# Real-time fMRI & Neurofeedback

**ESCAN 2024 Tutorial**

by Florian Krause & Michael Luehrs

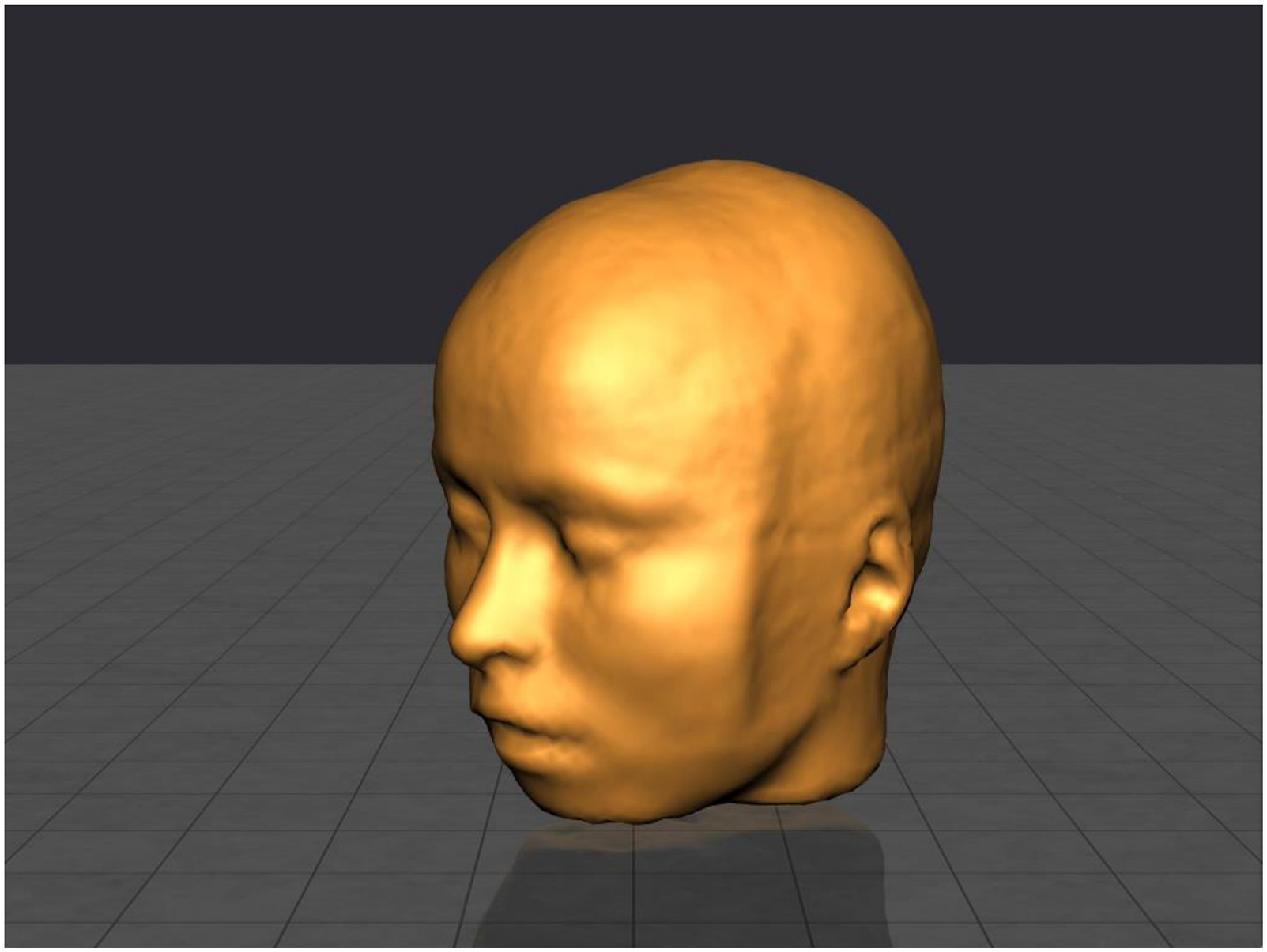
Welcome

# Tutorial overview

| | | |
|---|---|---|
| 15:30 – 15:45 | **Introduction** | *(Florian)* |
| 15:45 – 16:15 | **The real-time setup** | *(Michael)* |
| 16:15 – 16:45 | **Designing a neurofeedback study** | *(Florian)* |
| 16:45 – 17:00 | **-- Break --** | |
| 17:00 – 17:45 | **Data preprocessing & analysis** | *(Michael)* |
| 17:45 – 18:00 | **A future outlook** | *(Florian)* |
| 18:00 – 18:30 | **Q&A/discussion session** | |

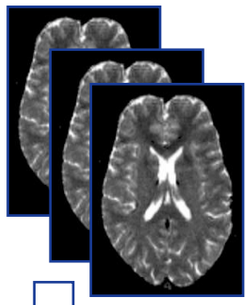
# Real-time fMRI

- Analyse fMRI data directly ***during image acquisition***



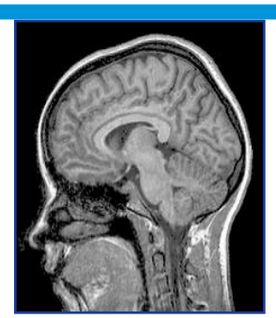
# fMRI analysis

**Recorded time series (EPI)**



Correction of head motion
Spatial and temporal filtering

Coregistration of functional and anatomical data



**Anatomical images**

Spatial normalization

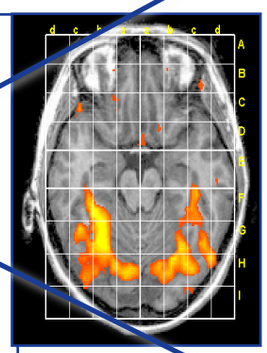
Segmentation
Cortex reconstruction

**Offline**

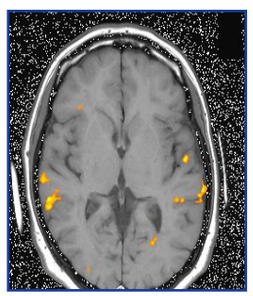
Statistical localization of brain activation, functional maps

