Neuroscience & Education

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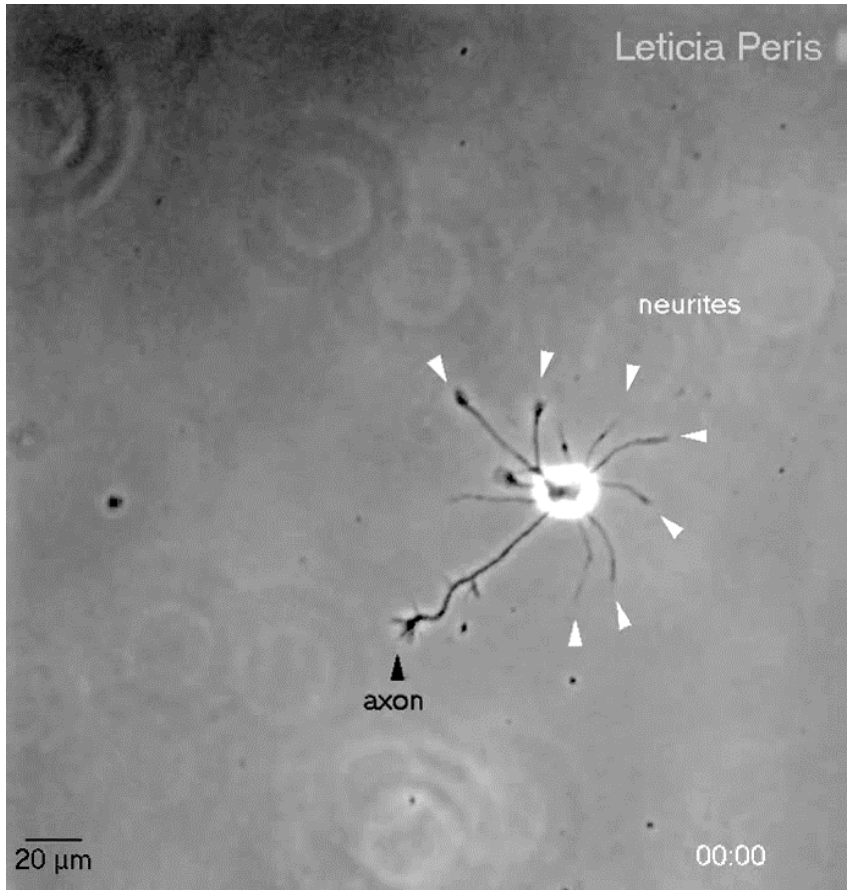
Neural Correlates of Learning

- Developmental changes in brain structure
- Functional roles fulfilled by specific brain regions
- Nerual efficiency
- Plasticity
- Memory structures
- Limits in attention and processing
- Motivational/attentional underpinnings of reasoning

- Neuroimaging (live recordings from the functioning brain)
- Neuropsychiatry – neurological disease, lesions, case studies
- Animal models

Neuroplasticity



Peris (2008)
https://www.youtube.com/watch?v=EP4yeyD8ktY&list=PLF0GImpXv9lKmxOmC2jKdnAAaKIQDT1jp

Plasticity does not have to be structural

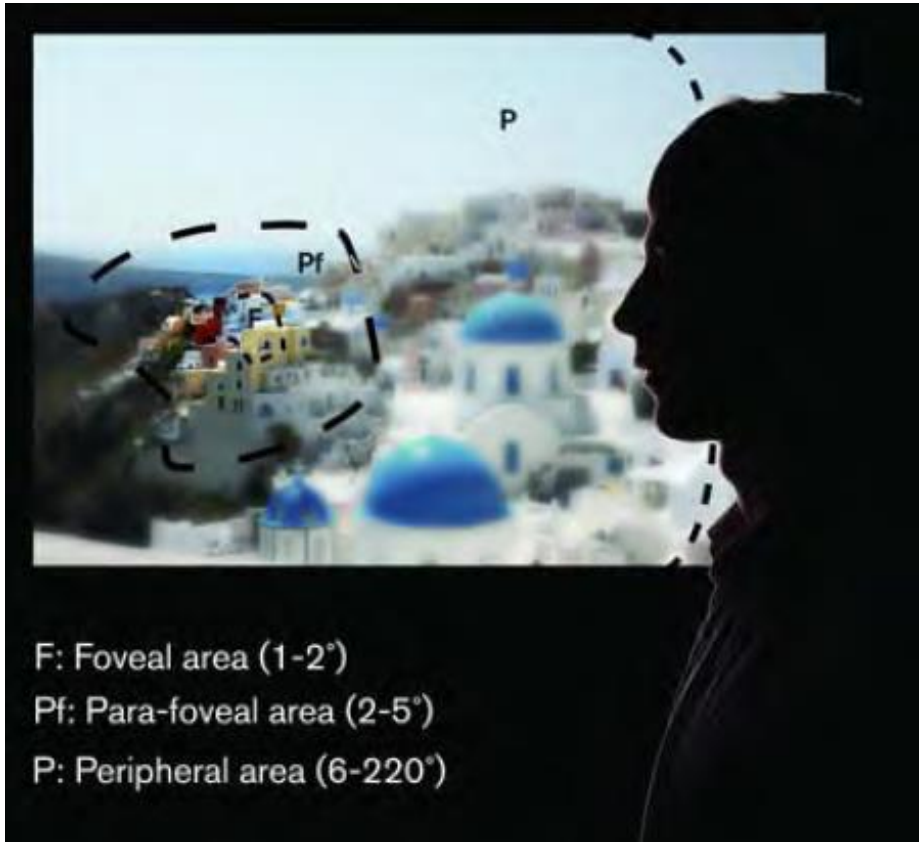
- Functional changes in the brain
- Connectivity patterns, oscillatory behavior of neural assemblies
- Metabolic efficiency of networks

Developmental Neuroscience

- The prefrontal cortex continues its development until adulthood
- Plasticity is now known to exist even in the aging brain
- Cognitive and attentional control, maintanence of context relevant information, modulating emotional responses are functions associated with frontal regions
- Excitatory synapses in PFC undergo extensive proliferation between birth and adolscence, followed by a decline
- In contrast, inhibitory synapses grow prenatally and do not change in circuitry after 1 year of age
- Neuromodulatory inputs to the PFC from dopaminergic neurons in the midbrain increase gradually during postnatal maturation and reach a maximum during adolscence
  - Reward processing, impulsivity – action control, maintanence of contextual info – working memory capacity

Attentional Control

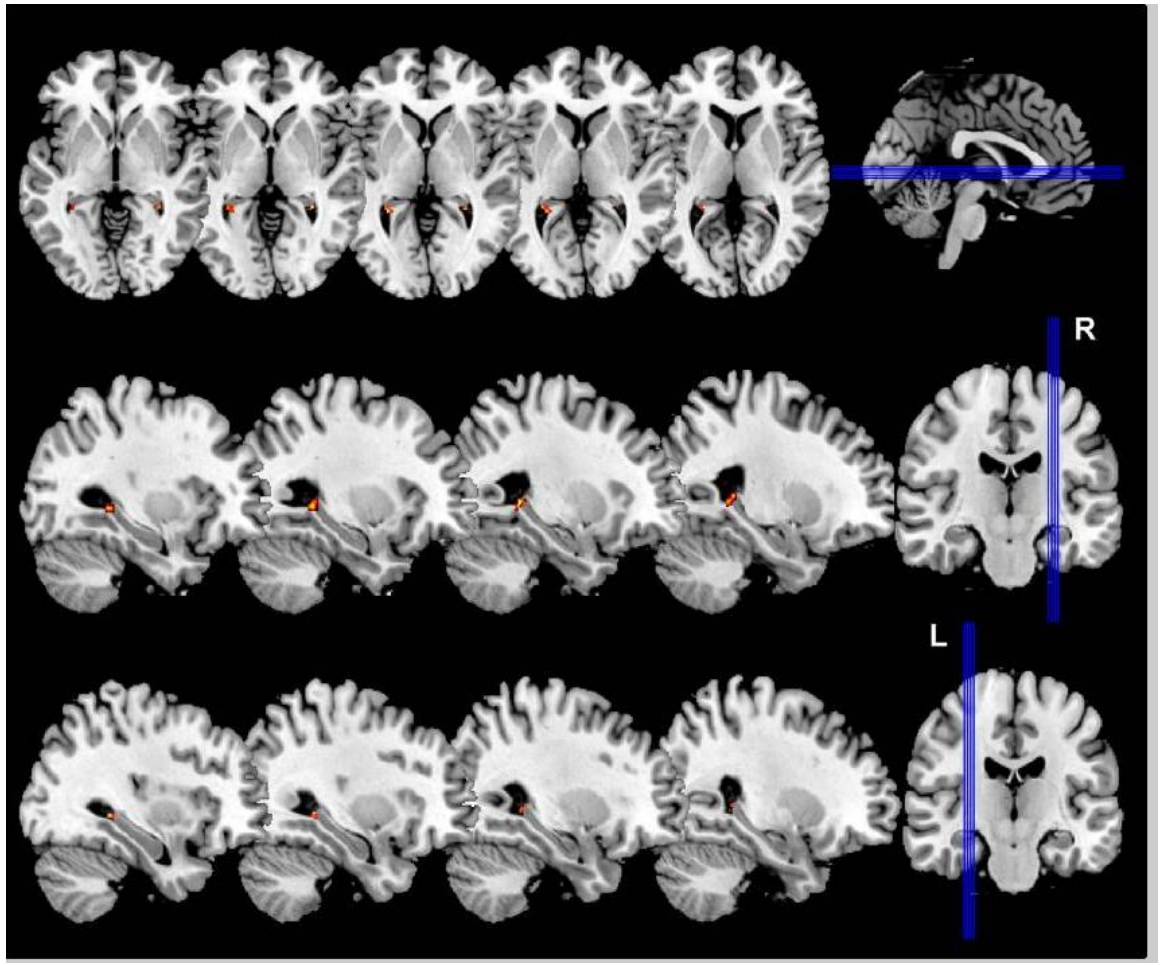
- Prefrontal cortex is specialized for flexible behavior (Barbas & Robbins, 2013).
- The flexibility entails selective attention to salient stimuli and suppresion of distracting stimuli
- Structural connections of PFC provide itself access to the entire xternal (sensory) and internal (emotional) environment
- Only relevant signals are used at any one time to accomplish a task at hand



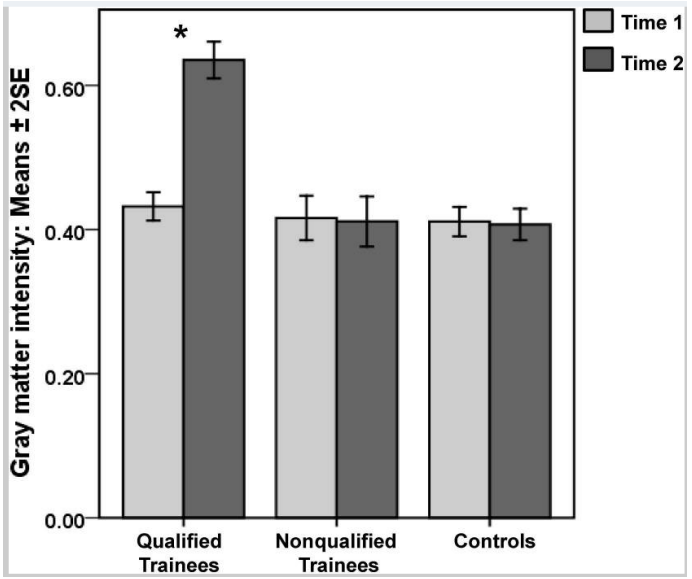
Memory

- Different memory systems
- Semantic, episodic, procedural memory
  - Hippocampus – fast, associative learning based on information sampled from a large number of cortical regions, available for conscious access
  - Procedural memory – distributed into the cortex, slow learning, fault tolerant, may not be easy to articulate, tacit in nature (tell me how can you speak, or ride a bike)
  - Two forms of memory mutually inform each other, some hippocampal patterns penetrate into cortical structures (i.e. İn the form of weight/connectivity changes)
- What is the benefit of having different forms of memory in our brains?

