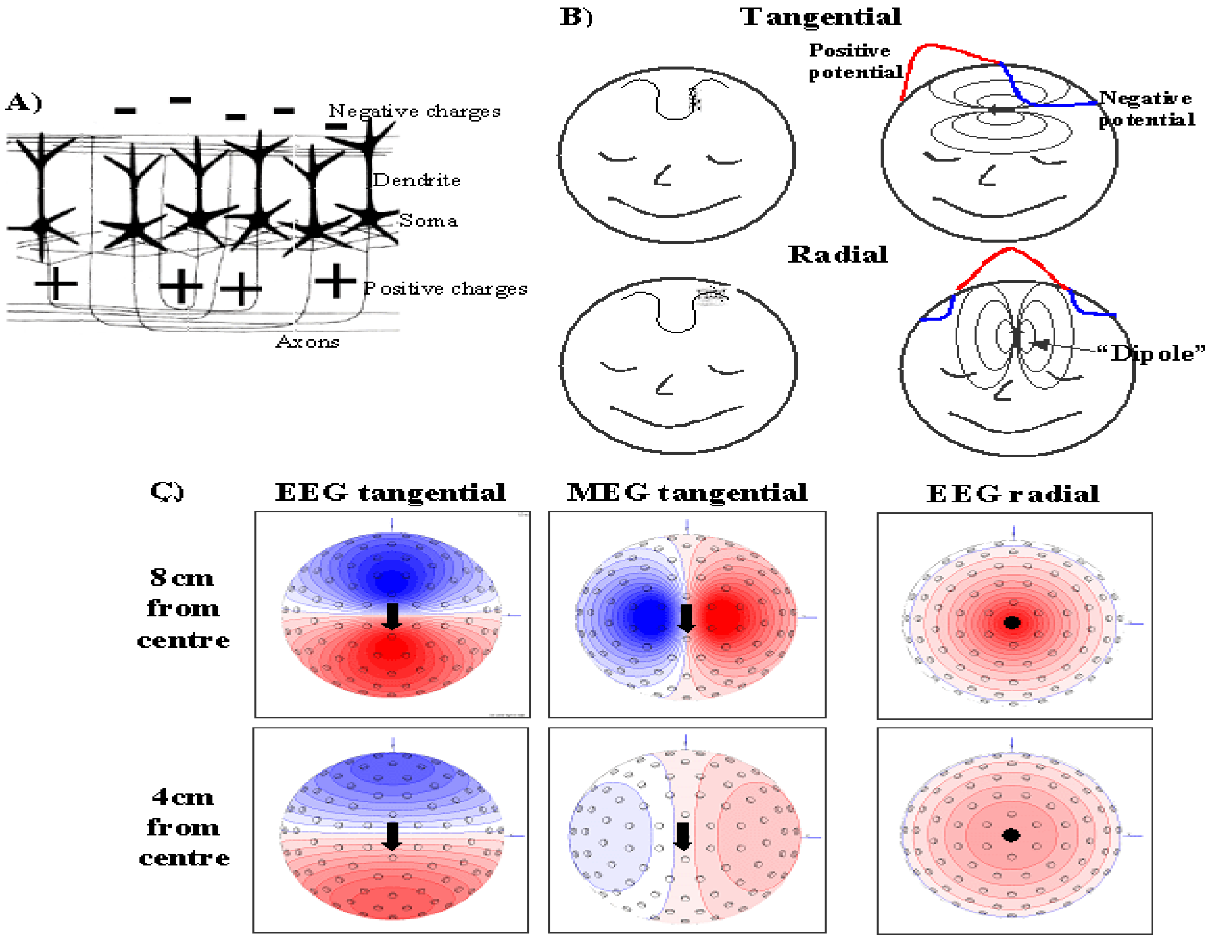
Openwater:

- Holography?
- ML to solve inverse problem?
- Using ultrasound to focus light?

Why not just EEG?

Why not EEG?

- Practical concerns:
  - Noisy signal
  - Physically messy and time-consuming
  - Doesn't work well near eyes/prefrontal cortex
- Interpretation concerns:
  - Only pyramidal cells
  - Only synchronous activity
  - Poor localization
  - Most EEG activity is idle rhythms



A)
Negative charges
Dendrite
Soma
Positive charges
Axons
B)
Tangential
Positive potential
Negative potential
Radial
"Dipole"
C)
EEG tangential
MEG tangential
EEG radial
8cm from centre
4cm from centre

EEG vs fNIRS

- EEG:
    - Measures interregional synchronous information flow
    - Artifact prone (eyeblink, muscle, EM noise)
    - Messy
    - Poor spatial resolution
    - Excellent temporal resolution (~10 ms)
    - Complex neurofeedback goals
        - Possibility for harm
    - Best away from the frontal lobes