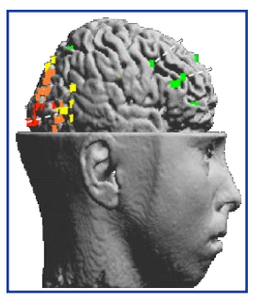
**Group analysis**
**MNI/TAL space**

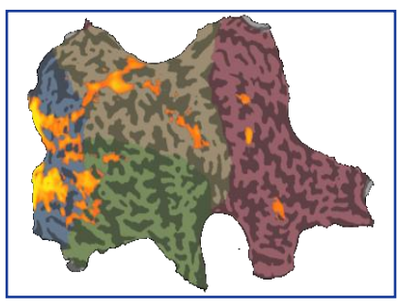
**Fixed effects**
**Random effects**



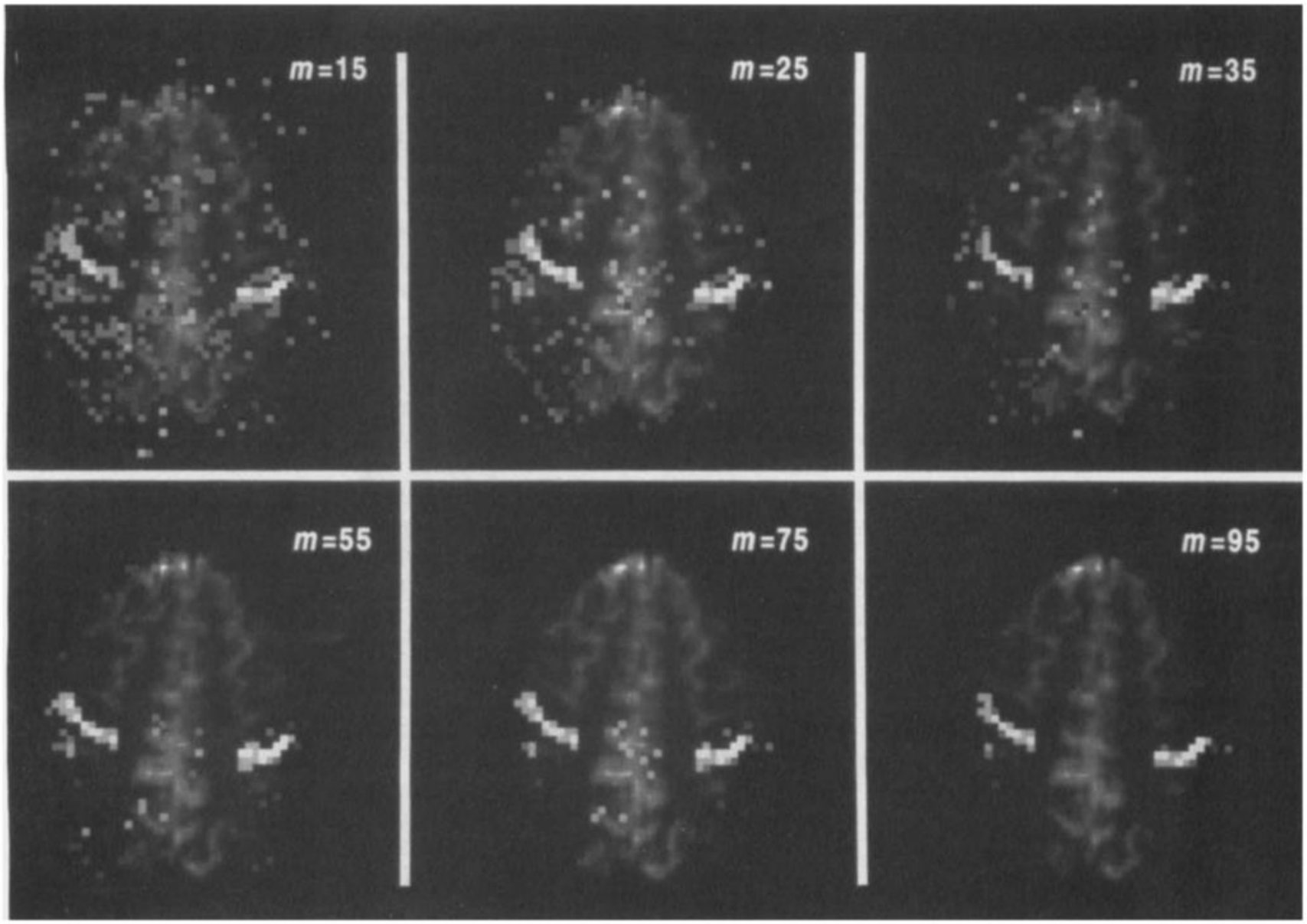
**Single subject analysis**





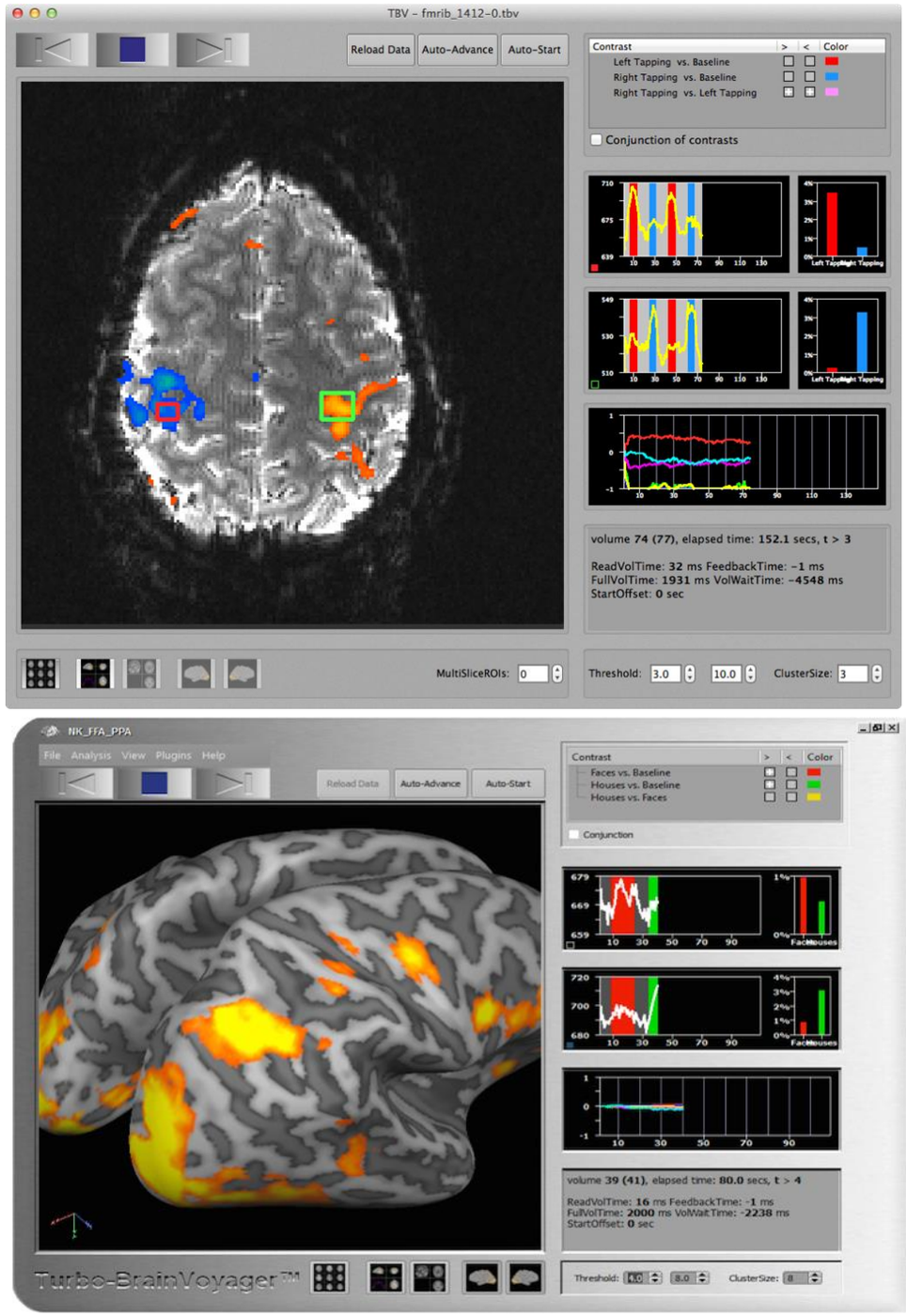


# First real-time fMRI

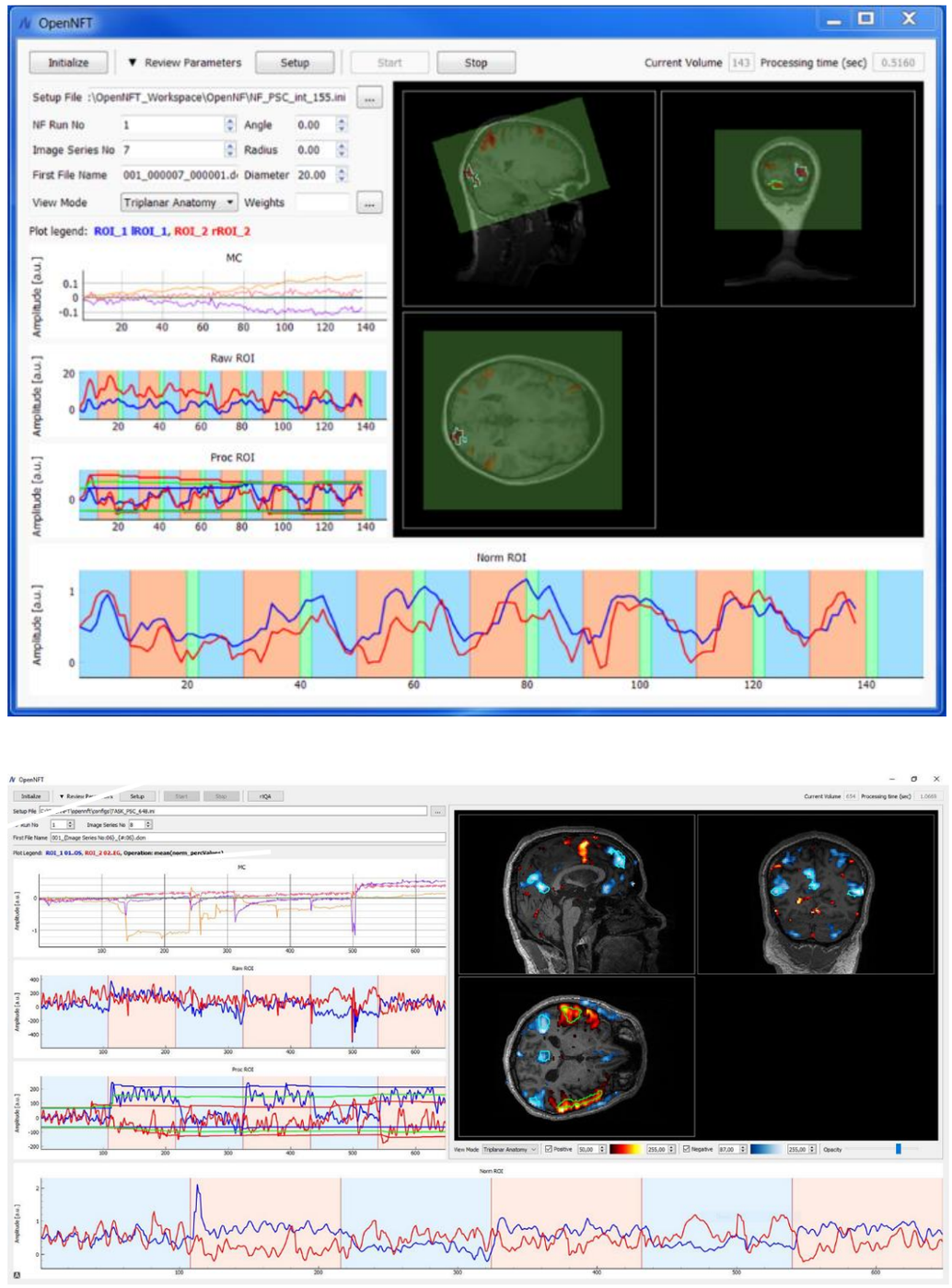



Cox et al., 1995

# Real-time fMRI today




**Turbo-BrainVoyager (Brain Innovation)**




**OpenNFT (Koush et al., 2017)**

# Real-time analysis

During functional runs, the following computations are repeatedly performed in real-time fMRI within the time window of one data point (one functional brain volume):

- Reading of EPI slices into working memory
- 3D motion correction
- 3D spatial smoothing (optional)
- Incremental statistical analysis (RLS GLM)
- Drift removal via design matrix (confound predictors)
- Incremental event-related averaging
- Thresholding, clustering and colour-coding of resulting statistical maps
- Advanced visualisations in volume and surface space (Goebel, 2001)
- Real-time ICA (Esposito et al 2003, *Neuroimage*, 20, 2009)
- Real-time SVM Classifier (LaConte et al., 2007; Sorger et al., 2010)
- Real-time RSA (Ciarlo et al., 2022)

# Real-time data export

MRI console computer (GE, PHILIPS, SIEMENS)

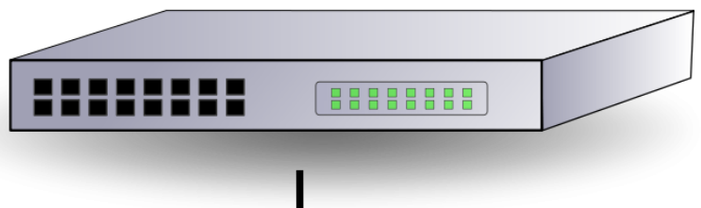

IP: 192.168.1.1

Real-time data analysis computer

IP: 192.168.1.2

Both computers have to be in the same network to access the shared folder provided by the Turbo-BrainVoyager computer. The folder can be reached on the defined location.

