ENLIGHTENING INNOVATION

Introduction to fNIRS

Dalila Burin, Franziska Keller
Scientific Consultants – NIRx

6.5.2025 SYNCC lectures and workshops - Warsaw

We are NIRx!

NIRx

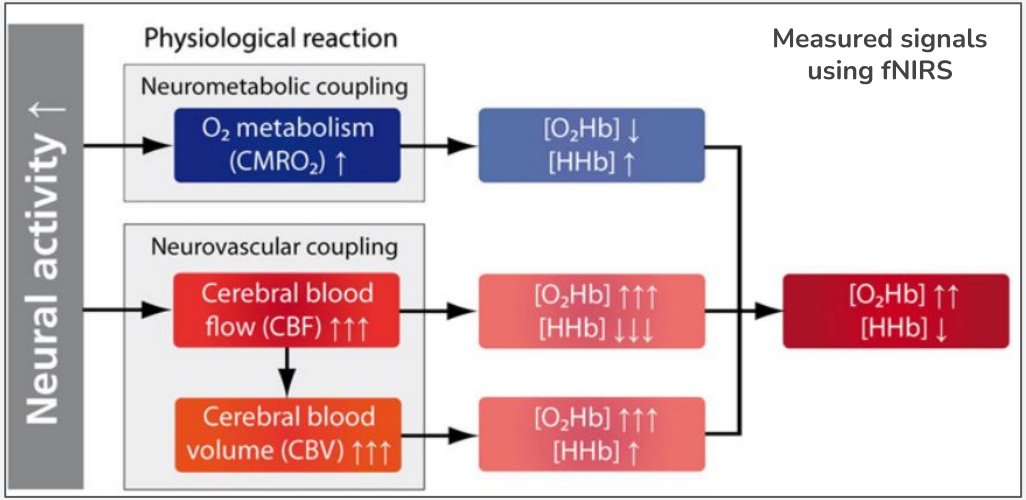
fNIRS: Functional Near- InfraRed Spectroscopy

A form of functional optical imaging used to measure superficial cortical hemodynamics.

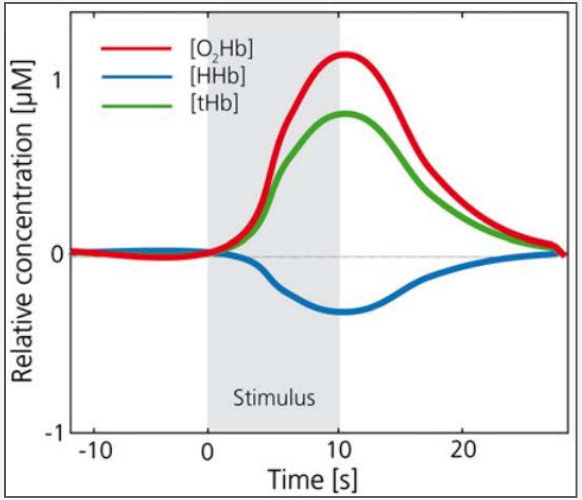
Hemodynamic Response

NIRx

Oxygenated blood is routed to areas of increased neural activity…



…which induces the **hemodynamic response**!

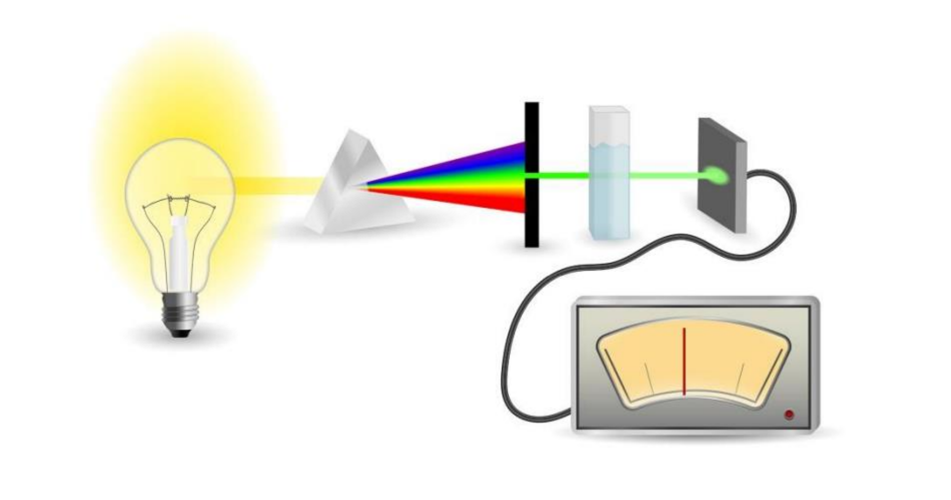


Scholkmann et al., 2014

Spectroscopy

NIRx

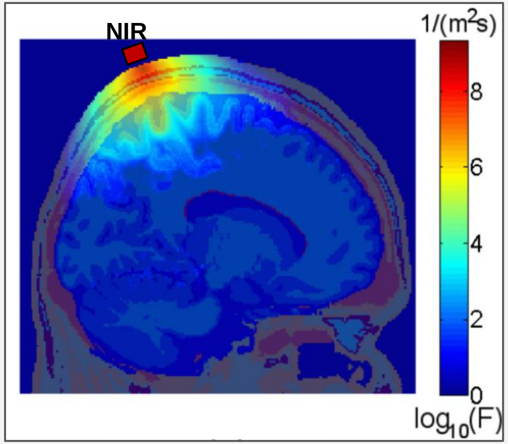
The study of interaction of light with matter
used to identify or measure certain characteristics of molecular structures