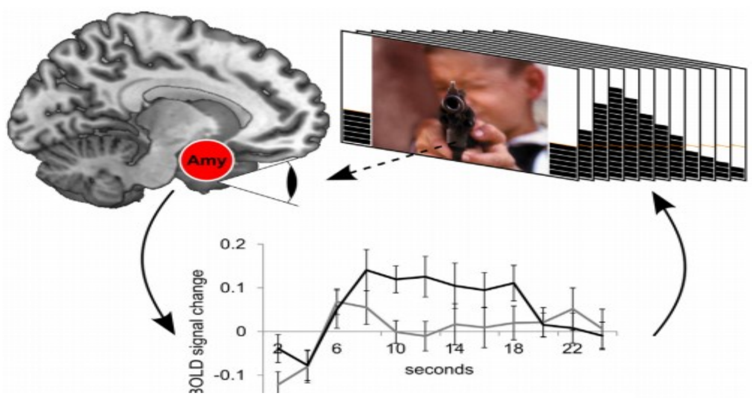
- fNIRS:
    - Measures overall neural activation level
    - Less artifact (movement, skin, fluorescent lights, EM noise)
    - Clean
    - Decent spatial resolution
    - Poor temporal resolution (~2 s physiological delay)
    - Simple neurofeedback goals
        - Less flexibility
    - Best at the frontal lobes
    - Similar to fMRI

Killer app of fNIRS: Biofeedback

fMRI/fNIRS biofeedback Amygdala

Amygdala downregulation for fear extinction and control

10.1016/j.neuroimage.2015.10.027



C. Paret et al. / NeuroImage 125 (2016) 182–188 185

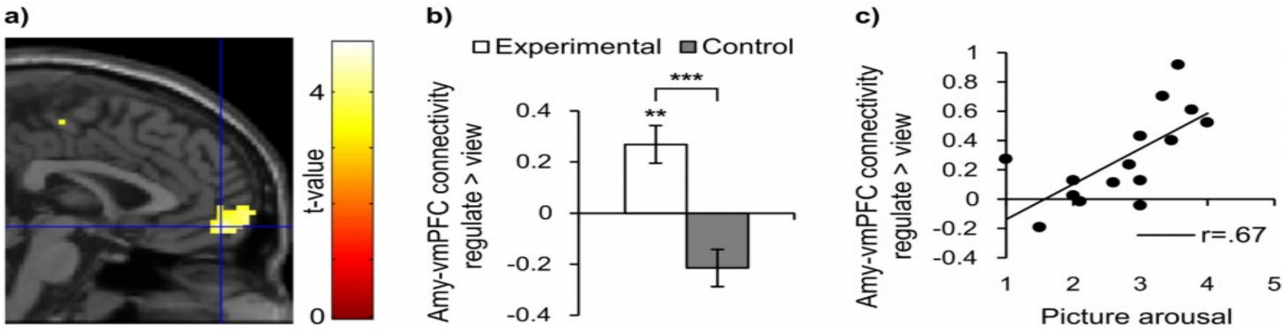
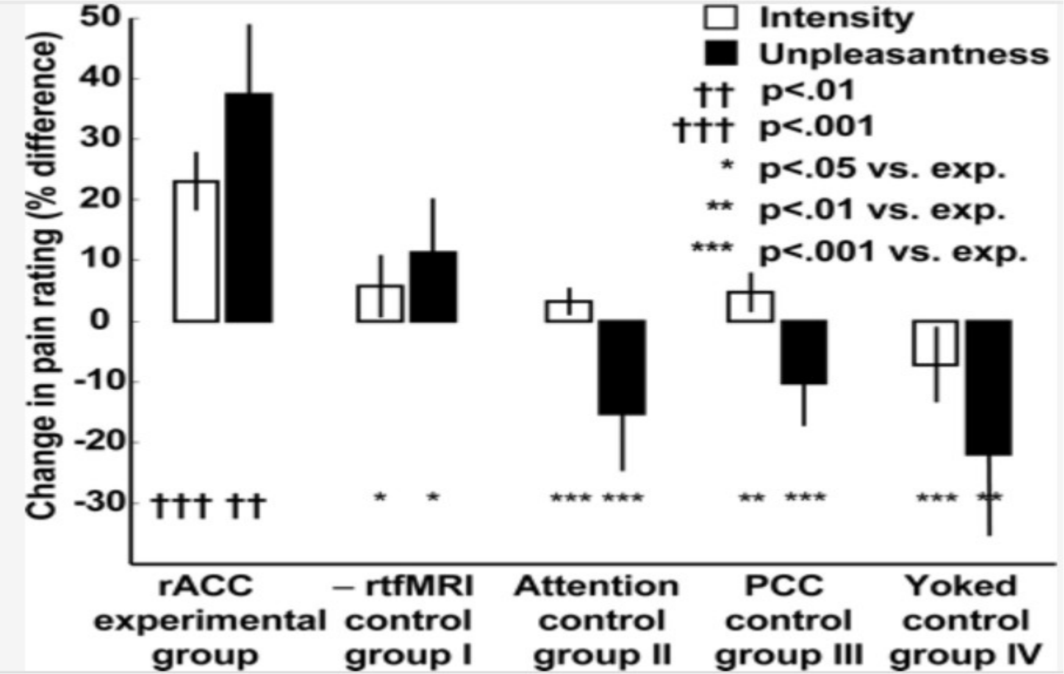


