



A future outlook

Florian Krause



# Open challenges and opportunities

## Where?

- Focus on neural targets
- Push beyond individual regions and simple connectivity
- Subcortical structures

## Who?

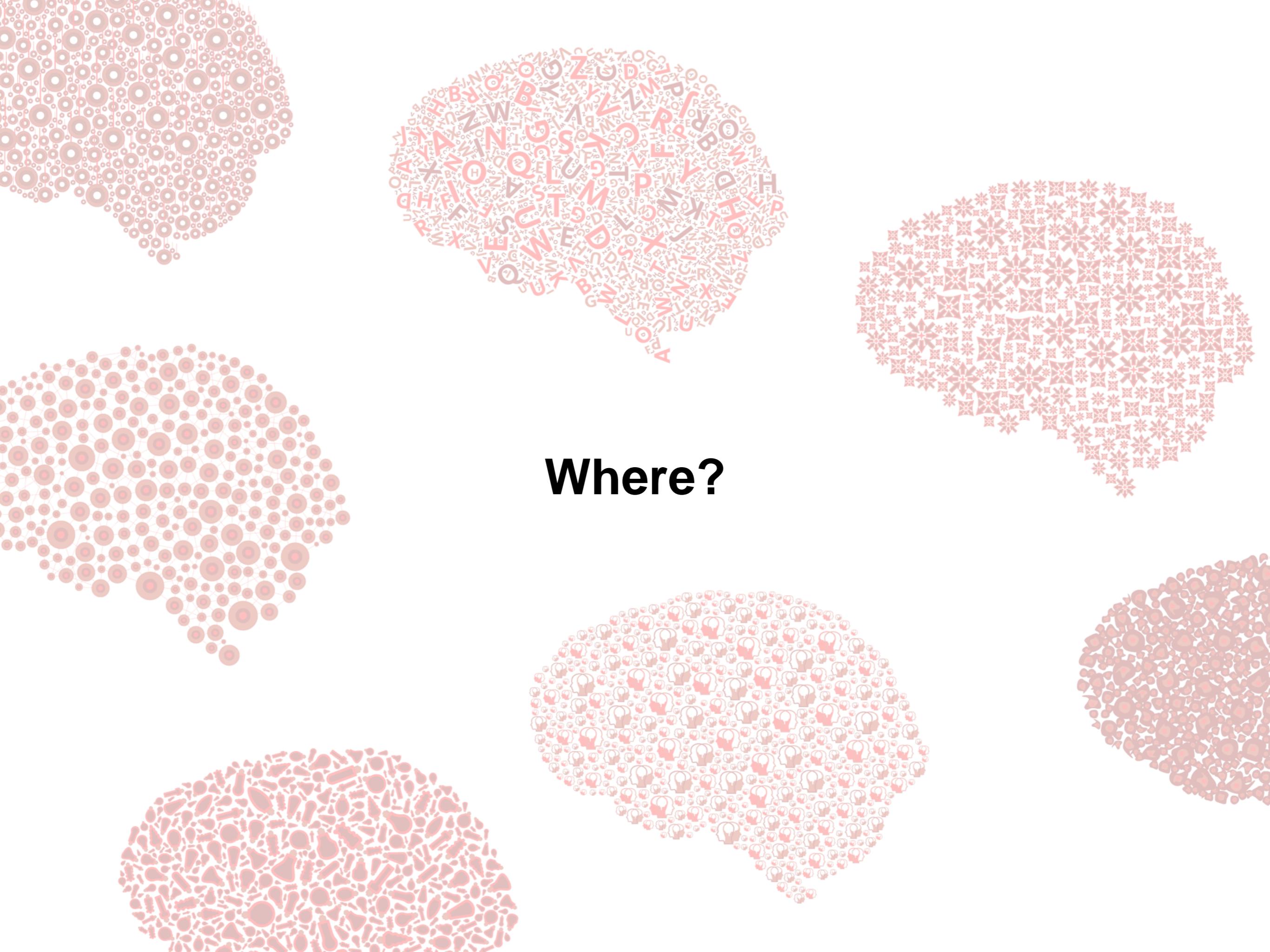
- Focus on individual
- Identify which individuals benefit from NF, understand why, increase that group

## How?

- Focus on training
- Understand training effects, optimizing procedure, finding potential transfer technologies