Memory – Structural Change



Structural difference in gray matter of London Taxi Cab drivers who could pass the demanding test versus controls (Woollett & Maguire, 2011)



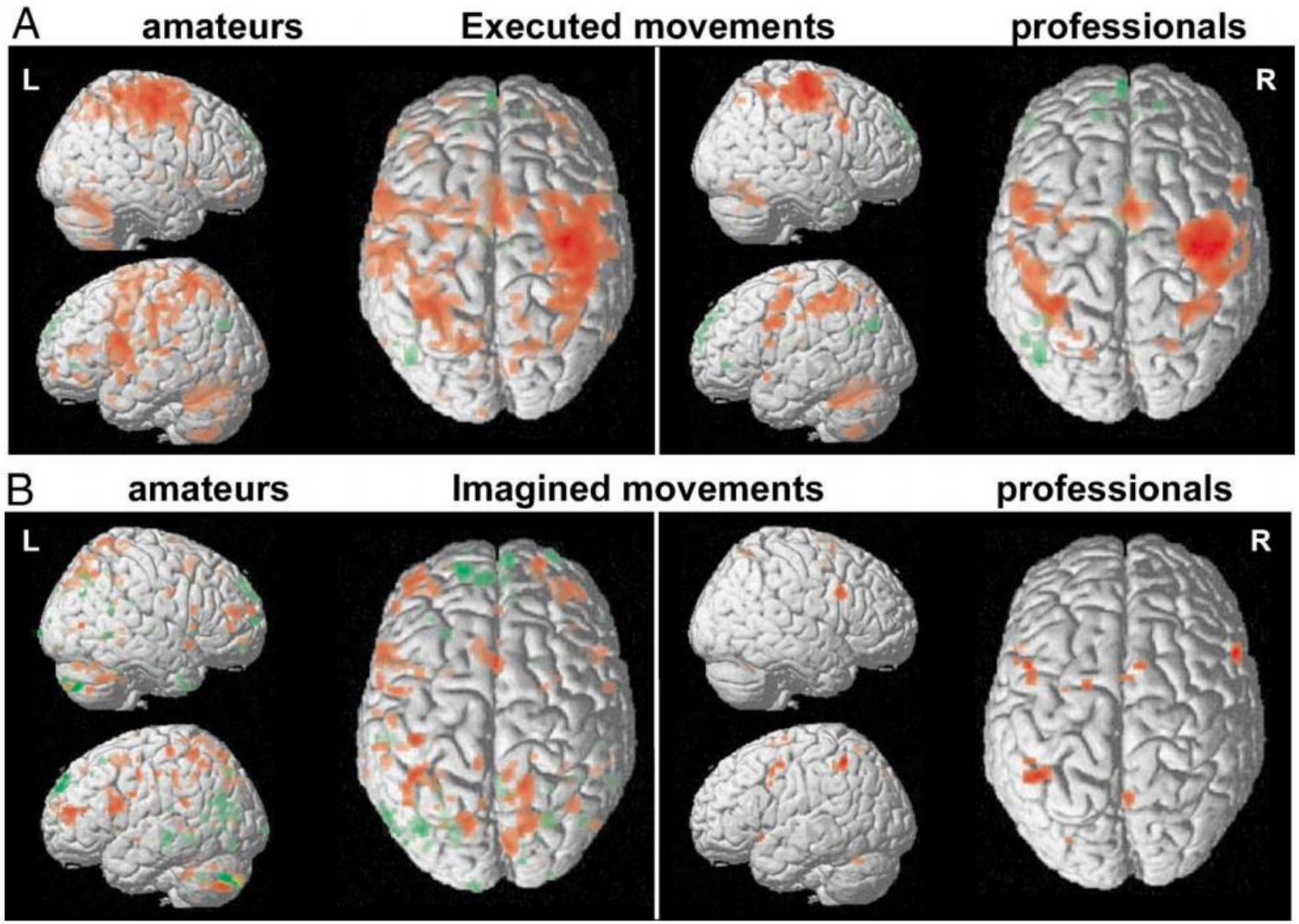


Fig. 2. Within-group-analysis: fMRI activation maps during executed (A) and imagined (B) left-hand performance of the musical sequence in the group of amateurs (left) and the professional musicians (right). The 3D-segmented top view and the left and right lateral view are shown. Increased BOLD effect during the task is coded red, while decreased BOLD effect is coded green. (A) Executed performance. Both groups manifested very similar activations, being more distributed in the amateurs, compared to the more circumscribed activities observed in professional violinists. Deactivations in both groups were present mainly in the medio-dorsal prefrontal and in the left inferior parietal lobe. (B) Imagined musical performance. Amateurs (left) manifested sparsely clustered but widely distributed activity, with particular prominence in bilateral lateral frontal, inferior opercularis, primary and supplementary motor, parietal, and anterior temporal and posterior lateral cerebellar regions, whereas those in professionals (right) were observed in few but specific clusters within right M1, SMA, bilateral posterior cerebellum, bilateral superior and left inferior parietal cortices, and right superior opercular part of the inferior frontal gyrus.

Functional Differences between Experts and Novices

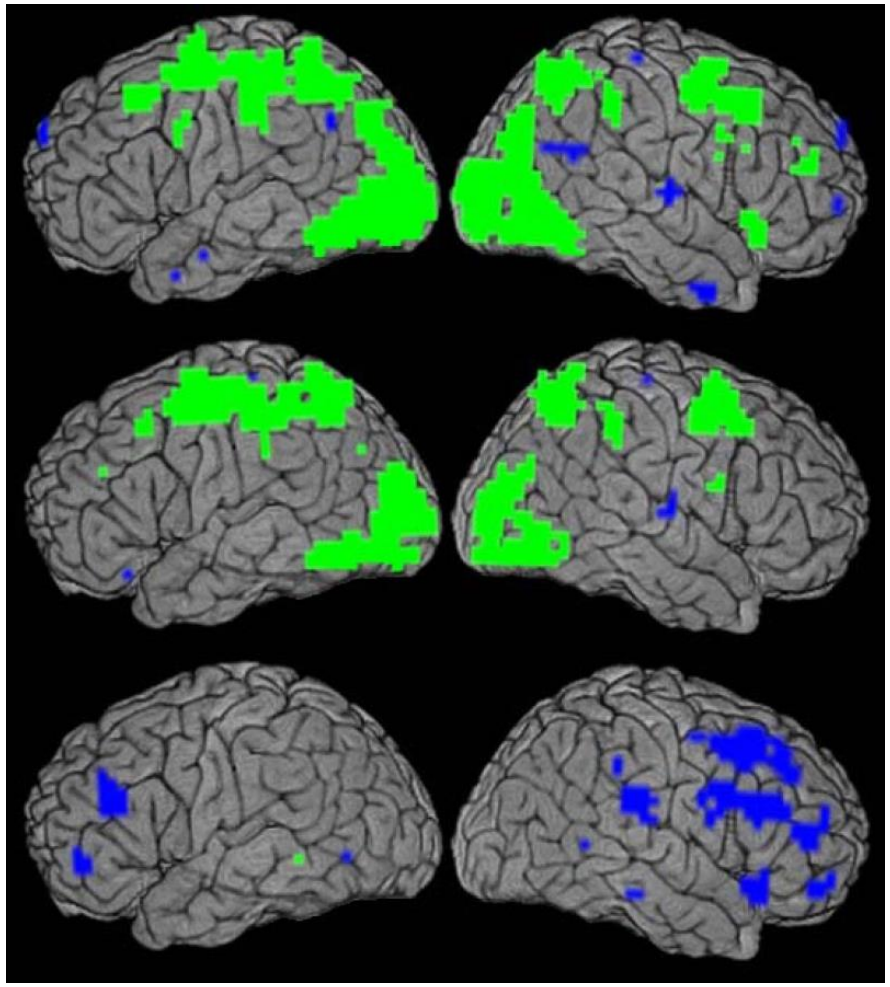
Lotze et al. (2003)
Expert vs novice differences in brain activity

You cant play the violin inside an fMRI scanner
So researchers just asked subjects to move their left fingers to simulate playing a piece they did some prior training

In another condition subjects were asked to imagine that they were playing

Neural Efficiency due to Training - Tetris

- Haier et al. (2009) found that areas in the parietal and frontal cortex were involved when subjects play tetris.
- The level of activation in the frontal areas decreased among subjects who regularly practiced *Tetris* for three months.
- Structural MRI scans indicated that the thickness of those subjects' left parietal cortex was increased (i.e. Brodmann Areas 6, 22/38) as compared to the control group.
- The increase in cortical thickness is considered to indicate the formation of circuits dedicated to this visuospatial task.
- The overall decrease in activation suggests that the brain utilizes its neural resources in a more efficient way as a result of **learning**.
- Such functional and anatomical changes can be considered as neural correlates of developing visuospatial reasoning and motor skills relevant to playing tetris.



Cognitive Neuroscience of Mathematical Cognition

- Neural correlates of arithmetic and geometric reasoning
- The number sense (Dehaene,1997/2011)
  - Experimental evidence suggest primates and human babies have
    - Basic grasp of one, two, three
      - Spatially grouping and labeling of objects
    - Approximate comparison of quantities
      - Imaginary number line in the parietal cortex
  - Linguistic abilities & cultural influences
    - Recruit cortical areas known to be involved during language processing
    - Linguistic abilities transform the neural networks to develop exact arithmetic

Numbers and Arithmetic

- What is going on when you have the thought that 98 is one more than 97?