Fig. 2. Right amygdala functional connectivity to vmPFC (BA10) is increased by amygdala neurofeedback in healthy participants. A) Group × Condition interaction analysis of PPI beta estimates. Image displays activation on sagittal slice of the canonical SPM template ($p < .001$, $k > 10$). Right is anterior. Crosshairs indicate location of peak voxel at [0,56,−11]. B) Group mean of PPI beta estimates at peak voxel from the experimental (white) and control group (gray) for the 'regulate > view'-t-contrast, N = 32. **$p < .01$, ***$p < .001$. Amy = amygdala, vmPFC = ventromedial prefrontal cortex. Error bars = SEM. C) Experimental group: variance of PPI beta estimates at peak voxel is predicted by arousal ratings. Line indicates linear association. R = Pearson correlation.

fMRI/fNIRS biofeedback
Anterior cingulate (pain)

Control over brain activation and pain learned by using real-time functional MRI

10.1073/pnas.0505210102

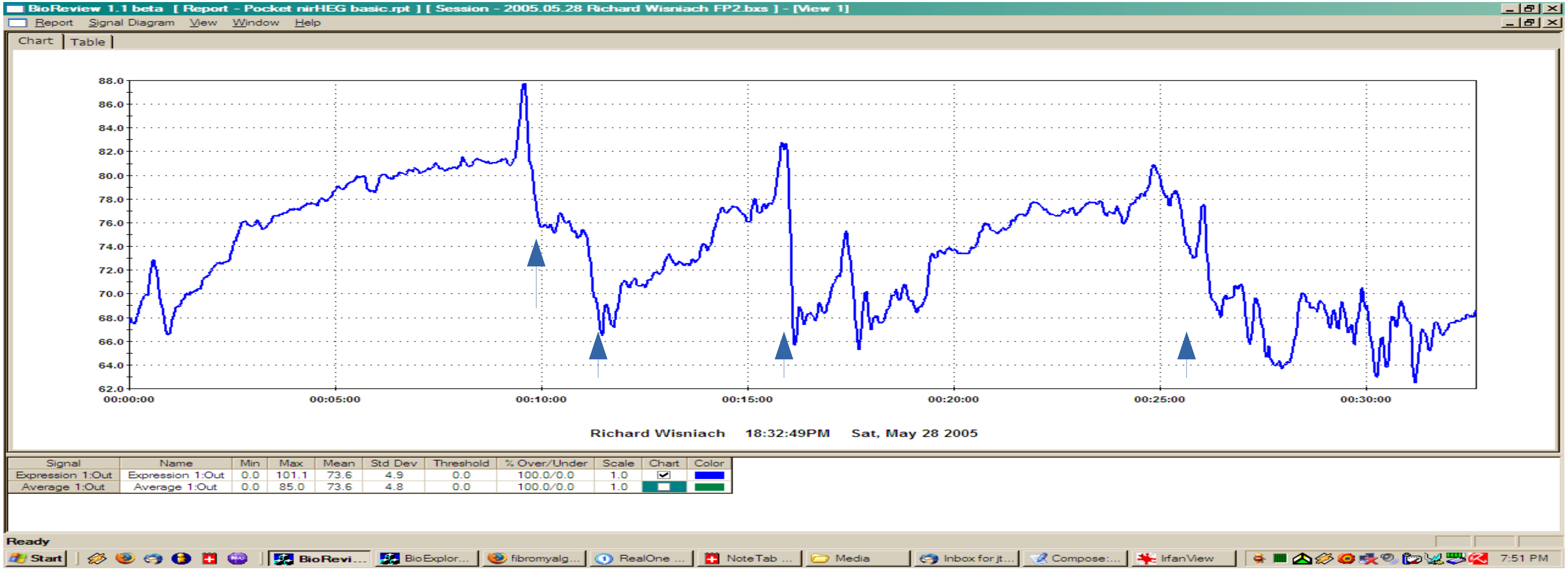


HEG

HEG stands for hemoencephalography

- hemo = blood
- encephalo = relating to the head
- graphy = the representation of

Conscious control of blood O_2



Can we actually increase neural activity with HEG?

Known:

Increased activity => increased O_2

Unknown:

Increased O_2 via NF => increased activity?

"Reverse causality" not established.

(Likely beneficial either way.)