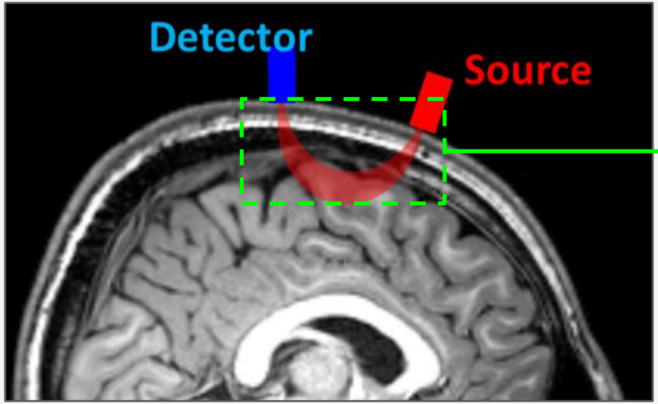
fNIR-Spectroscopy: changes in light absorption reflect hemodynamic activity

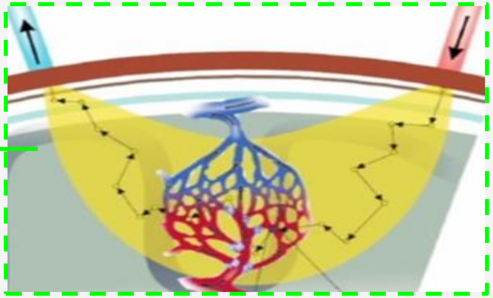
Light Scattering and Absorption

Photons scatter in all directions...



...but **most detected photons** follow this path distribution profile, i.e. the **photon banana**.



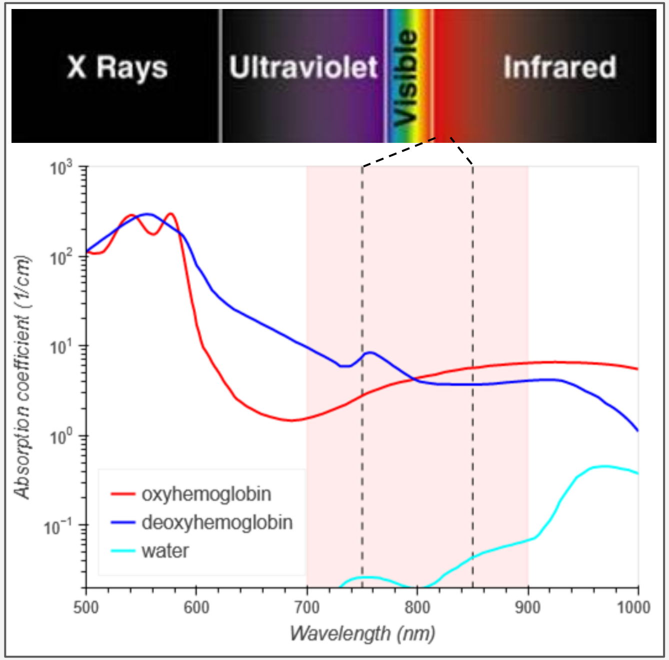


Near-Infrared Light

NIRx

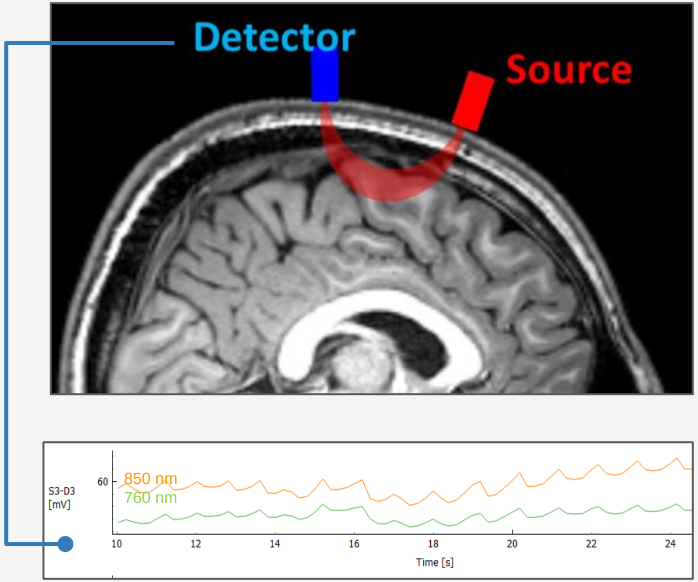
Longer wavelengths can propagate better through biological tissue...

...and near-Infrared light is absorbed by **oxygenenated and deoxygenerated hemoblogin** at **850 and 760 nM**, respectively.