- Although most of us cannot form a clear image of 98, the number word 98 names a distinct quantity between 97 and 99

- Does the human capacity for mathematical intuition depend on linguistic competence or on visuo-spatial representations?

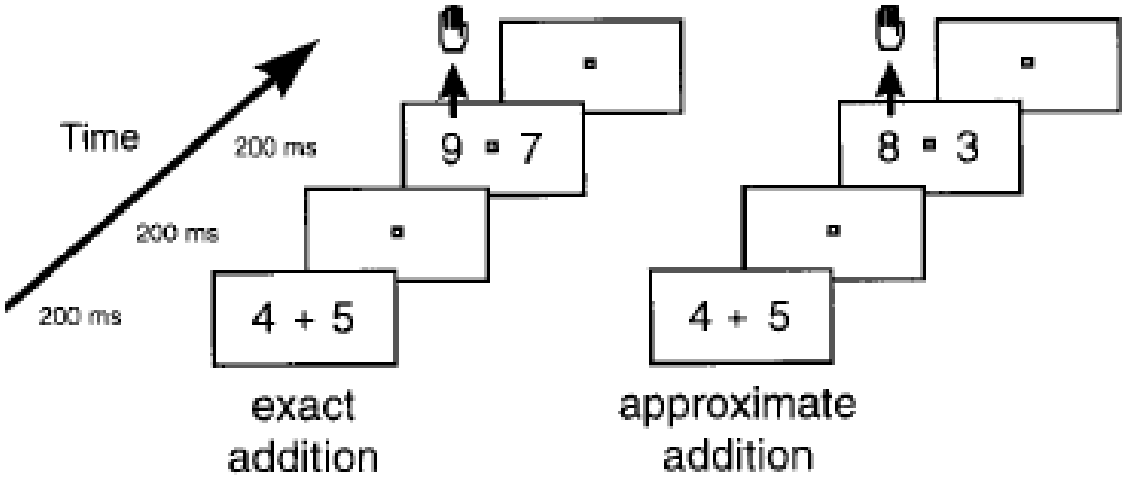
Dehaene et al.’s study

- Dehaene et al. claim that this kind of precise mathematical thinking emerges via the interplay of three distinct cognitive processes
  - A basic biological capacity to individuate small quantities 1-ness, 2-ness, 3-ness
    - Even most isolated cultures have words for such quantities
    - Primates, animals and infants can discriminate such quantities
  - A biological capacity for approximating quantity
    - E.g. discriminating 8 dots versus 16
  - Learned capacity to use number words of a language where each number word names a distinct quantity

Dehaene et al.

- A series of behavioral and brain-imaging experiments provides evidence for both sources.
- Exact arithmetic is acquired in a language-specific format, transfers poorly to a different language or to novel facts, and recruits networks involved in word-association processes.
- In contrast, approximate arithmetic shows language independence, relies on a sense of numerical magnitudes, and recruits bilateral areas of the parietal lobes involved in visuo-spatial processing.
- Mathematical intuition may emerge from the interplay of these brain systems.

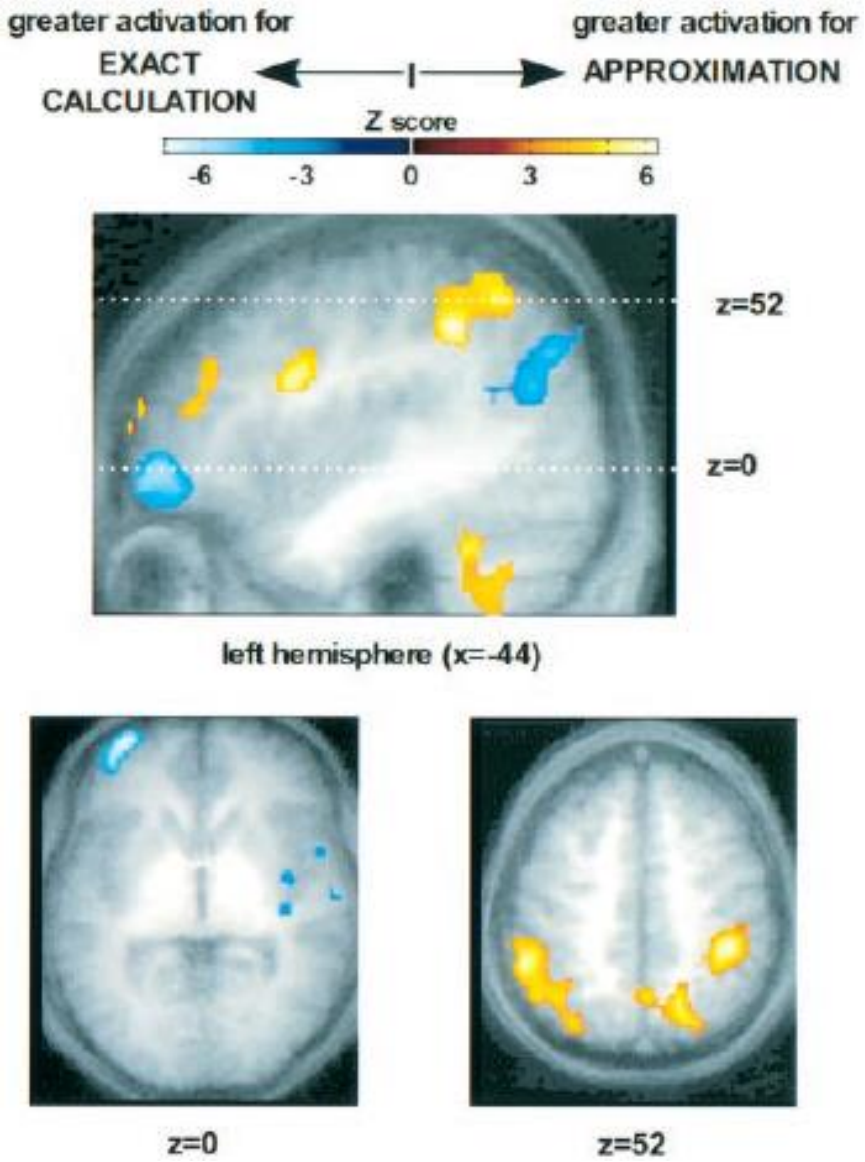
- Is there a dissociation between exact and approximate arithmetic calculation?



Dehaene et al. (1999) **Sources of Mathematical Thinking: Behavioral and** *Science* ***284, pp 970***

Previous studies have found left inferior frontal activation during verbal association tasks, including generating a verb associated with a given noun

These areas may constitute a network involved in
the language-dependent coding of exact addition facts as verbal associations



involved in various visuo-spatial and analogical mental transformations

Evidence from Lesion Studies

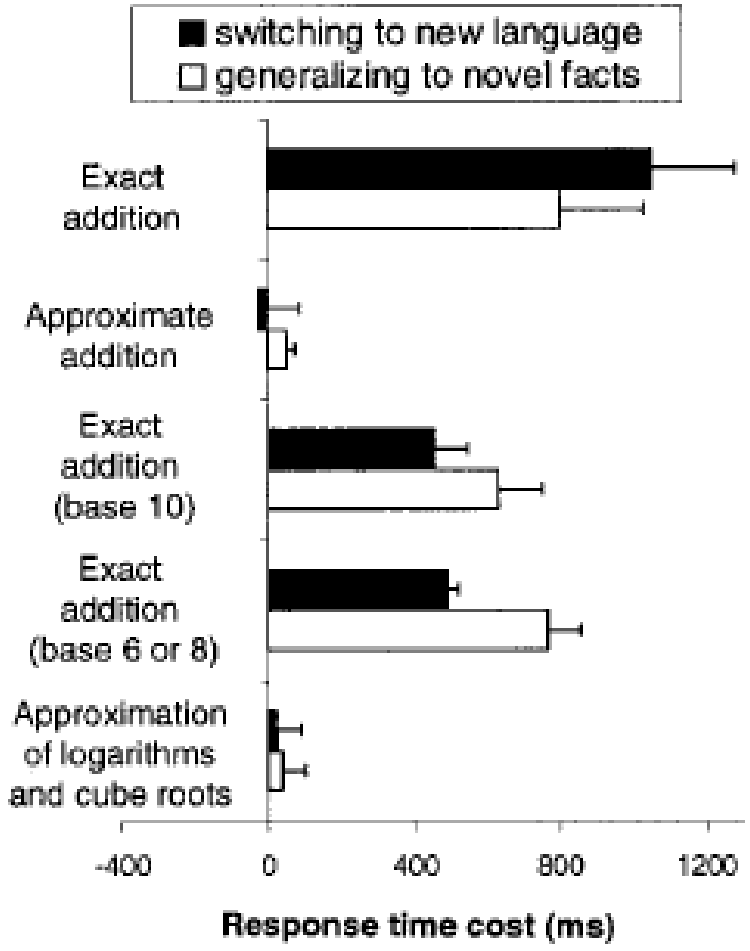
- Patients with calculation deficits, in whom the lesion localization fits with the fMRI results of Dehaene et al.
- Several lesion sites can cause acalculia. *However, on closer examination, at least* two distinct patterns of deficit are found.
- Some patients with left parietal lesions exhibit a loss of the sense of numerical quantity (including an inability to decide which number falls between 2 and 4 or whether 9 is closer to 10 or to 5), with a relative preservation of rote language-based arithmetic such as multiplication tables.

Evidence from Lesion Studies

- *Conversely, aphasia following* left-hemispheric brain damage can be associated with a selective impairment of rote arithmetic and a preserved sense of quantity, including proximity and larger-smaller relations between numbers.
- *Particularly relevant to the* present work is the case of a severely aphasic and alexic patient with a large left-hemispheric lesion who could not decide whether 2 + 2 was 3 or 4, indicating a deficit for exact addition, but consistently preferred 3 over 9, indicating preserved approximation.
- *So, lesion data* suggest that distinct circuits underlie the sense of quantity and knowledge of rote arithmetic facts.