HEG NF affects EEG

5 min rest
(baseline)

10 minutes HEG NF

5 min rest

HEG signal
(trained)

EEG beta
activity
(untrained,
passively
recorded)

EEG NF does not affect HEG

10 min rest
(baseline)

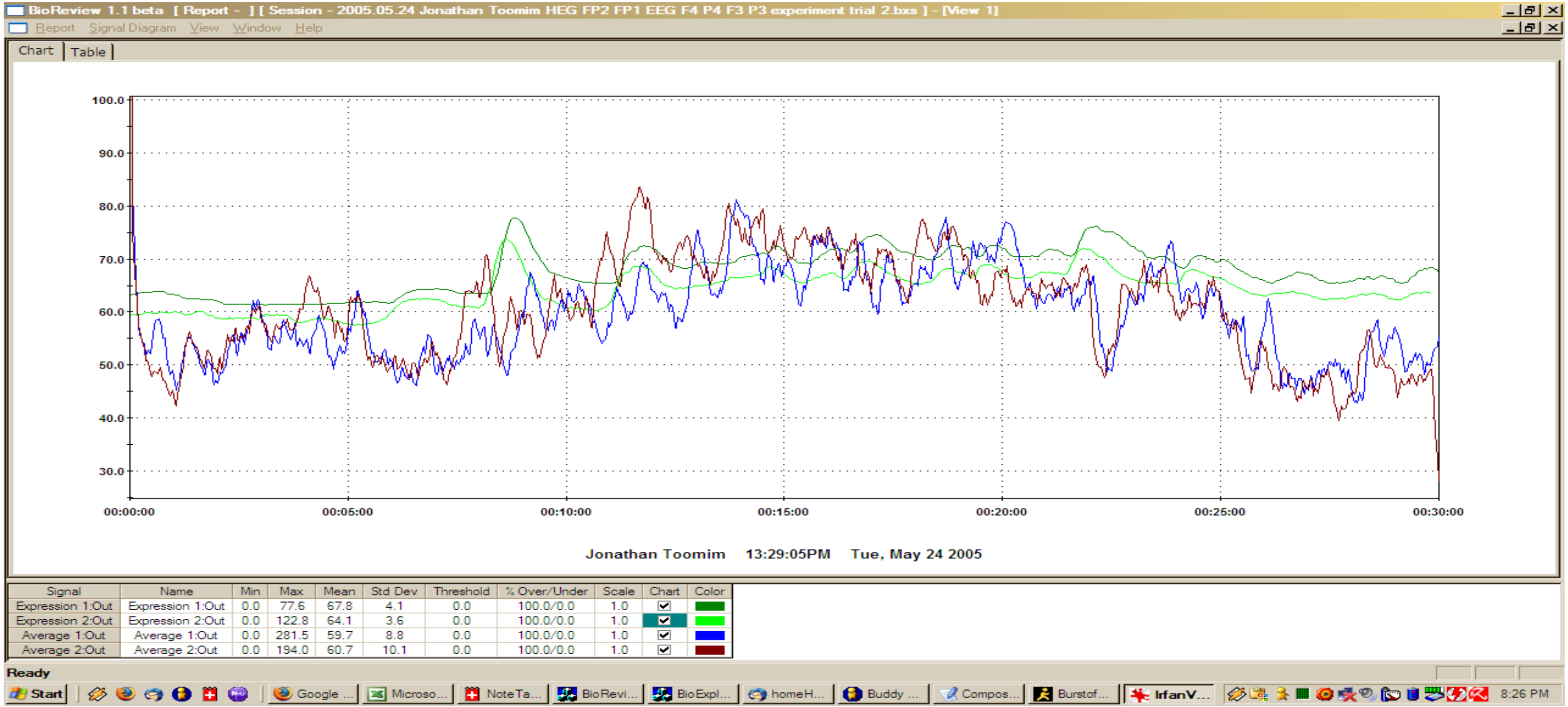
10 minutes EEG NF

10 min
rest

HEG signal
(untrained,
passively
recorded)

EEG beta
activity
(trained)