Network connection



Shared folder “rtfmri”

Location: \\192.168.1.2\rtfmri

# Applications of real-time fMRI

- Allows for ***quality assurance***:
  - How much head motion?
  - Are statistical maps and time courses o.k.?
  - Stop scanning or repeat runs

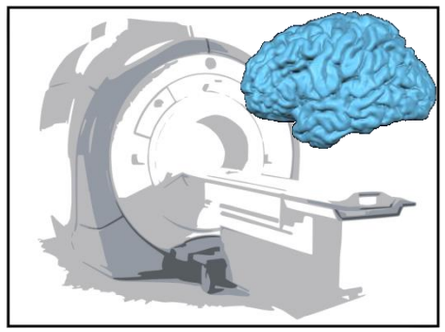
- Allows for ***adaptive*** fMRI experiments:
  - The decision when to start the next condition/block of an experiment can be based on observed levels of activity in brain areas (reflecting e.g. learning)

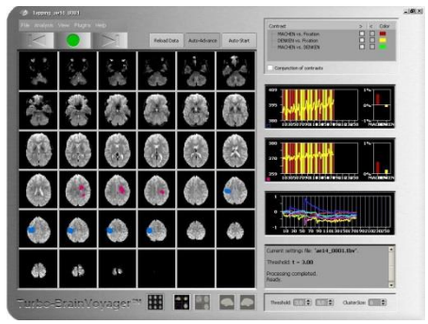
- Prerequisite for advanced applications, such as ***Brain-Computer Interfaces (BCI)***

# Real-time fMRI for BCI

**Real-time data export**

**MRI**





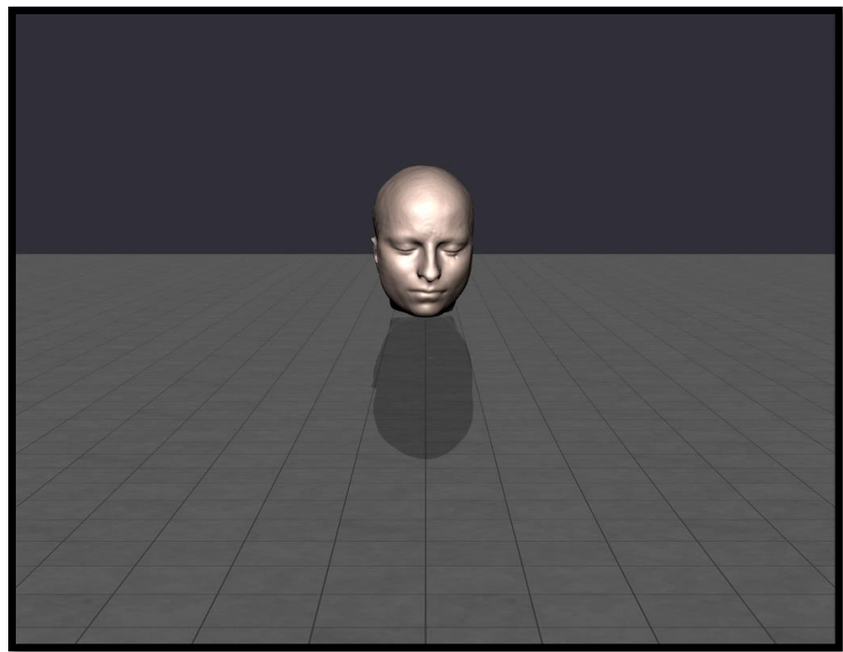
**Real-time data analysis**

*decoder / translator*

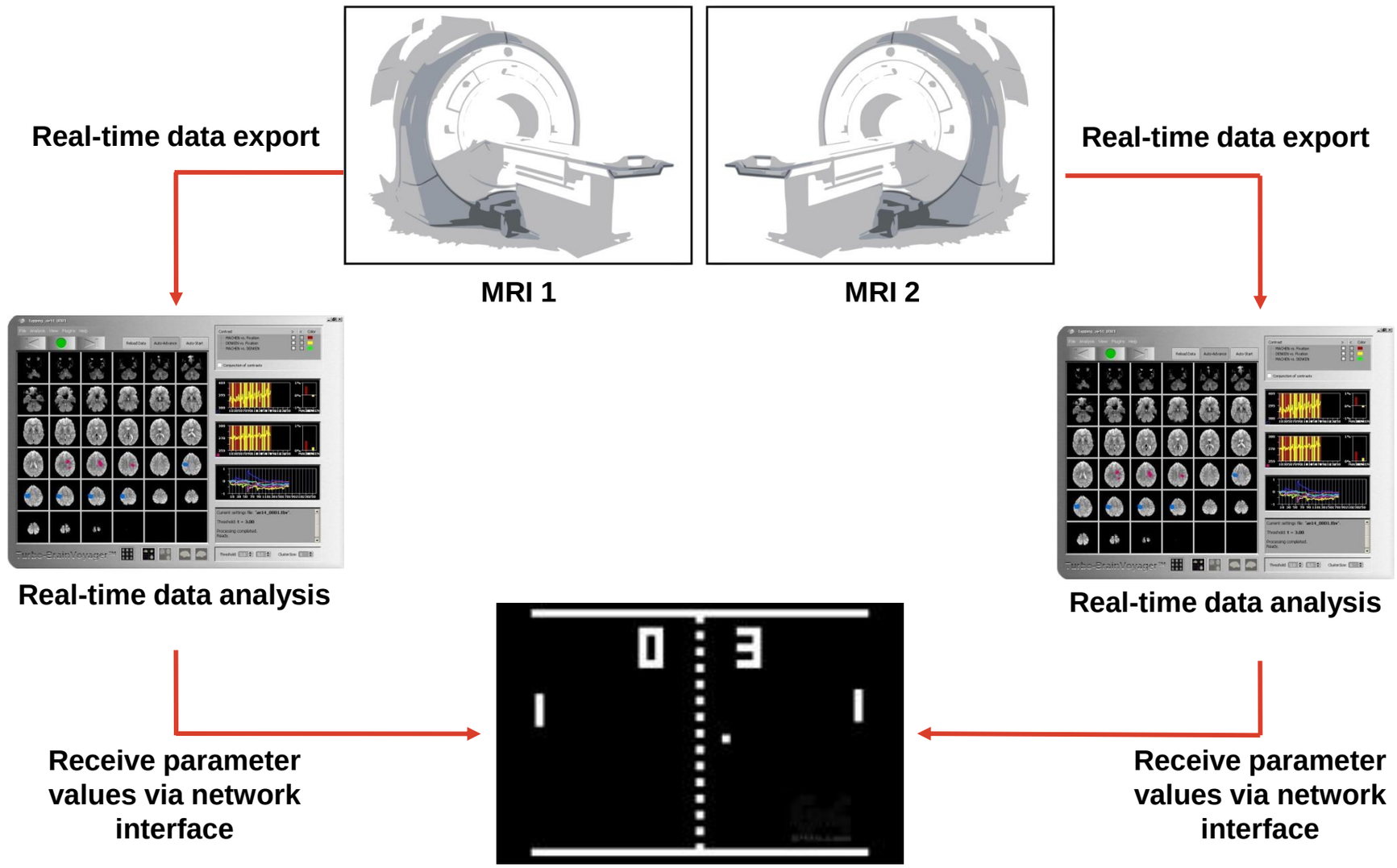
**BCI**

*optional: effect feedback*

“E”