Language Effect

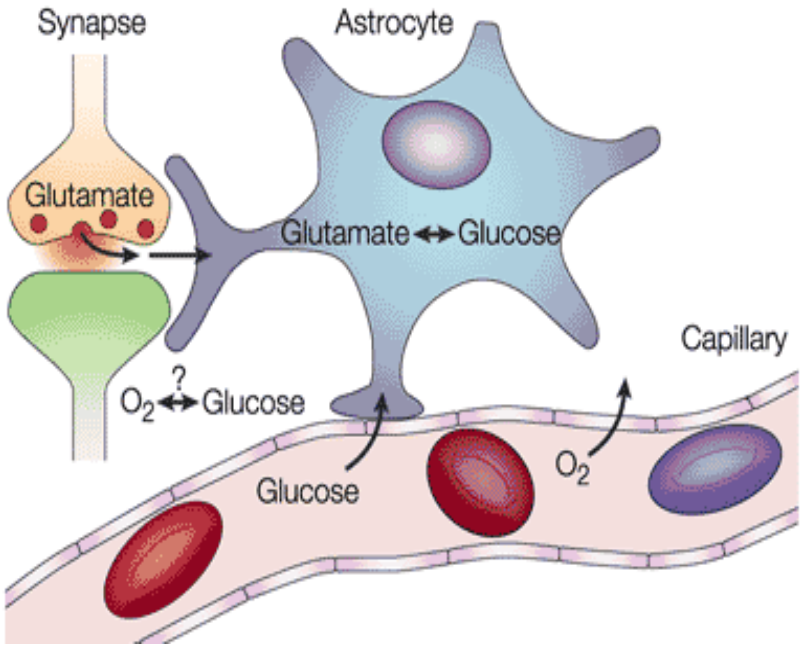
- Russian-English bilinguals
- Subject goes through exact and approximate tasks in one language
- Exact
  - “Four + Five” pick among “Nine” and “Seven”
- Approximate
  - “Four + Five” pick among “Eight” and “Three”
- After extensive training language is switched
- Performance in approximate condition is not affected by language change, whereas the exact condition is negatively affected



Summary

- Exact calculation is language dependent, whereas approximation relies on nonverbal visuo-spatial cerebral networks
- Even within the small domain of elementary arithmetic, multiple mental representations are used for different tasks
- Once a numeral is attached to the simple innate number line (i.e. approximating circuit) all numbers can be understood as precise quantities

Neural Activity & Blood Flow

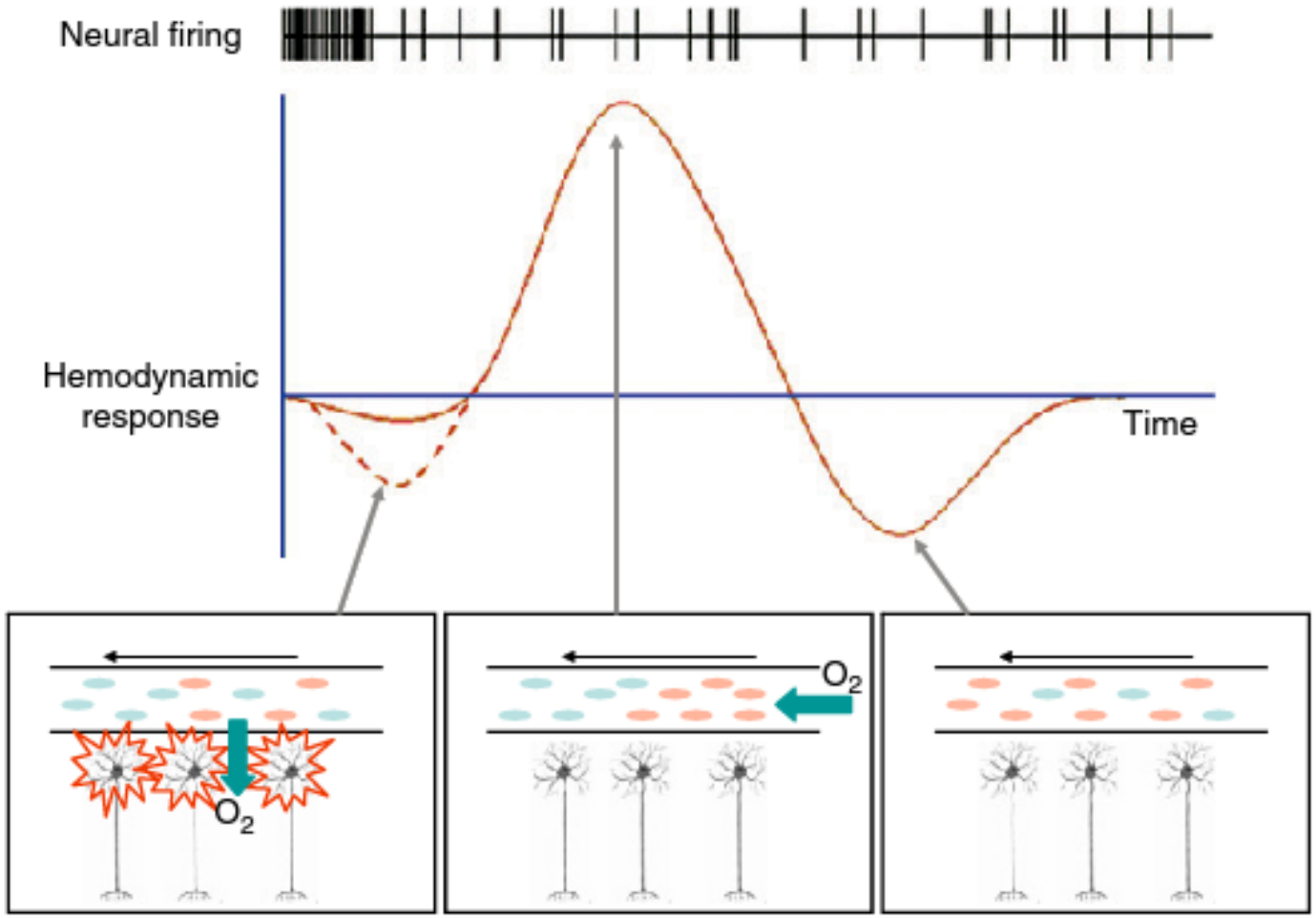


- Neurons consume energy (glucose) when activated
- **Oxygen** is required to metabolize the glucose
- As clusters of neurons are activated, there is an increased need for oxygen in that area
- Oxygen is transported to neural tissue via **oxy-hemoglobin** in the blood
- The oxygen exchange occurs in the capillary beds
- As oxy-hemoglobin gives up oxygen to the neural tissue, it is transformed into **deoxygenated hemoglobin**

Oxy-Hb and deoxy-Hb are correlates of brain activity through oxygen consumption by neurons

David J. Heeger & David Ress. (2002)What does fMRI tell us about neuronal activity? Nature Reviews Neuroscience 3, 142-151

Hemodynamic Response

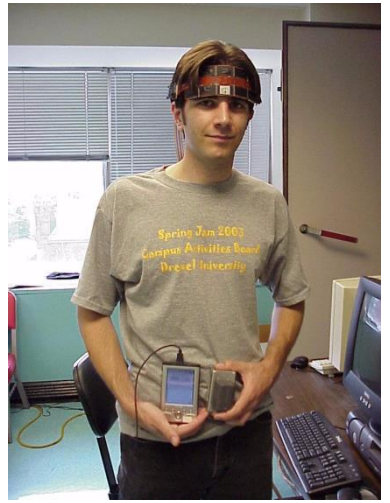


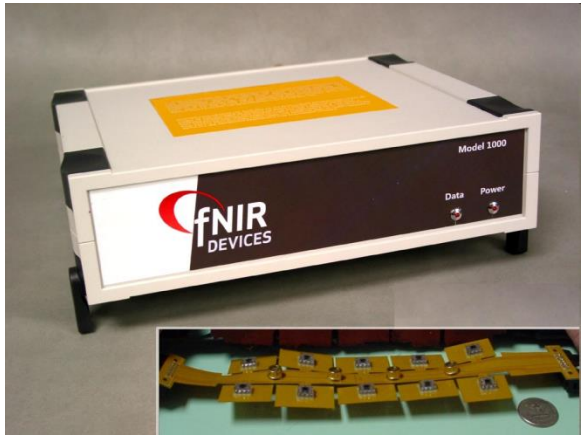
Vascular Density

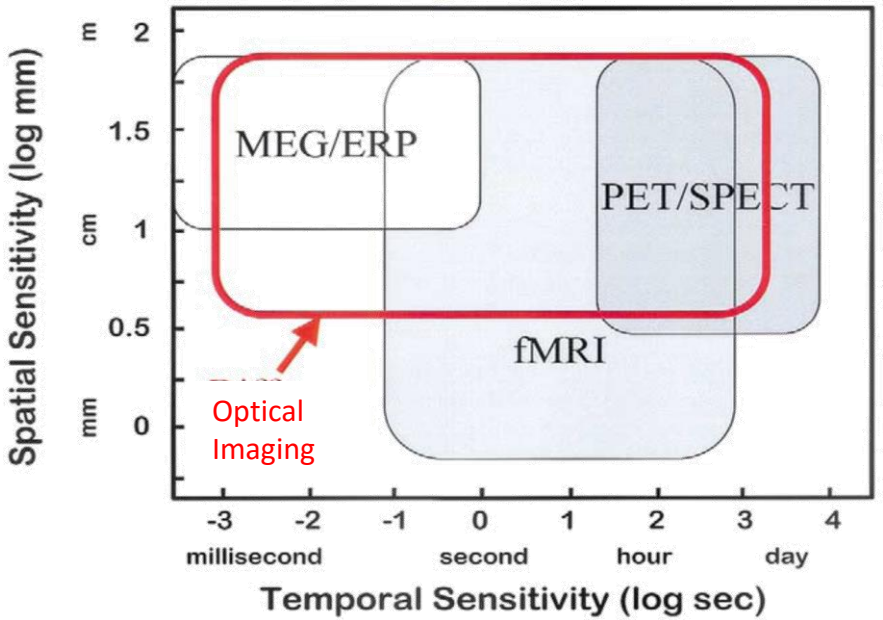
Why bother with arteries, capillaries?
Vascular density in the brain is proportional to synaptic density

Functional Near-Infrared Spectroscopy

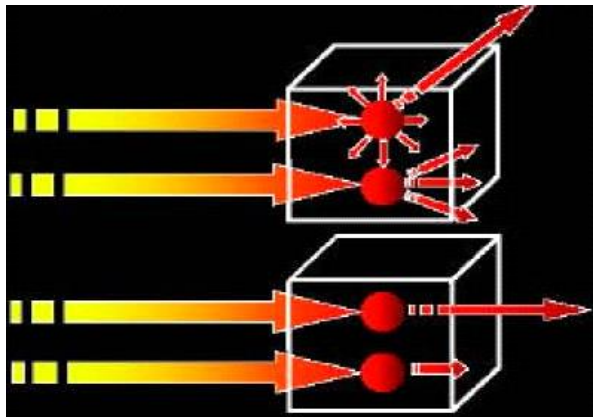
- Emerging technology
- Monitors hemodynamic changes
- Relatively good spatial resolution (compared to EEG)
- Good temporal resolution (compared to PET, fMRI)
- Safe, affordable, portable, non-invasive, minimally intrusive, rugged
- Relatively easy to integrate with other modalities