HEG NF's effects are not localized

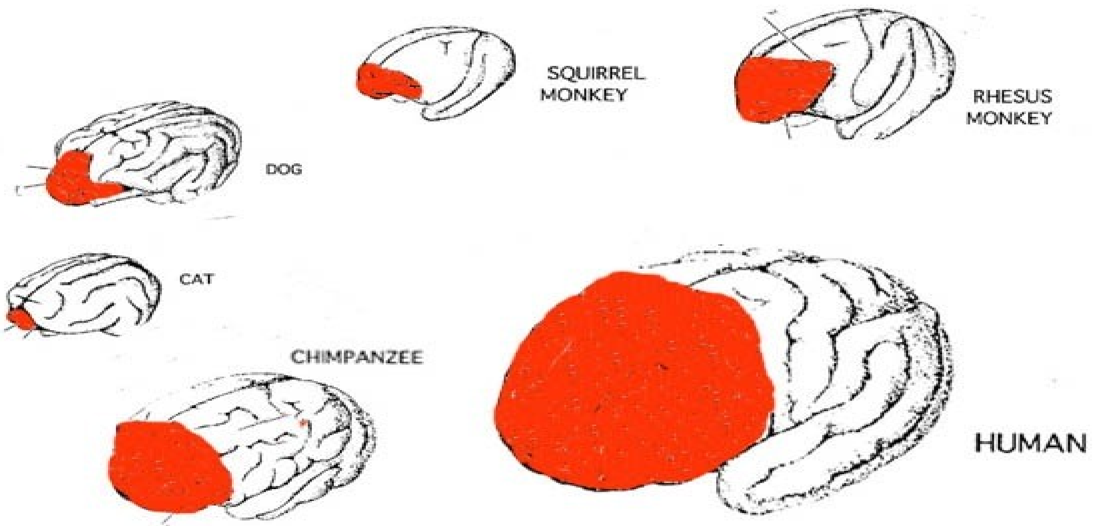


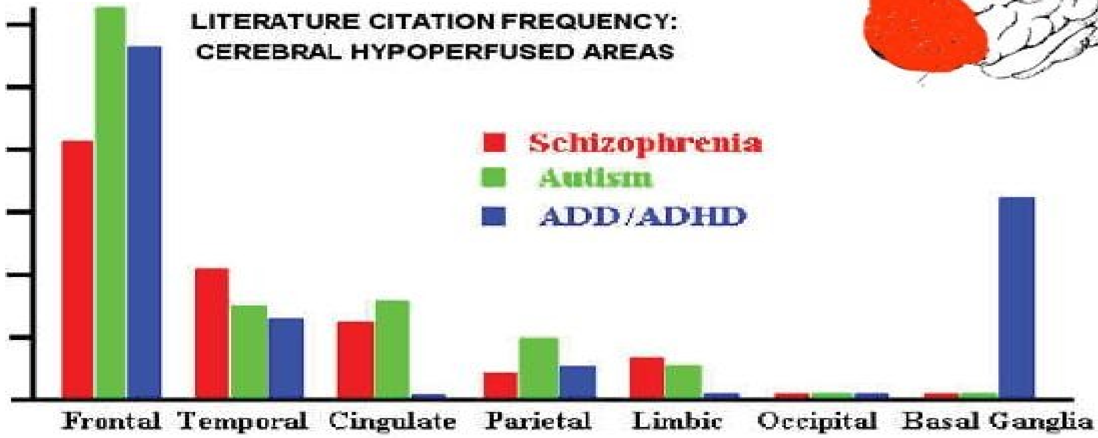
nIR HEG and pIR HEG

This type of HEG is based on near-infrared spectroscopy (NIRS).

There is also a technique based on thermal imaging, called passive infrared (pIR) HEG.