# Hyper Scanning

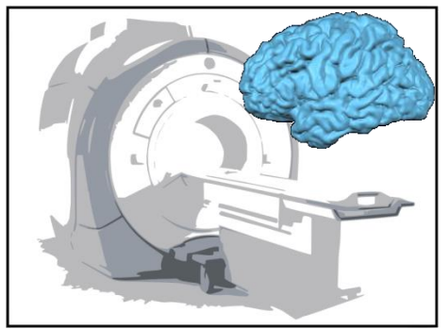


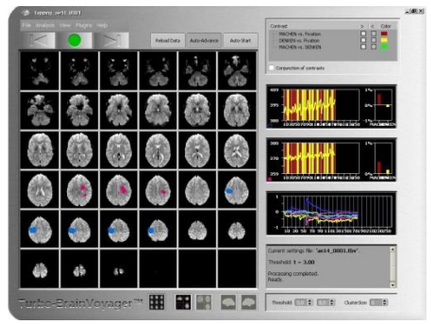

Goebel et al. 2004

# Real-time fMRI for Neurofeedback

**Real-time data export**

**MRI**





**Real-time data analysis**

*brain activity derived signal*

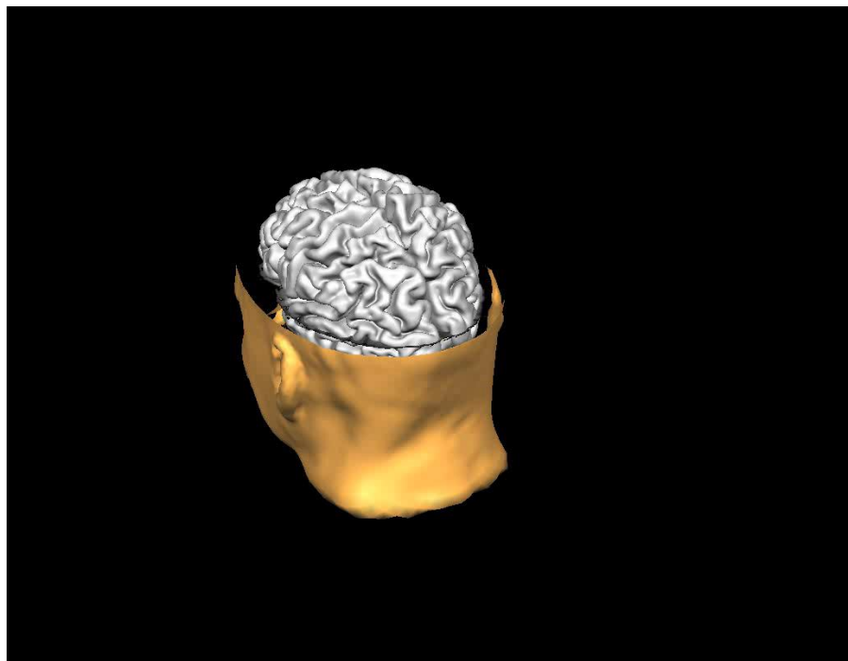
**Neurofeedback**

*decoder / translator*

**BCI**

*optional: effect feedback*

"E"

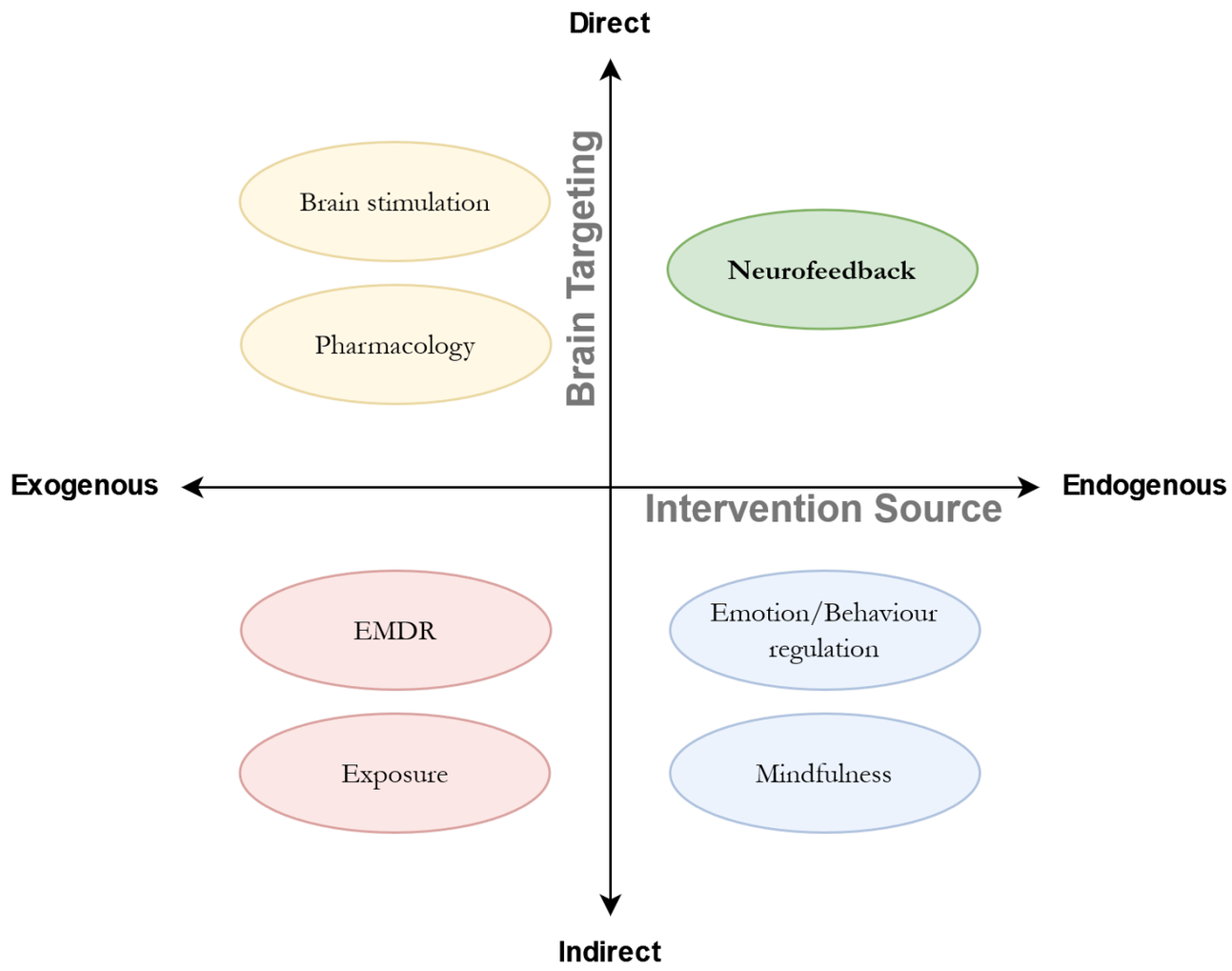


# Neurofeedback

- Form of biofeedback in which an individual is informed about a signal from their brain to facilitate ***self-regulation of neural substrates*** that underlie a specific behaviour or pathology
- Neurofeedback training may be considered to be a form of ***instrumental learning***

# Non-invasive neuromodulation

- In conventional neuroimaging, behaviour is the independent variable and the neural activity is the dependent one
- ***NF makes neural activity the independent variable, and behaviour the dependent one***