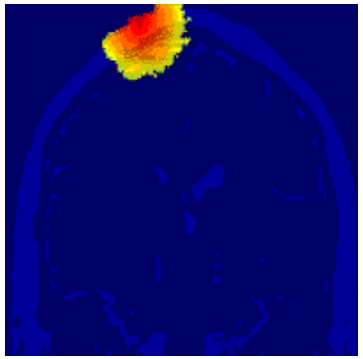


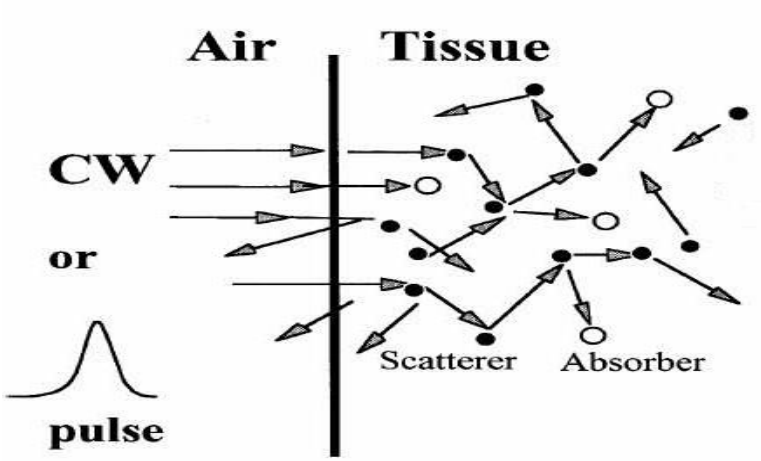


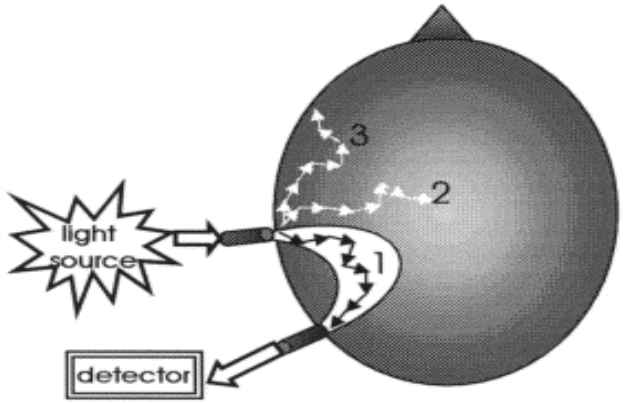
Principles of fNIRS



- Photons that enter the tissue undergoes two types of interaction:
  - Scattering
    - mainly causes the photons to change their direction of motion
    - due to cell membranes, tissue boundaries
    - assumed to be constant
  - Absorption
    - causes the photons to lose their energy to the medium
    - due to chromophores in the tissue i.e. Hb,HbO2,water
    - can be changing depending on the changes in the concentrations of the chromophores





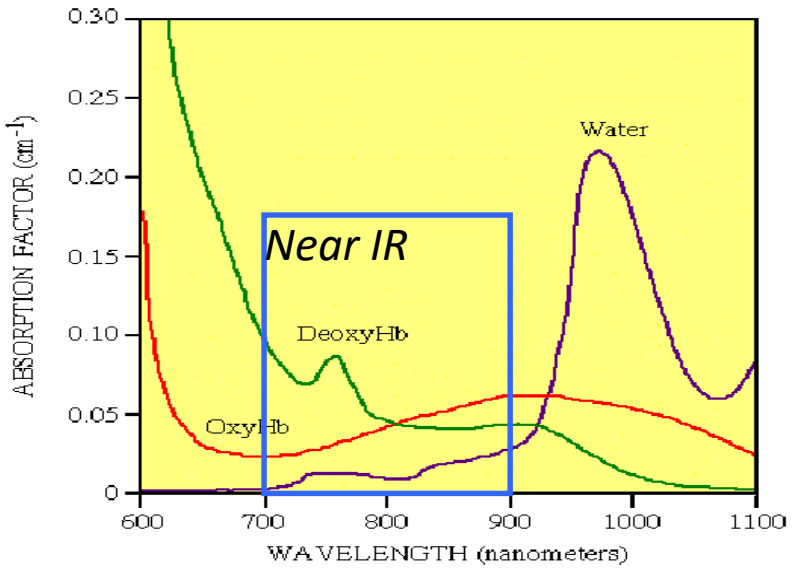


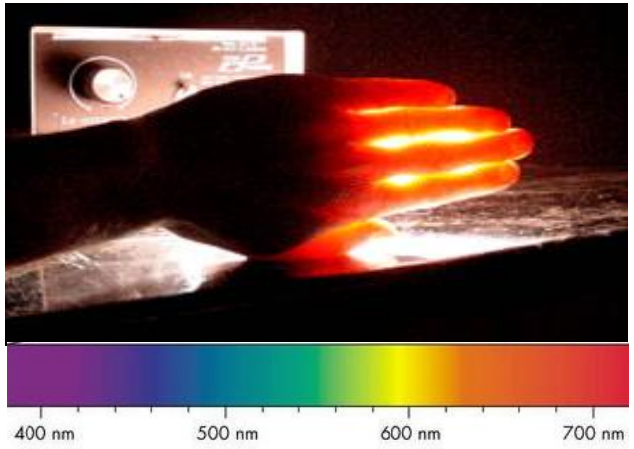
Light Propagation in Tissue

Courtesy of Christopher H. Contag, Stanford University

Principles of fNIRS (cont.)

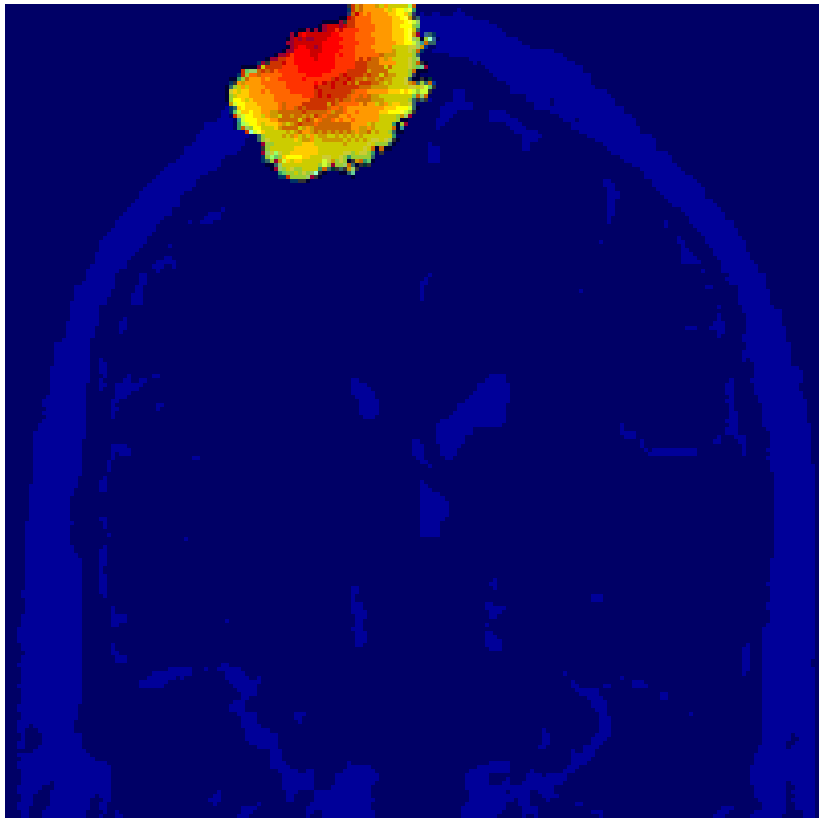
Optical Window in Tissue

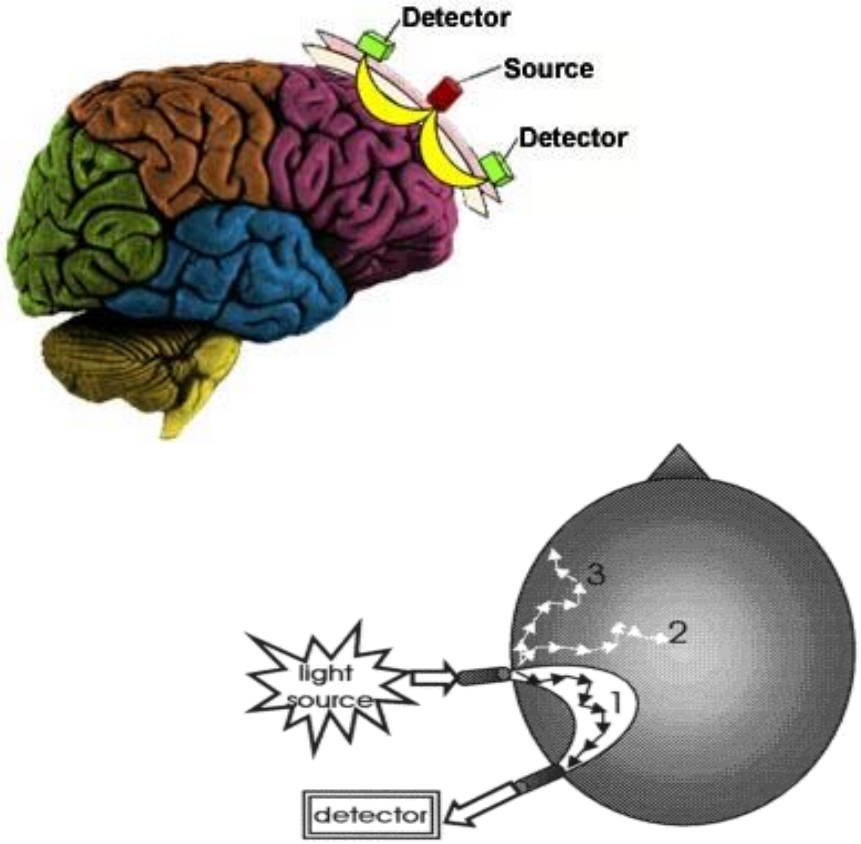




- Tissue is transparent to light within the near Infrared (NIR) range
  - hence NIR can penetrate through human tissue.
- Main chromophores (absorbers) within the NIR light range are oxygenated and deoxygenated hemoglobin as compared to other tissue components such as water, lipid, melanin, etc.
- Oxy and deoxyHb have distinct absorption characteristics within the NIR range which allows spectroscopic measurements
- Prefrontal cortex is activated during cognitive tasks
- By monitoring the attenuation changes due to the changes in absorption, concentration changes of oxy-Hb and deoxy-Hb can be obtained, hence it is possible to obtain information on:
  - Oxygen consumption
  - Blood volume changes

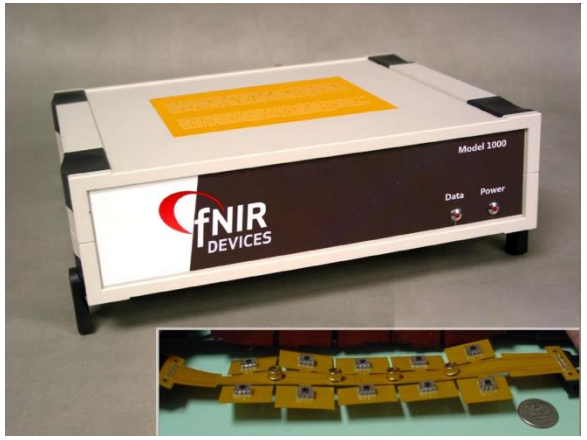
Principles of fNIRS (cont.)