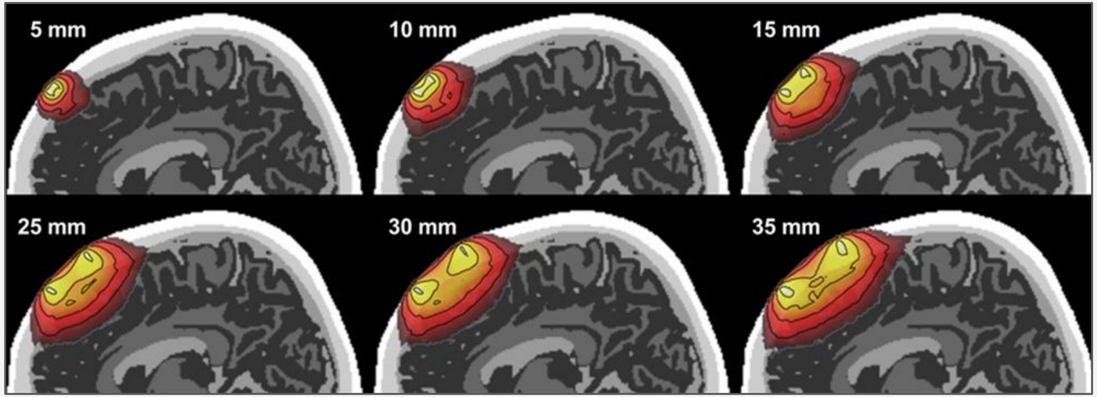


Channels, Source to Detector

NIRx

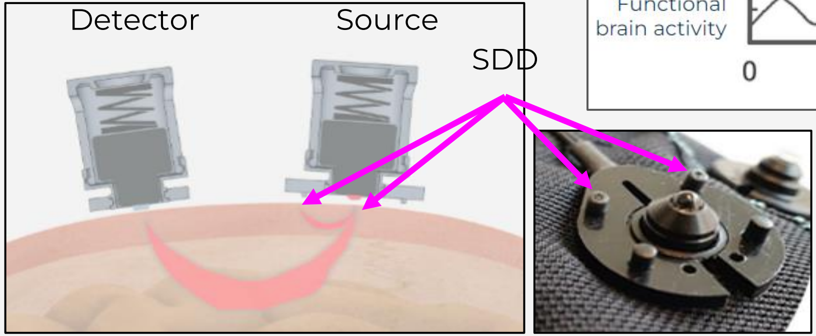


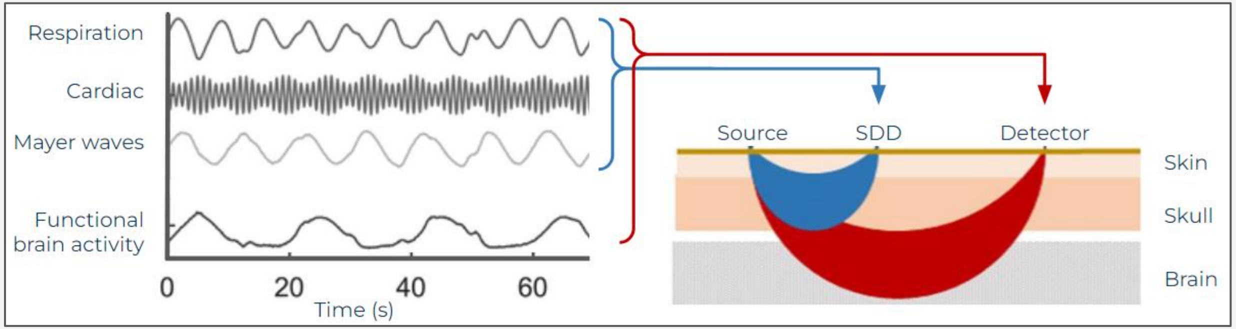
Depth of channel depends on distance between source and detector