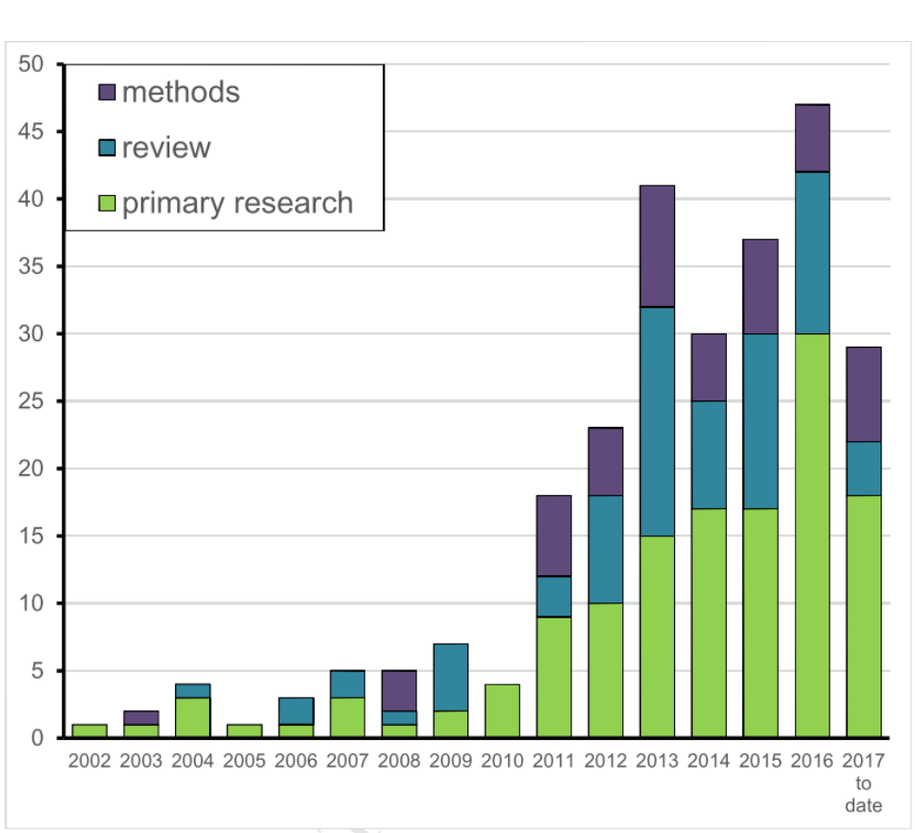

Krause et al., submitted

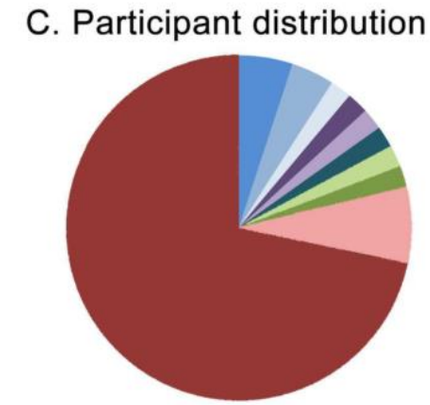
Florian Krause - Neurofeedback

# Real-time fMRI Neurofeedback (rtfMRI-NF)

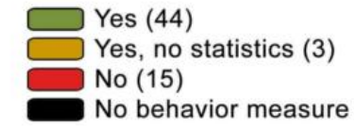
## Neurofeedback with fMRI: A critical systematic review

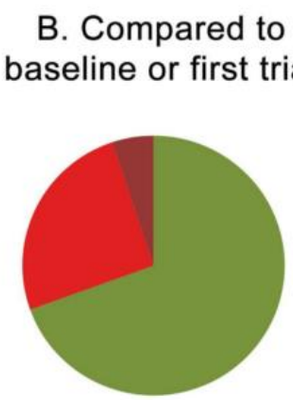
Robert T. Thibault [a, b] ✉, Amanda MacPherson [a], Michael Lifshitz [a, b], Raquel R. Roth [a], Amir Raz [a, b, c, d] ✉