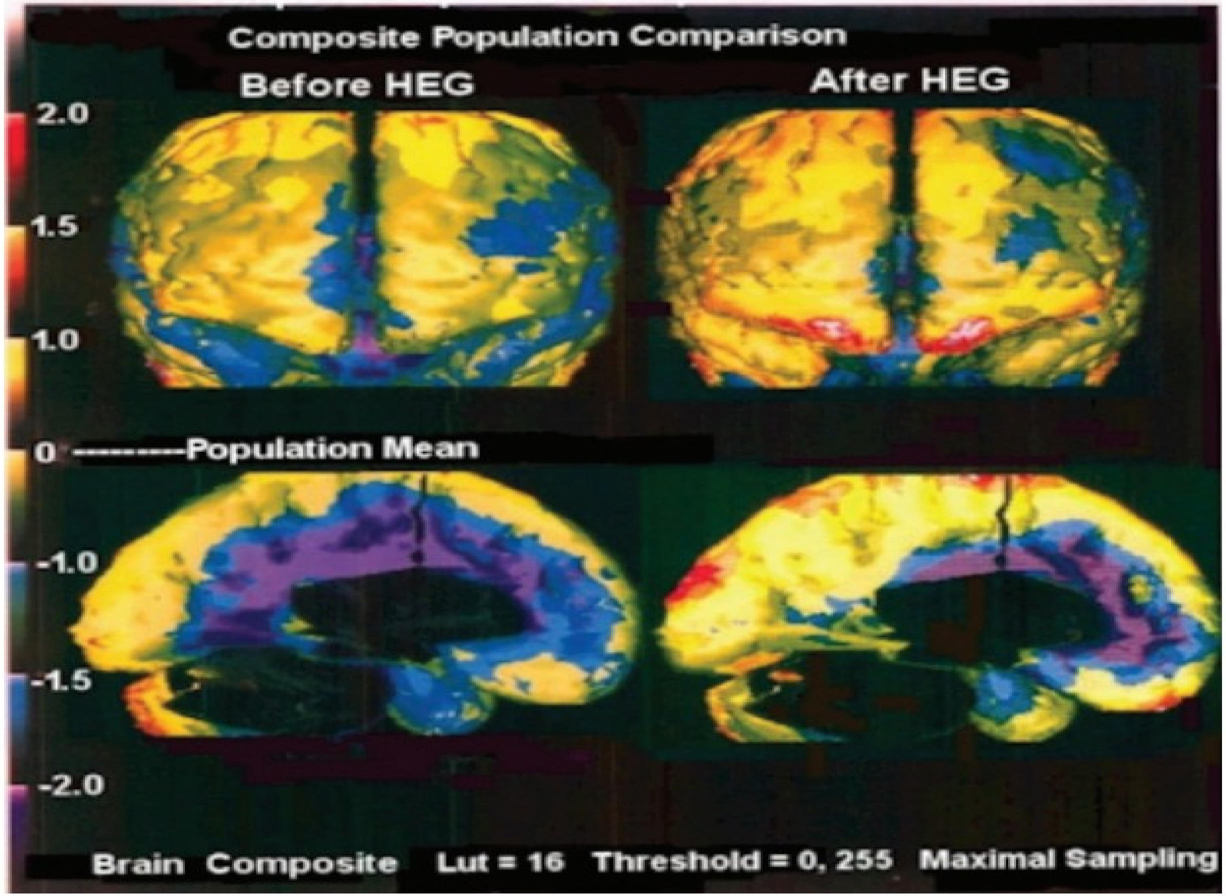
The frontal lobes are important



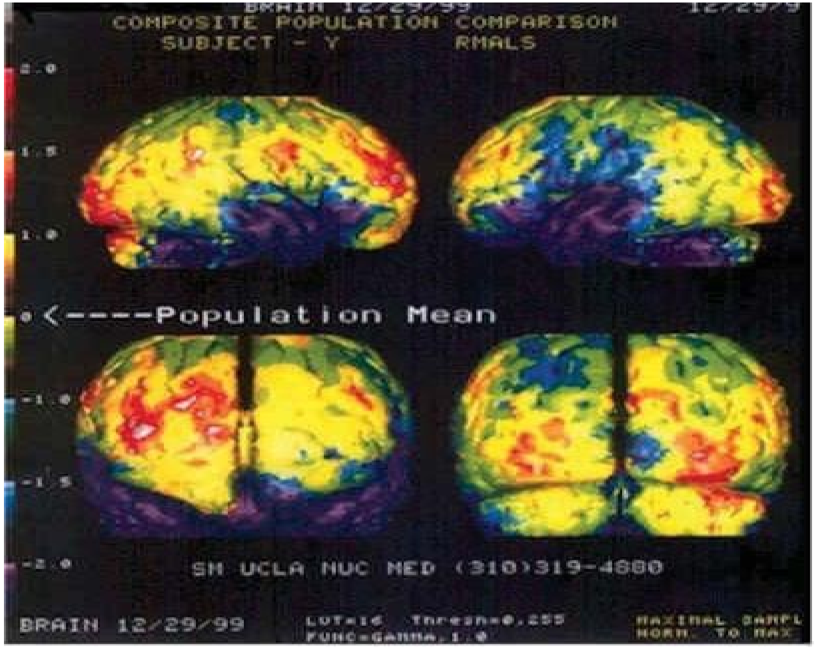


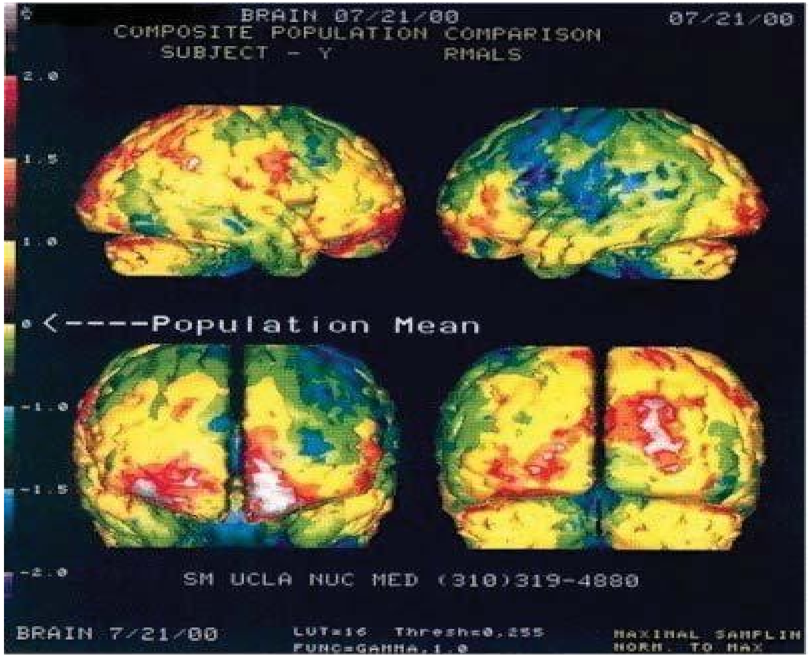
Demo

SPECT Results 1



SPECT Results 2





HEG and Microcog (IQ)