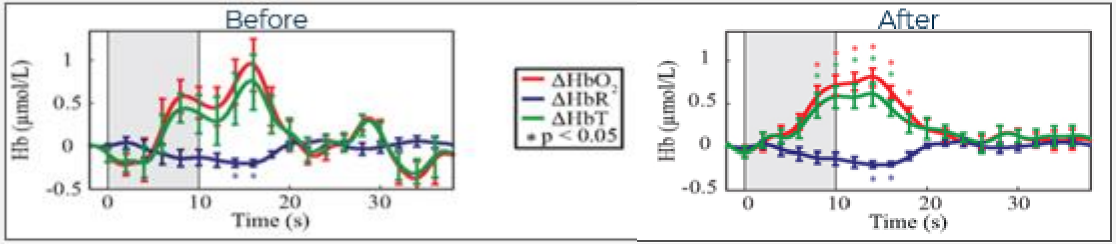


Strangman et al., 2013

Short Distance Channels



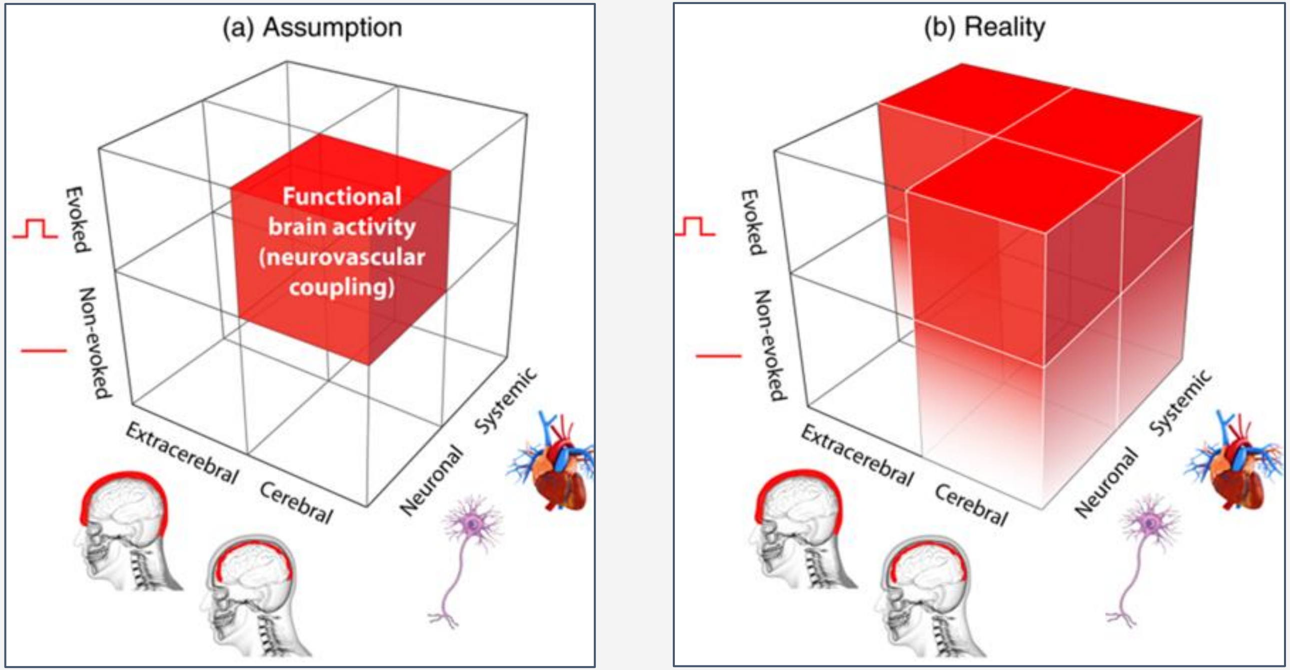




Physiological Confounds

NIRx

Sources of the hemodynamic response measured with fNIRS



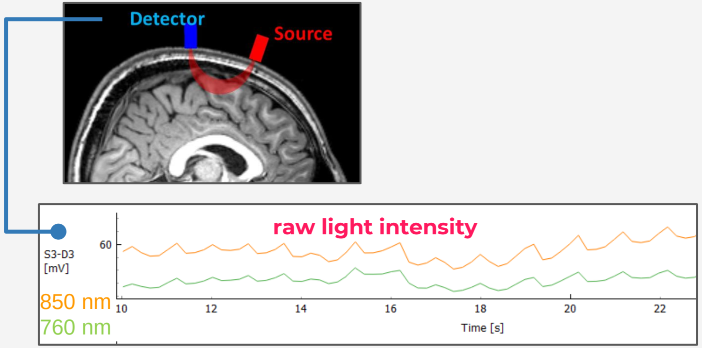
“We found that the use of SS fNIRS channels as regressors of no-interest within a linear regression model was the best performing approach examined.”

Santosa et al., 2020 Neurophotonics

Hemoglobin Concentration

NIRx

First, calculate change in
light attenuation (optical density, OD),
relative to baseline...



$$OD = -\log_{10}\left(\frac{raw}{mean\ (raw)}\right)$$

...and then, calculate change in
hemoglobin concentration (CC)
with the modified Beer-Lambert law.

$$\Delta CC = \frac{\Delta OD\ (\lambda)}{\varepsilon\ (\lambda) * d * DPF\ (\lambda)}$$