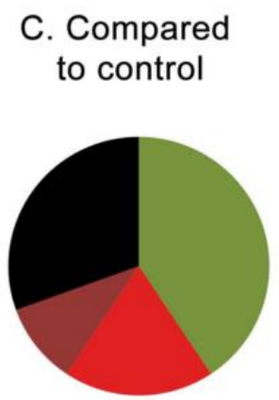



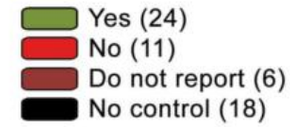


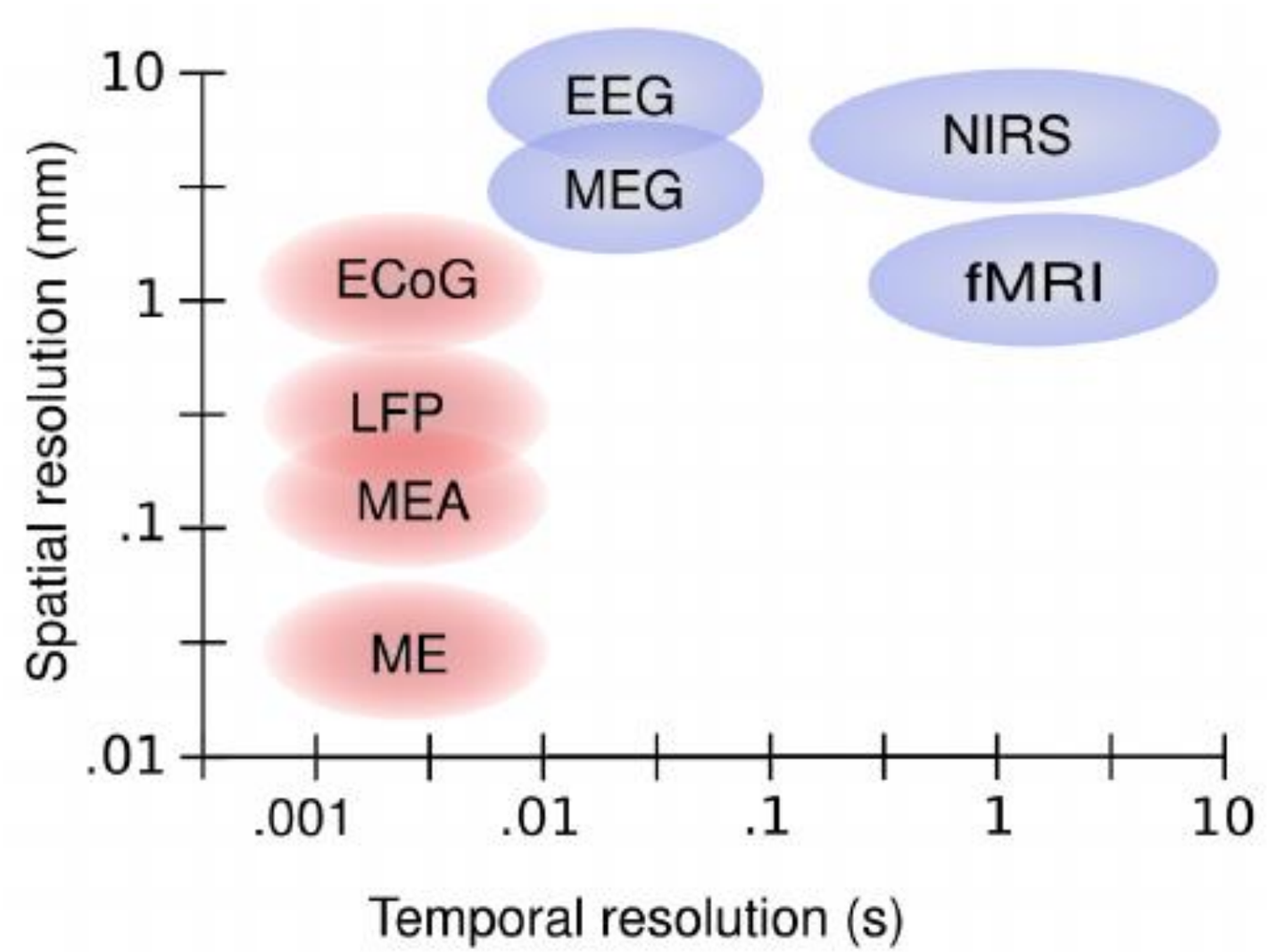




# fMR…Why?

- **Slow**
- **Loud**
- **Non-mobile**
- **Low availability**
- **(Unnatural) Lying position**
- **Expensive**

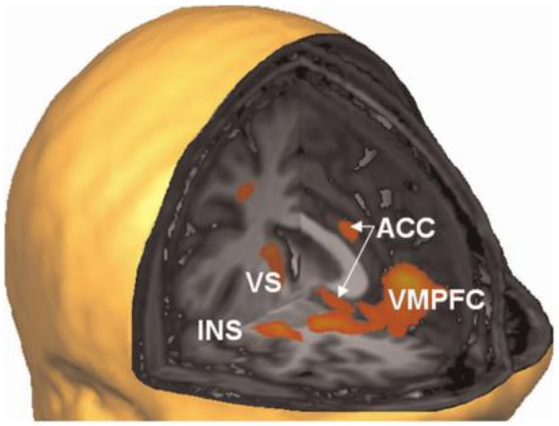


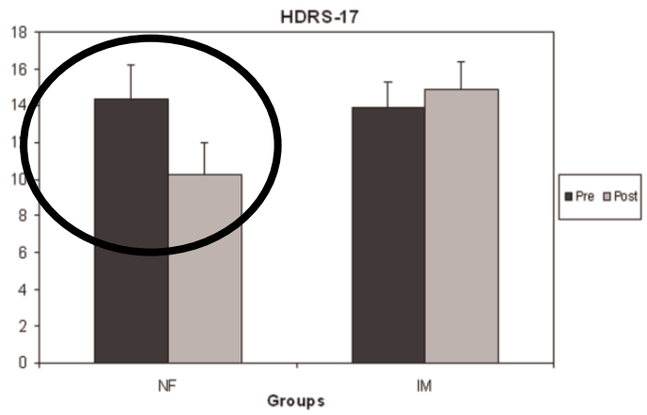

van Gerven et al., 2009

# rtfMRI-NF for specific brain areas

## Real-Time Self-Regulation of Emotion Networks in Patients with Depression

David E. J. Linden[1,2,3]*, Isabelle Habes[1,3], Stephen J. Johnston[4], Stefanie Linden[5], Ranjit Tatineni[6], Leena Subramanian[1], Bettina Sorger[3], David Healy[1,6], Rainer Goebel[3]

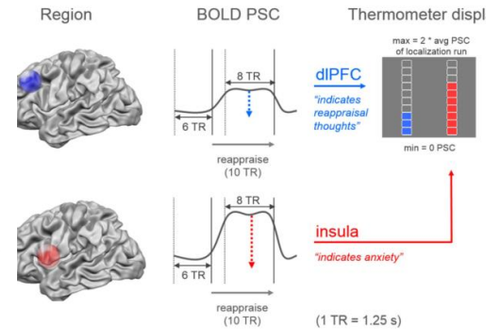


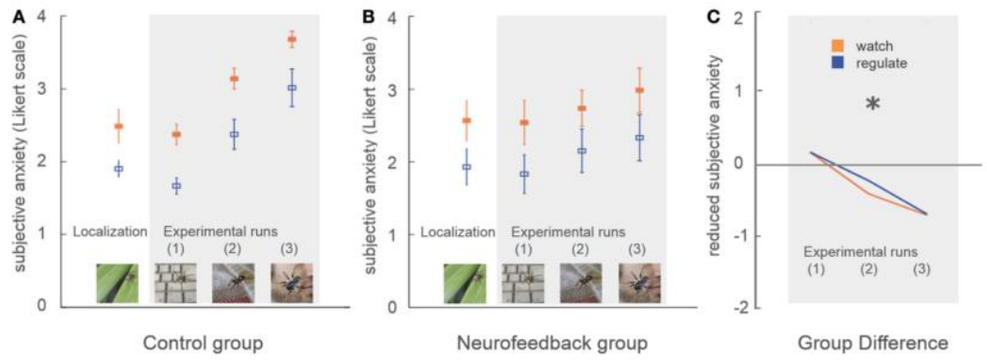




## fMRI neurofeedback facilitates anxiety regulation in females with spider phobia

*Anna Zilverstand[1,2]*, Bettina Sorger[1], Pegah Sarkheil[1,3] and Rainer Goebel[1,4]*

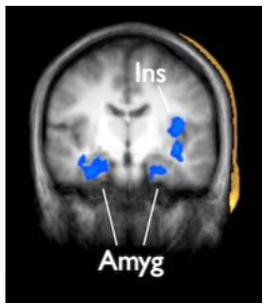
[1] Department of Cognitive Neuroscience, Maastricht University, Maastricht, Netherlands, [2] Department of Psychiatry, Icahn School of Medicine at Mount Sinai, New York, NY, USA, [3] Department of Psychiatry, Psychotherapy and Psychosomatics, RWTH Aachen University Hospital, Aachen, Germany, [4] Department of Neuroimaging and Neuromodeling, Netherlands Institute for Neuroscience, Amsterdam, Netherlands

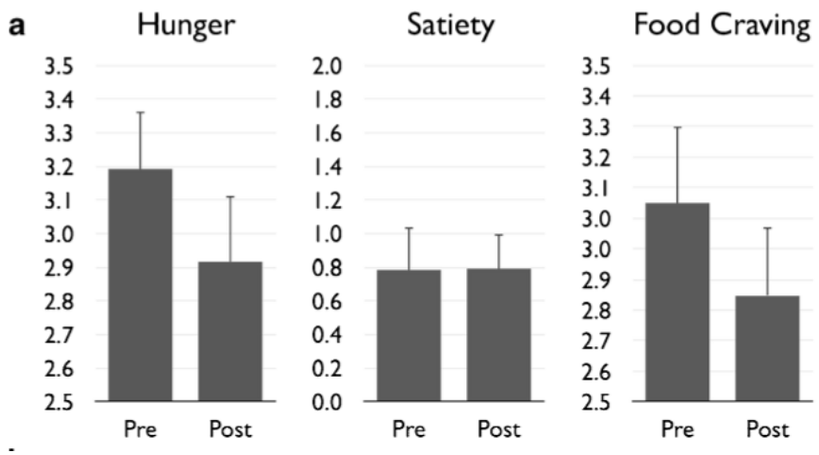



## Neurofeedback of visual food cue reactivity: a potential avenue to alter incentive sensitization and craving

Niklas Ihssen[1,2] · Moses O. Sokunbi[1,3,4] · Andrew D. Lawrence[1] · Natalia S. Lawrence[5] · David E. J. Linden[1,3]