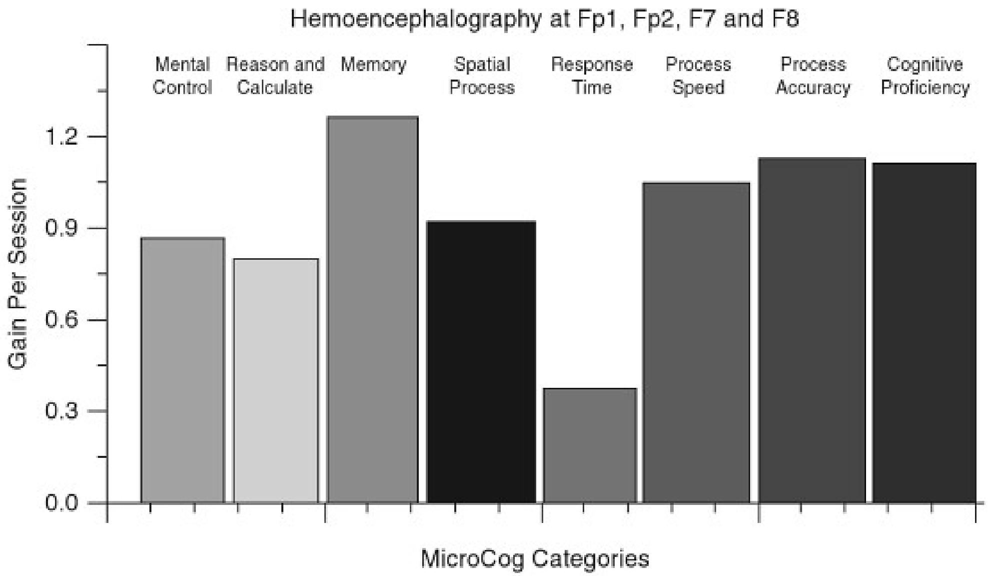
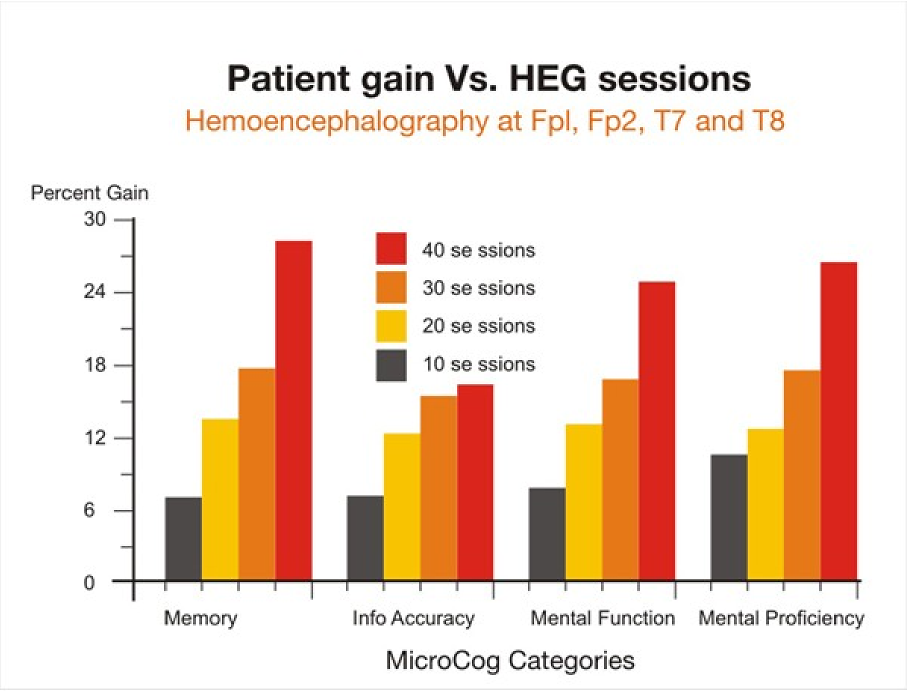
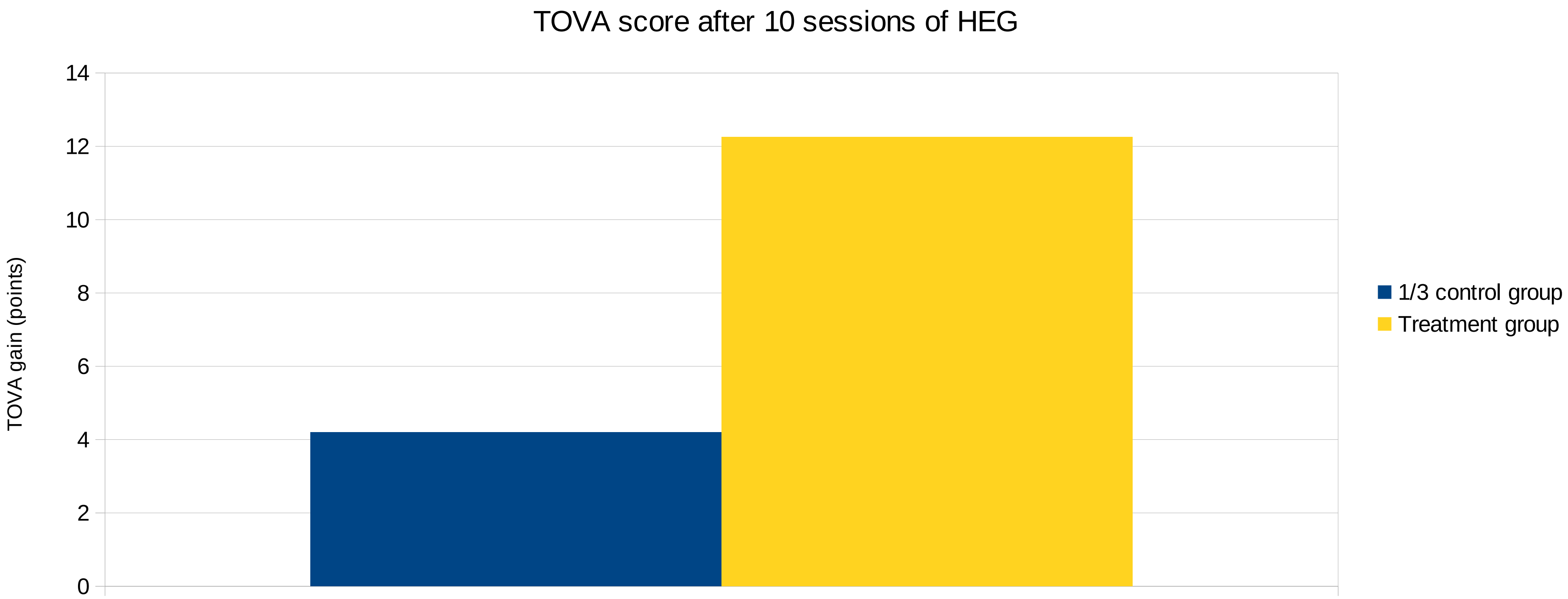