H Obrig , R Wenzel, M Kohl, S Horst, P Wobst, J Steinbrink, F Thomas, A Villringer. Near-infrared spectroscopy: does it function in functional activation studies of the adult brain? International Journal of Psychophysiology 35(2-3):125-142, 2000

The fNIR System

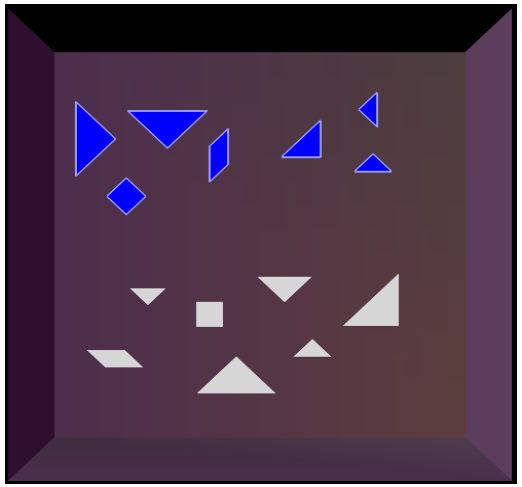


- The fNIR device provides relative change in hemoglobin levels, calculated using modified Beer-Lambert law.
  - Oxygenated hemoglobin change: delta O2Hb (µmol/L)
  - Deoxygenated hemoglobin change: delta HHb (µmol/L)
  - Total hemoglobin change: delta cHb (µmol/L)

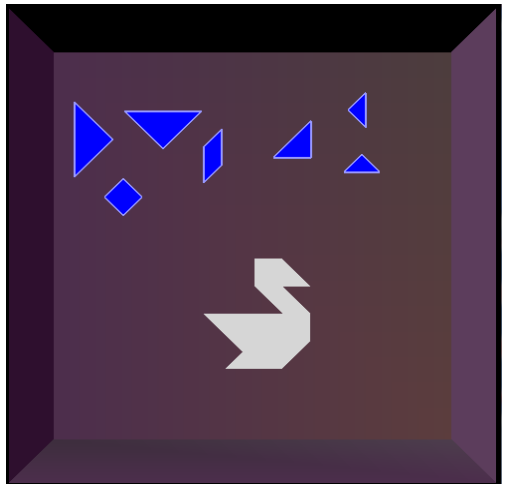
$$Oxygenation = \Delta C_{HbO2} - \Delta C_{Hb}$$

$$BloodVolume = \Delta C_{HbO2} + \Delta C_{Hb}$$

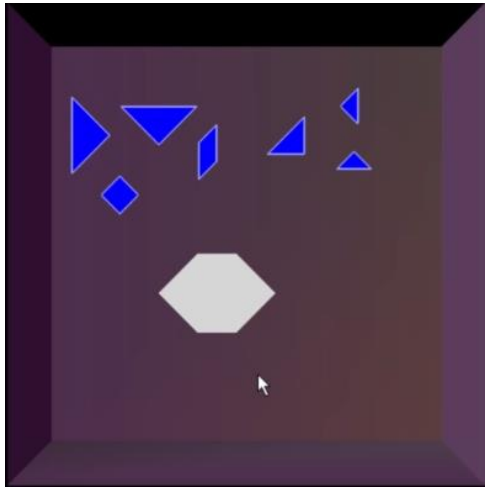
Experimental Setup



Control



Swan

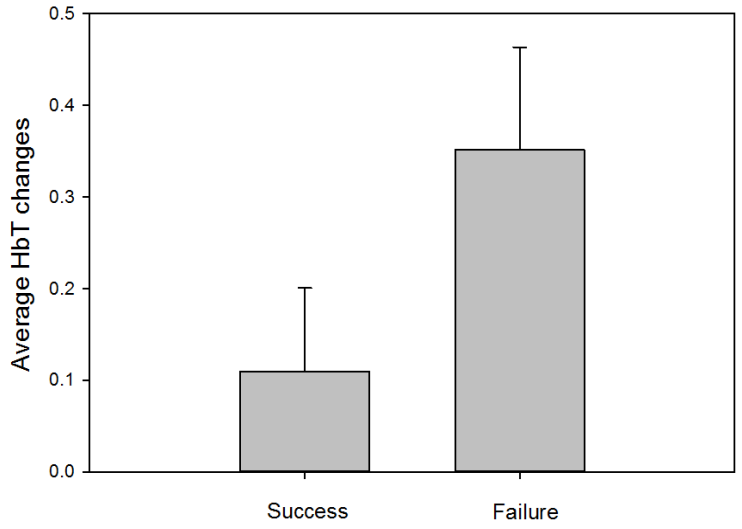


Hexagon

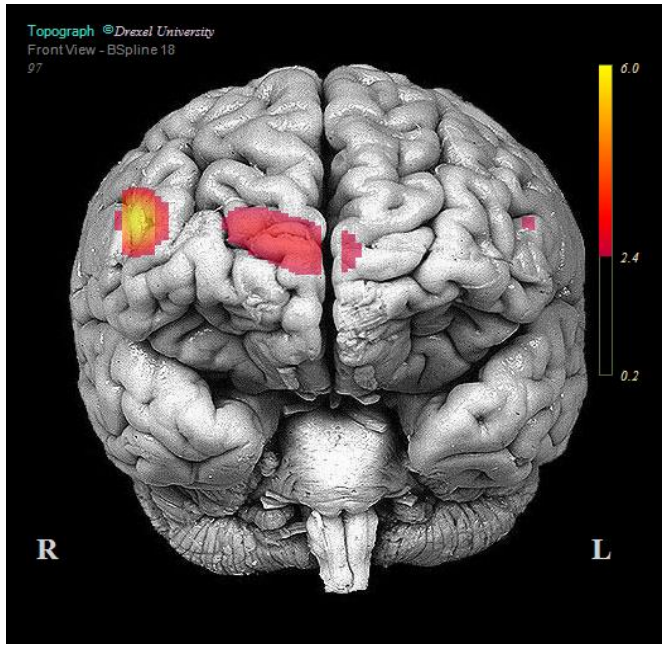
the subjects were given a 5 min PVT task in between phases

3 of the puzzles were repeated

2 geometric type, 4 animal type puzzles were used



Comparison of HbT changes for success versus failed task periods at optode 15.



Projection of t-statistics map on brain surface image indicates right hemisphere dominance.

(BSpline interpolation was used to generate surface representation from t values of comparisons of each control vs task conditions along with thresholding by significance limit $p<0.05$.)

Assessment of Cognitive Function

Working Memory (n-back task)

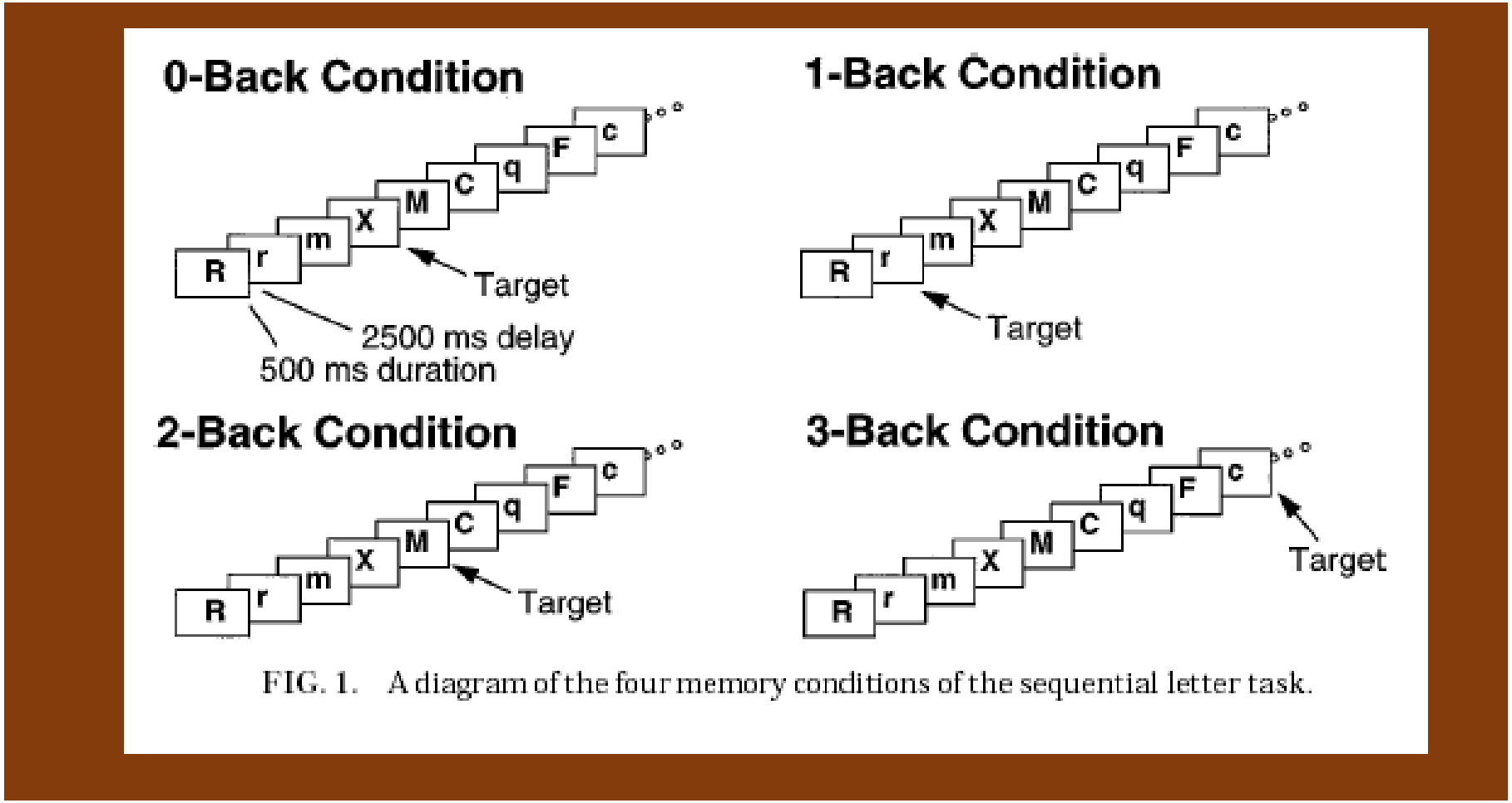


FIG. 1. A diagram of the four memory conditions of the sequential letter task.