Hemoglobin concentration

Extinction coefficient

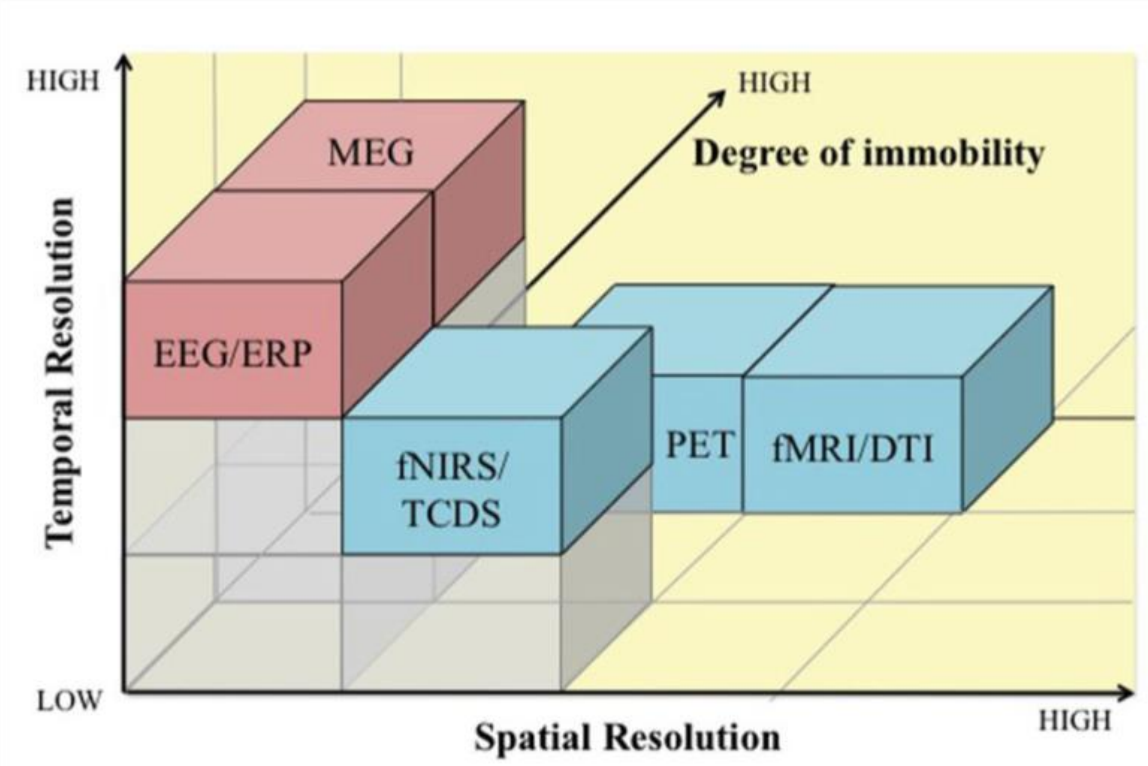
Source-detector distance

Differential pathlength factor

wavelenght

Herold et al., 2018

fNIRS in Neuroimaging



Mehta et al., 2013

fNIRS Applications

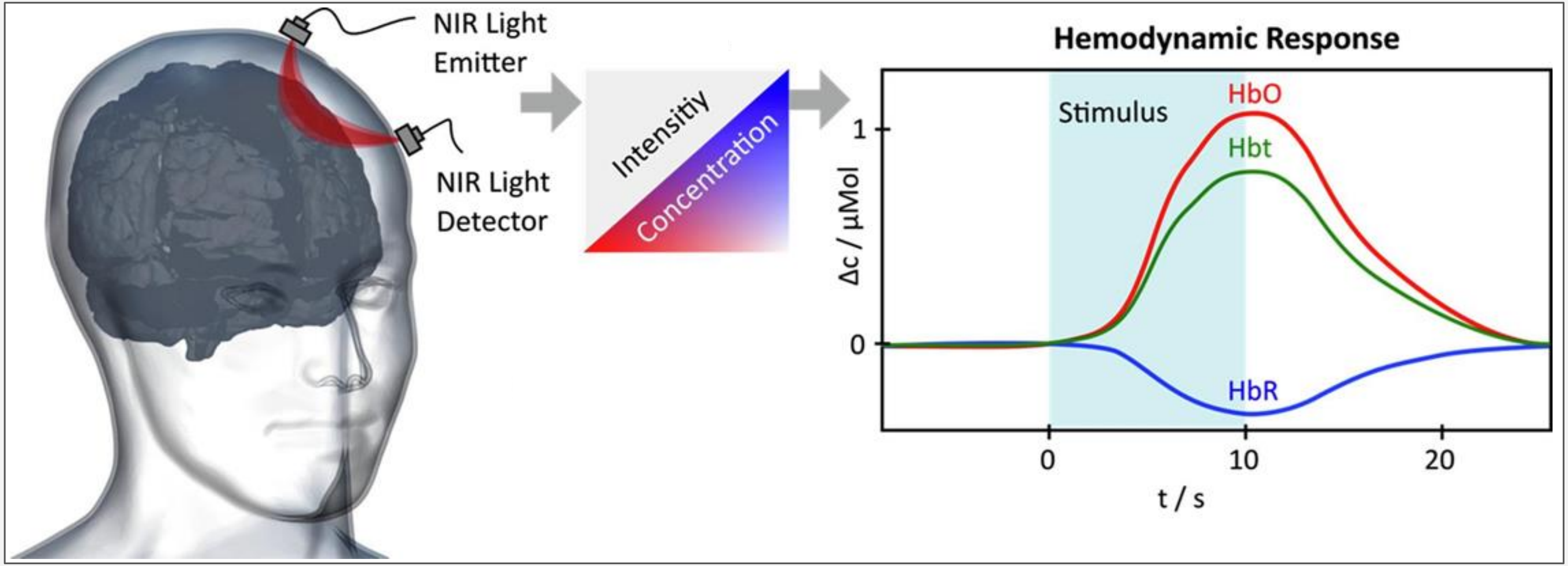
NIRx

BCI/Neurofeedback
Cognitive Disorders
Developmental Disorders
Hyperscanning (multi-subject)
Movement/Balance
Infant Monitoring
Social Interaction
Speech/Language
Stroke and Rehabilitation
Traumatic Brain Injury
Visual Impairment/Stimulation

Multimodalities:
EEG
fMRI
TMS
tDCS
EOG
Physiology
Eye-tracking
Thermal Cameras
Accelerometer
Virtual Reality

Summary and Key Takeaways

NIRx



Soekadar et al., 2021

Resources

NIRx

Videos:

- Video: Introduction to fNIRS and NIRx
- Video: 2017 Workshop - Intro to fNIRS by NIRx co-founder

Reviews

- **Scholkmann F, et al. A review on continuous wave functional near-infrared spectroscopy and imaging instrumentation and methodology. Neuroimage. 2014. doi: 10.1016/j.neuroimage.2013.05.004.
- Boas DA, et al. Twenty years of functional near-infrared spectroscopy: introduction for the special issue. Neuroimage. 2014. doi: 10.1016/j.neuroimage.2013.11.033.
- Herold F, et al. Applications of Functional Near-Infrared Spectroscopy (fNIRS) Neuroimaging in Exercise‑Cognition Science: A Systematic, Methodology-Focused Review. J Clin Med. 2018. doi: 10.3390/jcm7120466.

Best Practices

- **Yücel MA, et al. Best practices for fNIRS publications. Neurophoton. 2021. https://doi.org/10.1117/1.NPh.8.1.012101

Signal Confounds

- Tachtsidis I, Scholkmann F. False positives and false negatives in functional near-infrared spectroscopy: issues, challenges, and the way forward. Neurophotonics. 2016. doi: 10.1117/1.NPh.3.3.031405.

Short channels

- Strangman GE, et al. Depth sensitivity and source-detector separations for near infrared spectroscopy based on the Colin27 brain template. PLoS One. 2013. doi: 10.1371/journal.pone.0066319.
- Santosa H, et al. Quantitative comparison of correction techniques for removing systemic physiological signal in functional near-infrared spectroscopy studies. Neurophoton. 2020. https://doi.org/10.1117/1.NPh.7.3.035009
- Gregg NM, et al. Brain specificity of diffuse optical imaging: improvements from superficial signal regression and tomography. Front Neuroenergetics. 2010 doi: 10.3389/fnene.2010.00014.