FIGURE 7.5 Effectiveness of nirHEG brain exercise is shown in improved cognitive characteristics. MicroCog relates cognitive changes in points per session on a 100 point scale for various trained behavioral functions.



… but no control group.

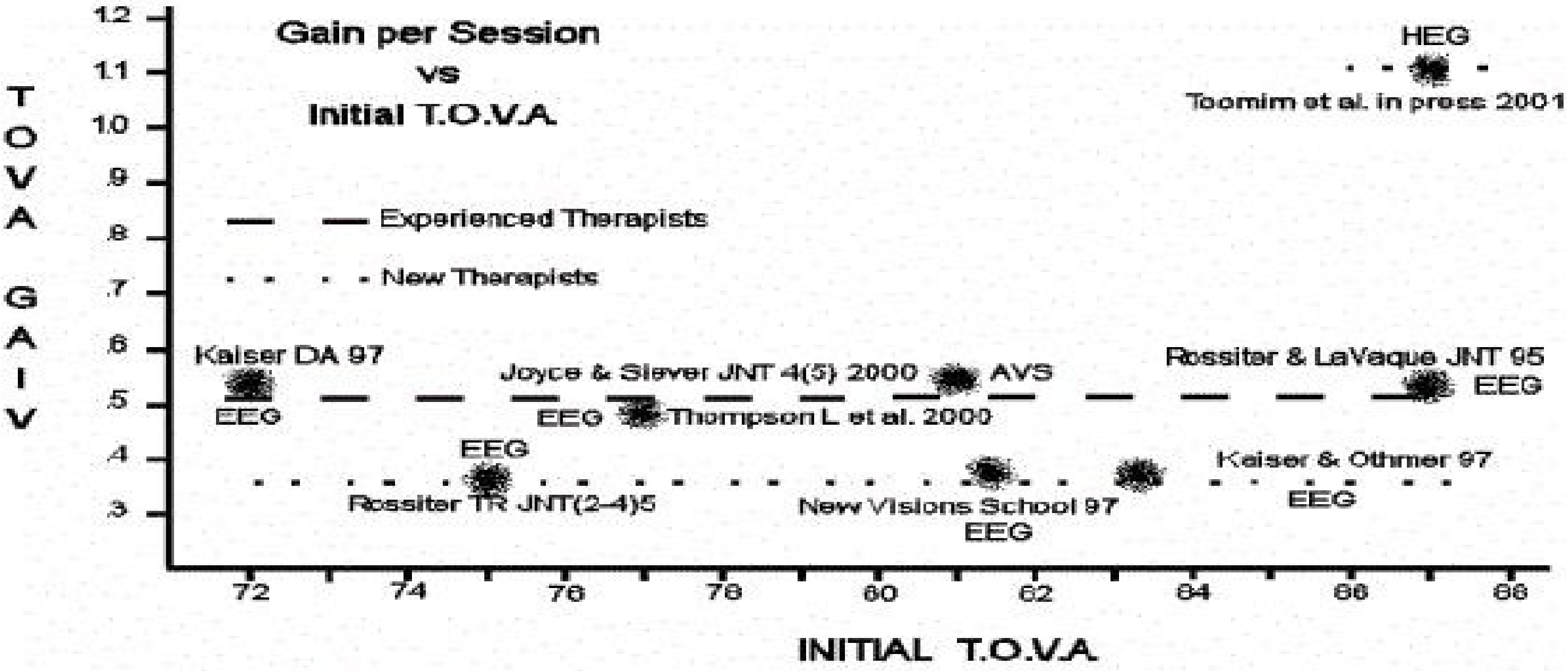
HEG and attention



Control group only increased HEG signal for 10 minutes per session;
Treatment group increased HEG signal for 30 minutes per session

doi:10.1300/J184v08n03_02

HEG and attention



Questions

Thank you for listening!

Questions:

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