Courtesy of Dr. Scott Bunce

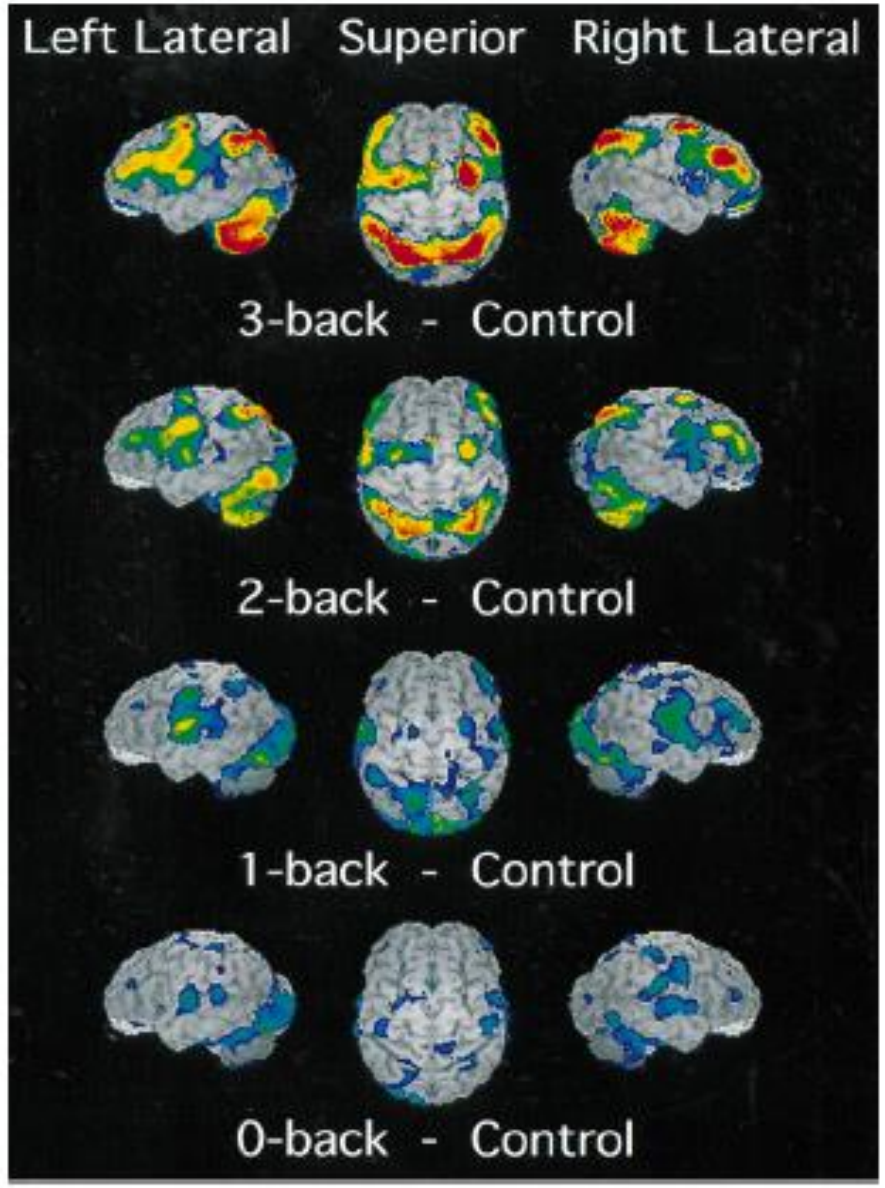
Assessment of Cognitive Function

Working Memory (n-back task)

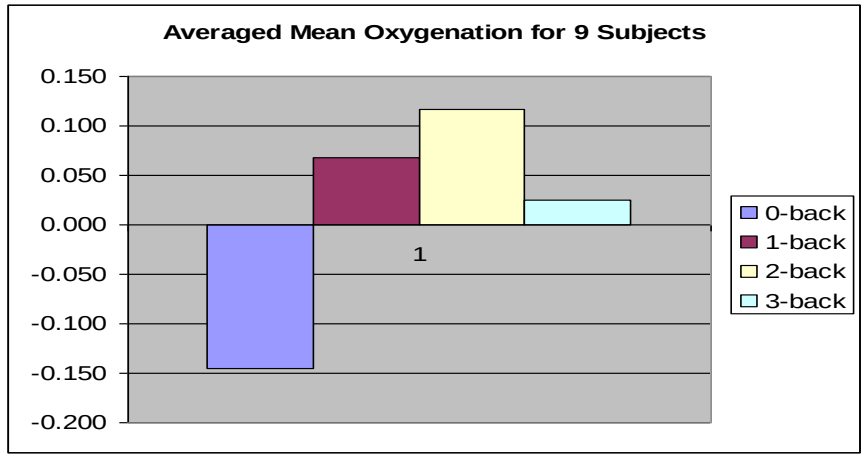
Expected Results from fMRI

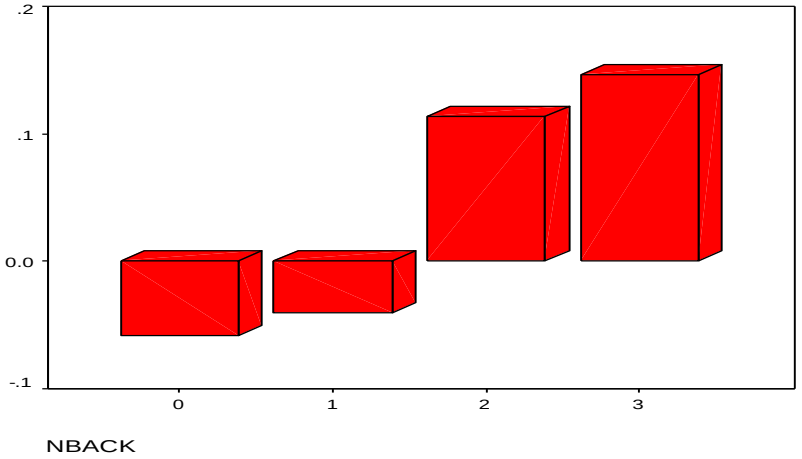
Smith E, & Jonides J. J. ,
COGNITIVE PSYCHOLOGY
33, 5–42 (1997)

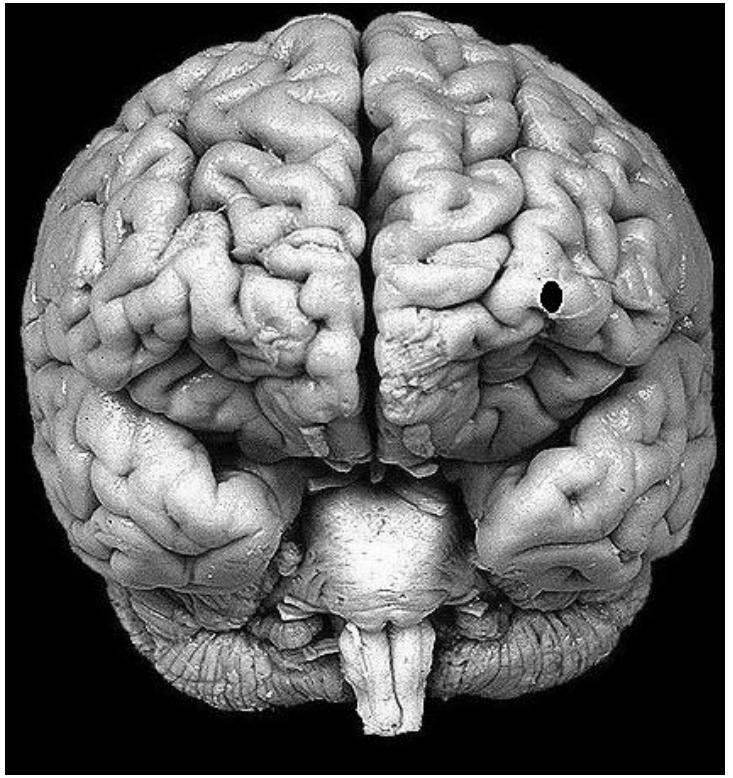
Courtesy of Dr. Scott Bunce



Assessment of Cognitive Function
Working Memory (n-back task)







n-back results performance>90%

Results agree with fMRI results from Smith & Jonides, 1997.

Izzetoglu M, Bunce S, Onaral B, "Single Trial Hemodynamic Response Estimation in Event Related fNIR Spectroscopy", *Proc. of Optical Society of America Conference, 2003*

Uygulama Sahası: İHA Operatörlerinin Bilişsel İşyükünün İncelenmesi

- İHA kullanımı sırasında biliişsel işyükünün ve durumsal farkındalık düzeyinin takibi önem taşımaktadır
  - Pilot, faydalı yük operatörü eğitimi
  - Arayüz/ergonomik tasarım değerlendirmesi

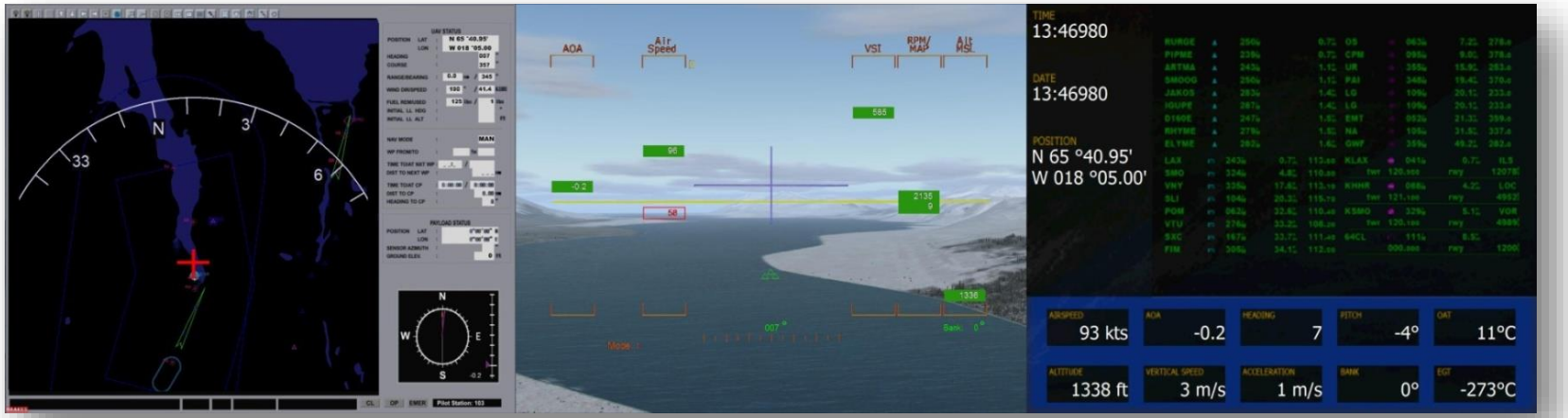
- Mevcut değerlendirme araçları
  - Anket bazlı ölçme (ör. NASA-TLX)
  - Sürecin sonunda yapılan, öznel değerlendirmeler