ENLIGHTENING INNOVATION

Basics of Experimental Design

Dalila Burin, Franziska Keller
Scientific Consultants – NIRx

6.5.2025 SYNCC lectures and workshops - Warsaw

Considerations

NIRx

- **Continuous Wave**
  - No absolute information (changes relative to a given baseline)
  - Precise pathlength unknown (cannot measure time of flight)
  - Depth discrimination requires multiple source-detector separations
- **Near-Infrared Light**
  - Cortex only -> deeper areas of the brain cannot be measured
  - Spatial resolution limits identification precision of anatomical landmarks
- **Inter-subject variability**
  - If no digitizer (or individual MR scan) available, spatial registration is less precise due to, for example, between-subjects anatomical variations
  - Higher inter-subject variability as compared to fMRI for example because of possibly different signal quality

Considerations

NIRx

- **Possible artifacts**
  - Continuously detecting other sources of light (sun, room light, Motion- and Eye-Tracking systems) -> thoughtful experimental setup is necessary → detector saturation possible?
  - Motion artifacts
- **Signal Confounds**
  - Extracerebral greatly contribute to measured signal (balance: SDS and SNR)
  - Cortex evoked responses may also be contaminated with systemic signals
  - Depending on the target region, underlying anatomy may be more susceptible to systemic contamination (for example proximity of blood vessels)
- **Setup time**
  - Is extending the coverage worth the additional time needed for subject preparation and instrument setup?

Experimental Question

NIRx

An effective fNIRS experimental design begins with a clearly defined research question, and a clear need for the neuroimaging equipment being used.

This design should stem from a priori knowledge of

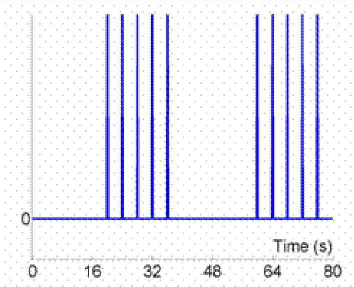
- The region of the brain being imaged
- The subject population being imaged
- The task being used in the study
- The comparison/contrast to answer the question

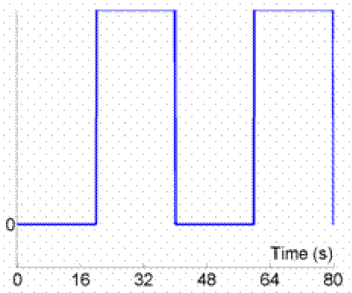
!!! Frequency of the experimental design = 1 / (stimulus duration + ISI)