## Real-Time fMRI Neurofeedback with War Veterans with Chronic PTSD: A Feasibility Study

*Mattia I. Gerin[1,2,3,4†], Harlan Fichtenholtz[5,6,7†], Alicia Roy[5,6], Christopher J. Walsh[4], John H. Krystal[5,6], Steven Southwick[5,6] and Michelle Hampson[4,6]**

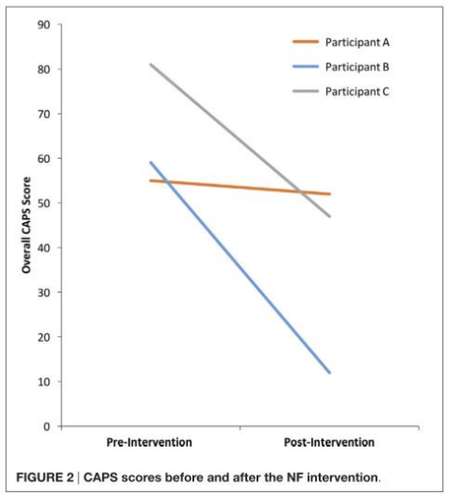
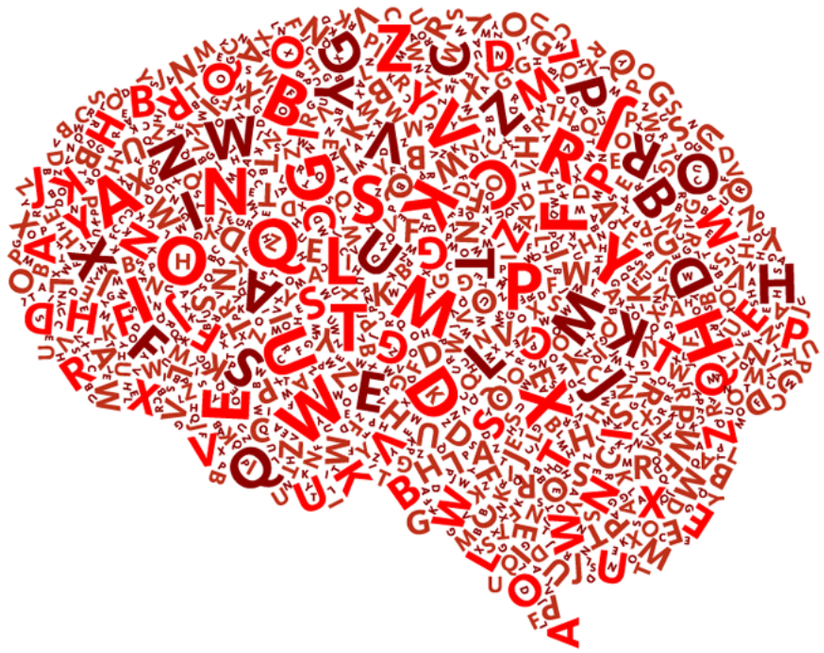
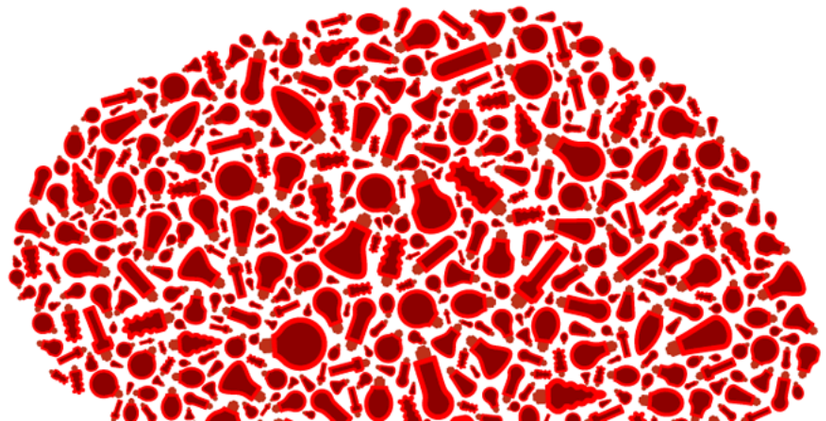


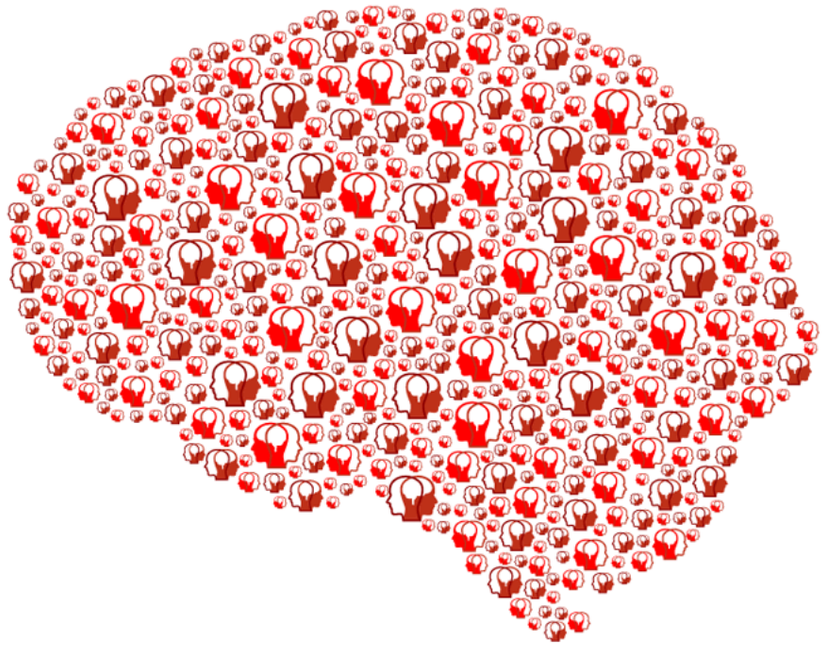

FIGURE 2 | CAPS scores before and after the NF intervention.

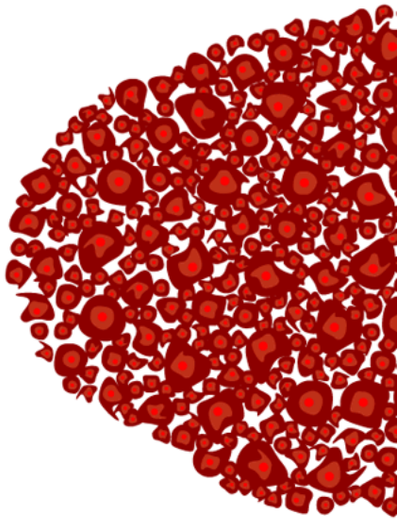


DONDERS INSTITUTE

# Questions?







Radboud University Radboudumc