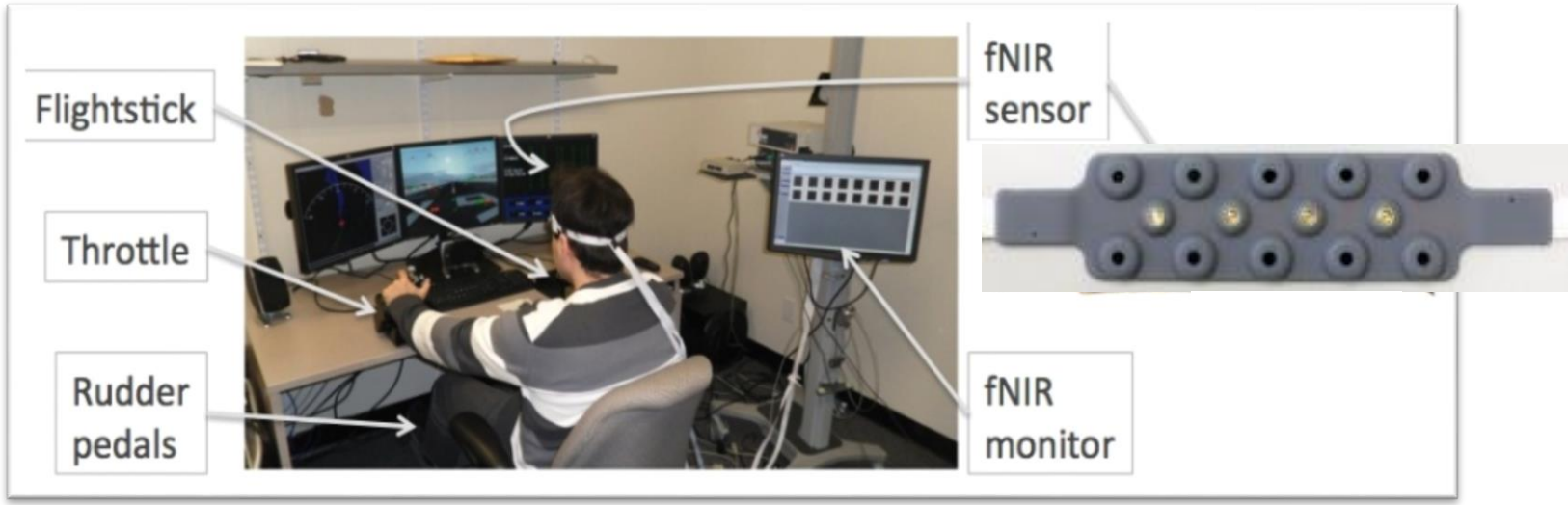
- Amacımız:
  - Optik beyin görüntüleme teknolojisiyle bu kavramların sinirsel izdüşümlerini belirlemek
  - Bilişsel işyükünü niceliksel ve gerçek zamanlı olarak takip edebilmek

Araştırma Sorusu

- Simulatör eğitimi sırasında uzmanlaşmaya bağlı olarak performans arttıkça beynin ön kısmında fNIR ile gözlenen sinirsel aktivitede anlamlı bir değişiklik olmakta mıdır?

Deneysel Düzenek





Deney Kurgusu

- **Katılımcılar**
  - Yaşları 21-28 arası değişen 12 gönüllü
  - Önceden hiçbir uçuş simulatörü tecrübesi olmayan kişiler

- **Görev**
  - İHA'nın havaalanına güvenli olarak indirilmesi
    - Yaklaşma açısı ve son hızın istenilen değerlerde tutulması beklenmektedir

- **Desen**
  - Tek deney grubu, tekrarlı-ölçüm
  - Katılımcılar 3 hafta içerisinde 1 saatlik 9 seans tamamlamıştır
    - 1. gün: simülatör kontrollerinin tanıtımı
    - 2 - 9. gün: 10'ar kere iniş denemesi

Veri İşleme

- **Ön İşleme**
  - Ham fNIR işaretleri (16 kanal x 2 dalgaboyu) Sonlu dürtü yanıtı (FIR) alçakgeçiren doğrusal fazlı ve 0.1Hz limitli bir süzgeçten geçirilmiştir
  - Yüksek sıklık (frekans) gürültüsünden ve fizyolojik etkenlerden (kardiyak ve nefes dönemsellikleri) arındırılmıştır.
  - Doyuma ulaşmış kanallar değerlendirme dışında bırakılmıştır

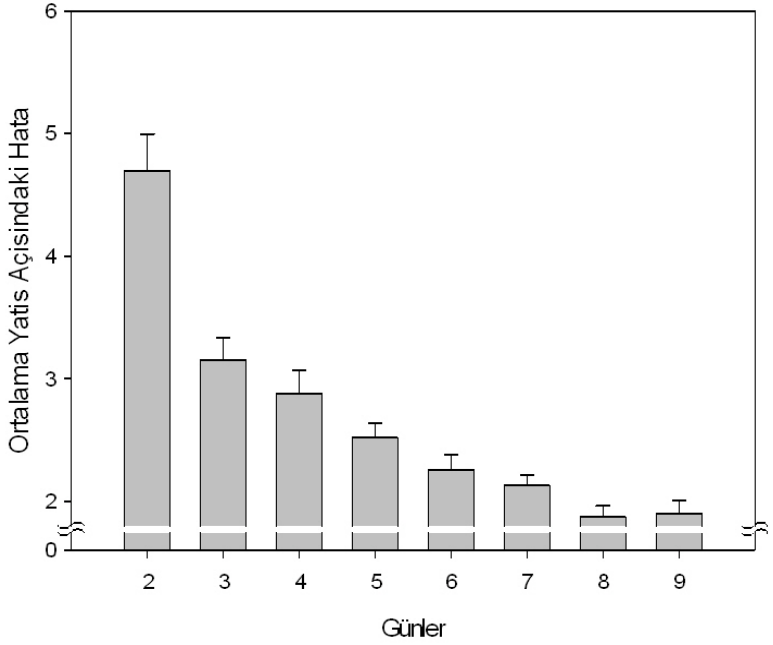
- **Görev Bloklarının Oluşturulması**
  - fNIR işaretleri, deney sırasında otomatik olarak toplanmış zaman eşleştirme bilgisi kullanılarak, görev sürelerine ayırıldı.

- **Oksijenleşme ve Kan Hacmindeki Değişim**
  - Her görev sırasında, kan oksijenlenmesi ve kan hacmi miktarlarında oluşan değişim, ham işaretlerin ***uyarlanmış Beer-Lambert*** kuralıyla dönüştürülerek hesaplanmıştır.

Davranışsal Analiz Bulguları

- Bağımlı değişken: **Hata Oranı**
  - Her deneğin uçuş sırasında gerçekleştirdiği yatış açılarının optimum modelden farkı
  - Optimum Model: Yatış açısının zamana göre izlediği ideal değer eğrisini ifade eden 4. dereceden polinom

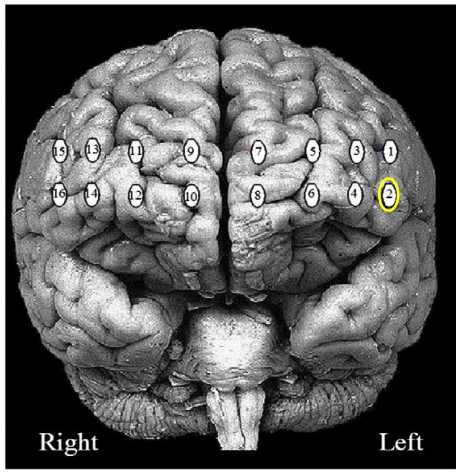
- Denekler kullanım konusunda tecrübe kazandıkça hata oranlarında istatiksel olarak anlamlı bir düşüş olduğu gözlenmiştir.
  - ($F_{7,850}$=38.17, p<0.01)



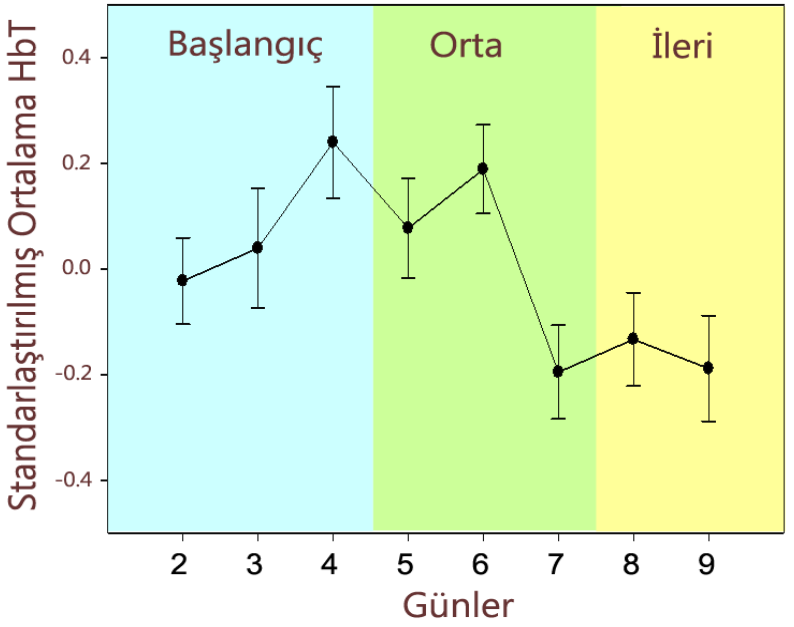
Uçuş sırasında yatış açısında modelden sapma miktarlarının günlere göre değişimi

fNIR Analizi Bulguları

- Bağımlı değişken: 2. voxel'de gözlenen **HbT** ortalamasındaki değişim
- Aşamalar arası anlamlı bir fark olduğu görülmektedir
  - $F_{7,832}=2.36$, $p<0.02$
- Başlangıç aşaması
  - performanstaki artış daha fazla bilişsel işyükü gerektirmektedir
- İleri aşamalar
  - daha az bilişsel çabayla daha iyi performans gösterilmektedir



Sol inferior frontal gyrus bölgesi



fNIR Analizi Bulguları

- fNIR ve performans verilerinin bir arada kullanımı
- Öğrenme süreci sırasında başlangıç aşamasından üst düzey aşamaya geçildikçe düşük etkililikten yüksek etkililiğe geçiş gözlenmiştir