Modeling the Hemodynamic Response Function

NIRx

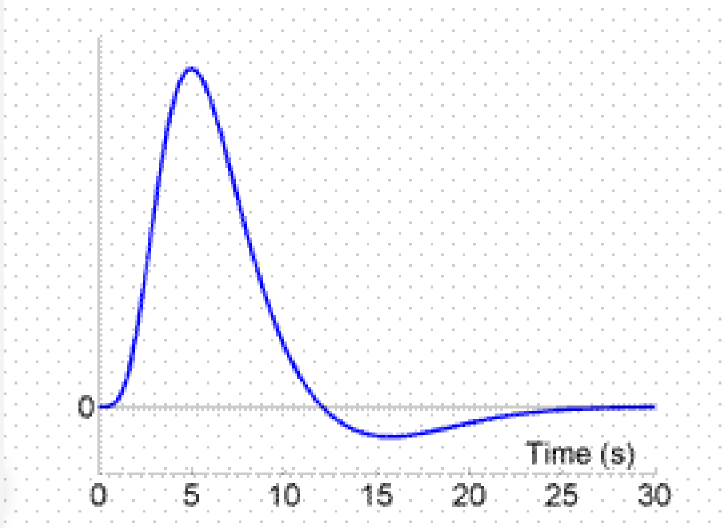
Stimulus





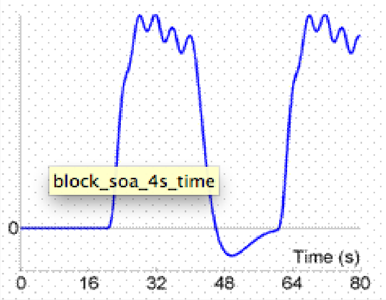
⊗

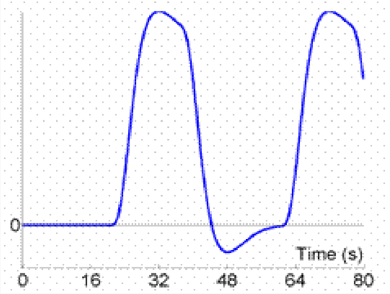
Canonical HRF



=

Predicted
fMRI Data

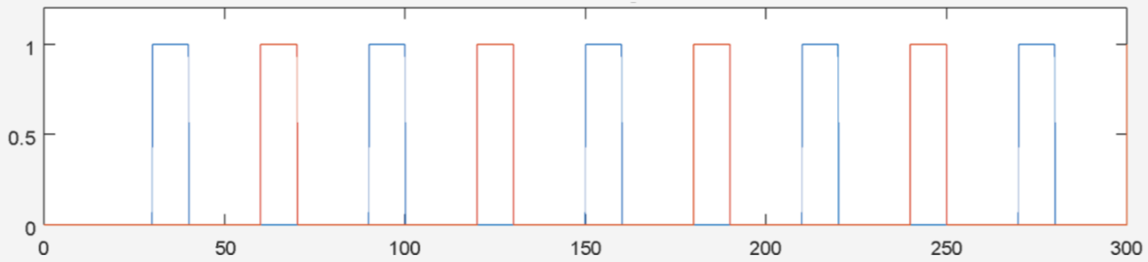


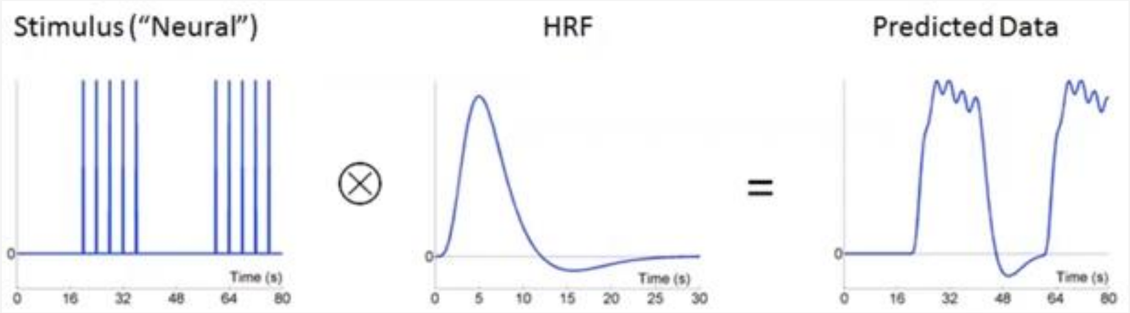


HRF is linear!

Block Design

NIRx

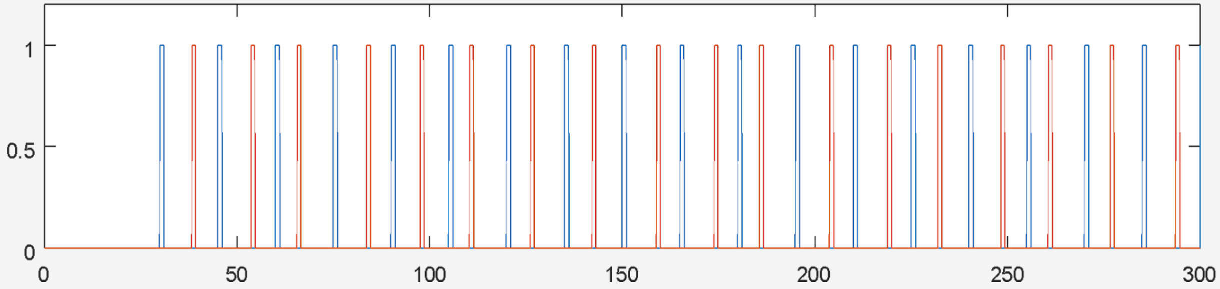


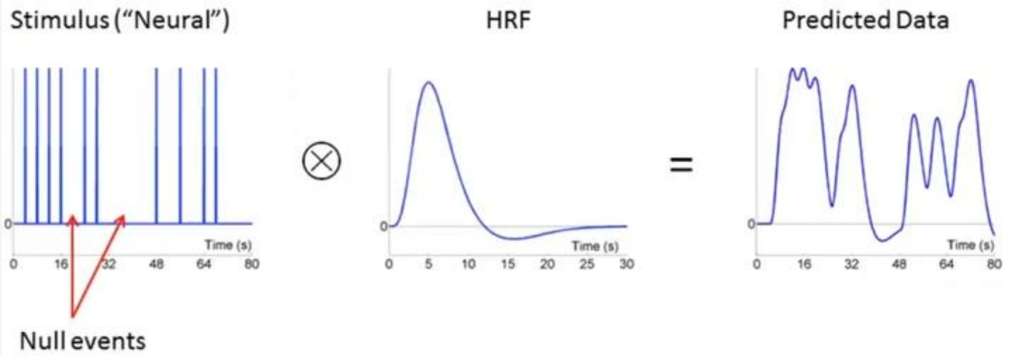


Advantages
Response adds linearly for durations between 2-50 seconds
Resting period duration should allow for time to return to baseline
Common, easy to implement

Disadvantages:
Anticipation
Participant engagement

Event-related Design



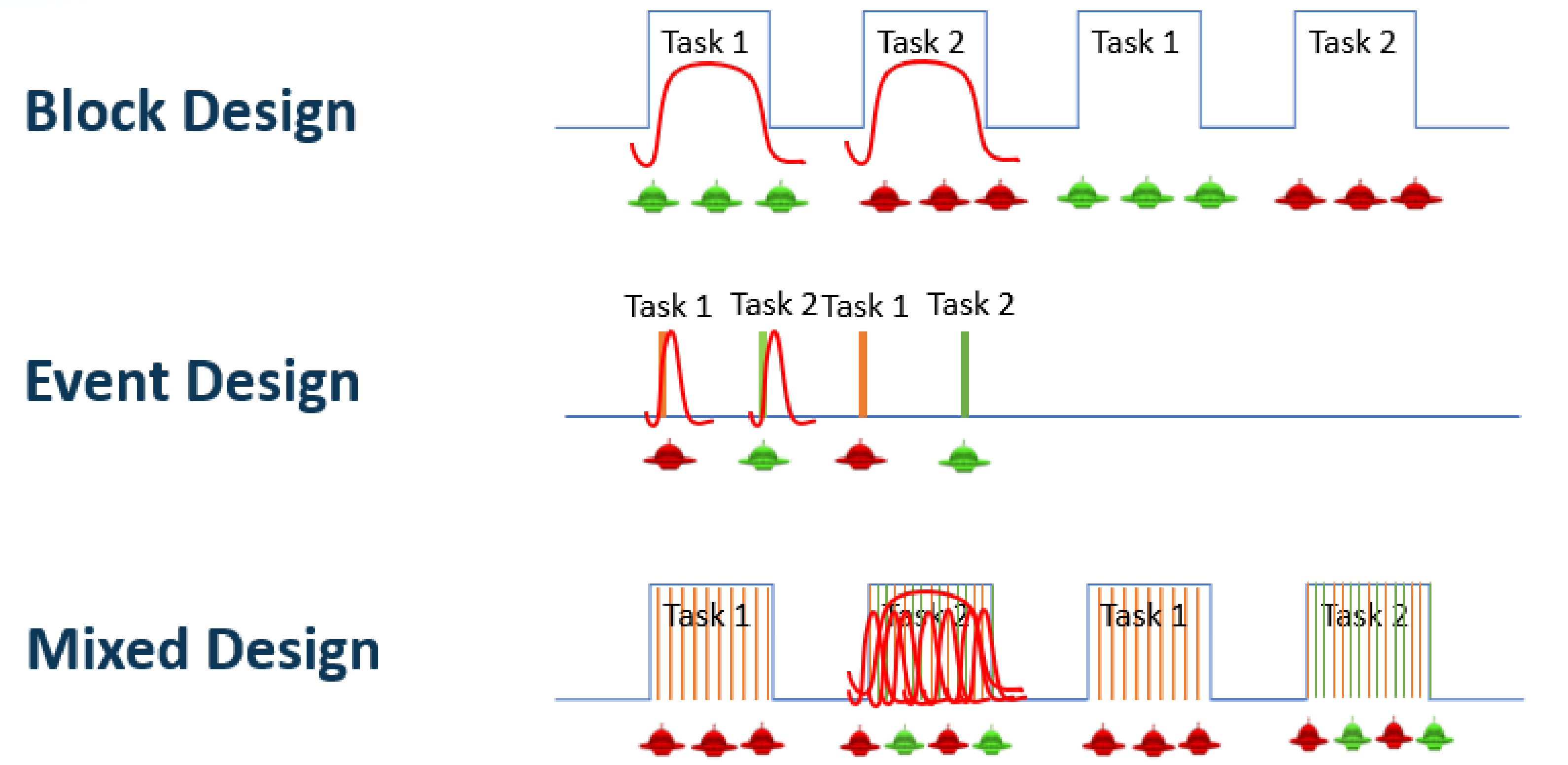


Advantages
Avoids predictability and learning effects
Ideal for certain task, ex. Go-no go

Disadvantages
Smaller amplitude response requires more trials, longer experiment time
Requires more precise of HRF because responses overlap

Mixed Design

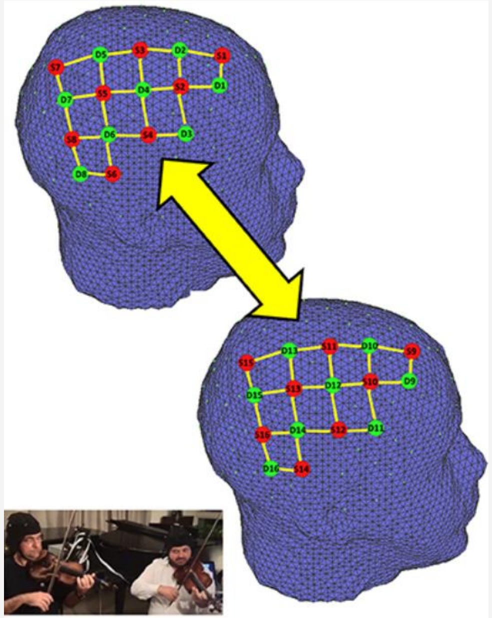
NIRx



‘Real World’ & Resting State Design

NIRx

- ‘Real World’ Design
  - Unconstrained imaging
  - Commonly used with Hyperscanning
- Resting State
  - Only ~5% of brain activation due to a task
  - Resting state data can be predictive of task performance & behavior
- Functional connectivity analysis
  - Synchronization of spatially remote neural activity
  - Illustrates how brain regions interact
  - Within a subject, between subjects



General Hints

NIRx

- Be aware of task length
    - Min ~10-15 seconds per block to capture the hemodynamic response
    - Resting blocks in between to allow the decline
- Randomizing the blocks
- More repetition is better
    - Efficiency of the design can increase with number of blocks
- Collect imaging data for each task in one session
    - Unless you need to compare the data before and after therapy etc.
    - Ensure that your task conditions and environment stay the same
- How many rest periods do you need?
    - As much as your task condition
    - You can sometimes use this rest period to see if you task is working
    - Better efficiency when the rest timing is equal to average stimulation time of the task-related conditions.

Resources

NIRx

Data and Experiment Examples:

- NIRx Support Site: Sample Experiments and Data

Videos

- **Video: Dr. Afrouz Anderson - Hypothesis Basics and Study Design
- **Video: Dr. Afrouz Anderson - Experimental Design

Guide:

- NIRx Experiment Design: Getting Started Guide

Block, Event, Mixed Design:

- Petersen SE, Dubis JW. The mixed block/event-related design. Neuroimage. 2012. 10.1016/j.neuroimage.2011.09.084

Functional Connectivity:

- Santosa et al., 2017. Characterization and correction of the false-discovery rates in resting state connectivity using functional near-infrared spectroscopy. J Biomed Opt. 2017 doi: 10.1117/1.JBO.22.5.055002.

Design Efficiency

- https://imaging.mrc-cbu.cam.ac.uk/imaging/DesignEfficiency