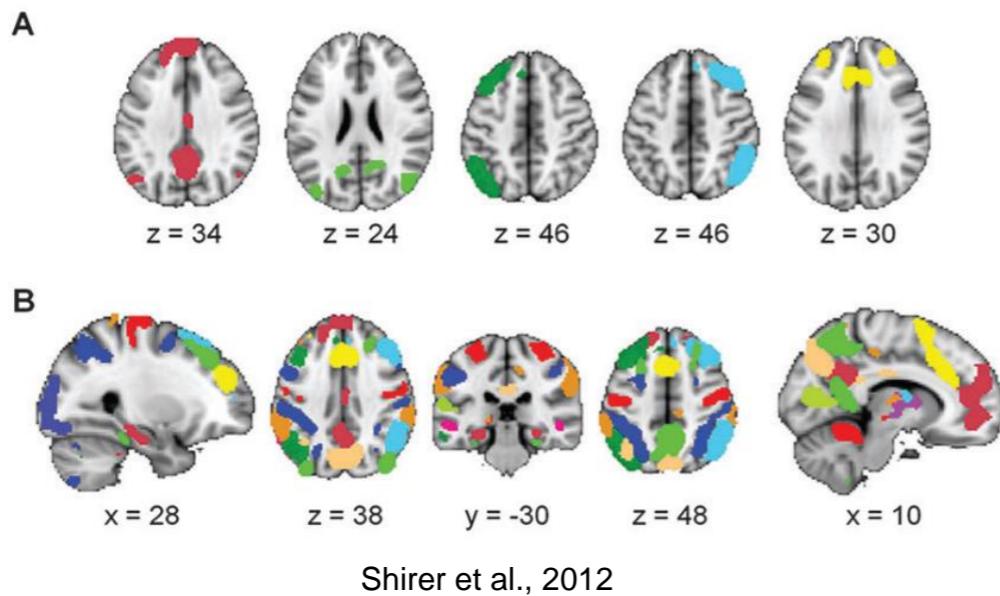
## When?

- Focus on application
- Identify best moments for intervention, combine with mHealth solutions

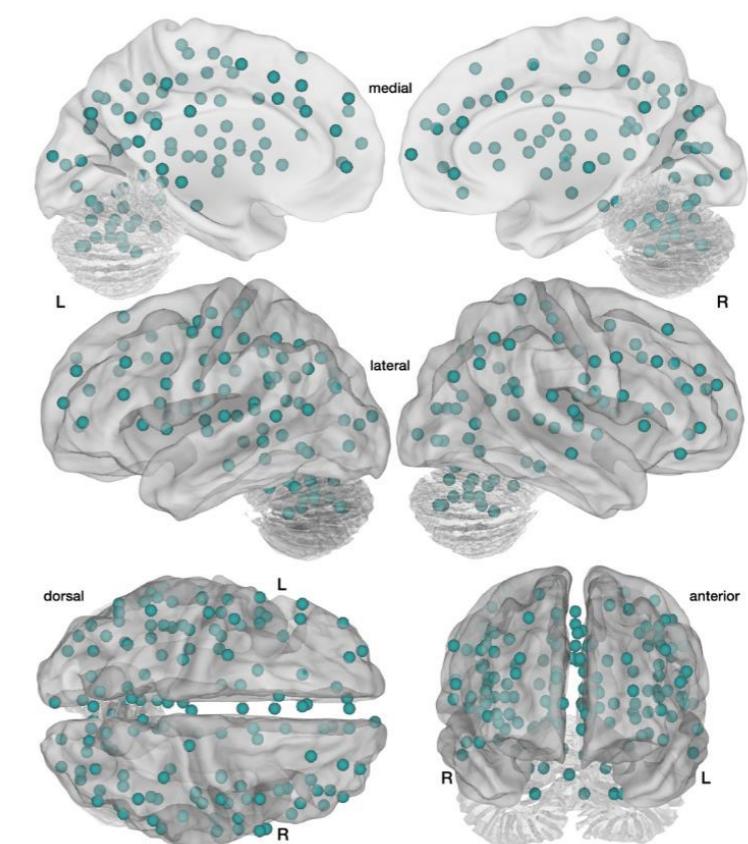


Where?

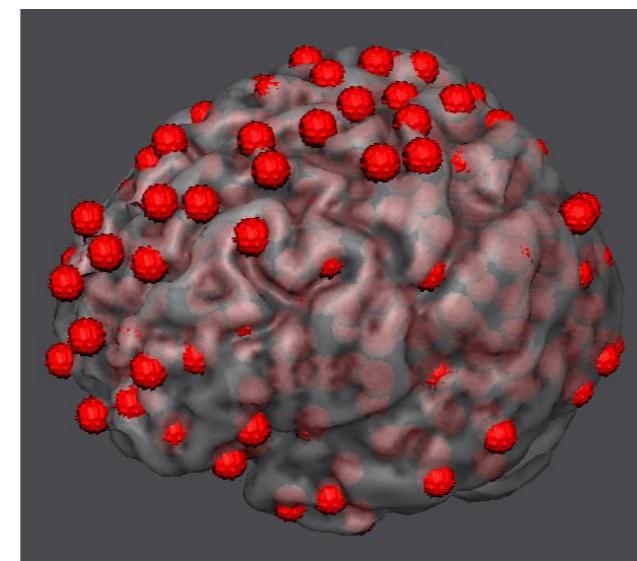
# Full-brain connectivity profiles/brain states



Shirer et al., 2012



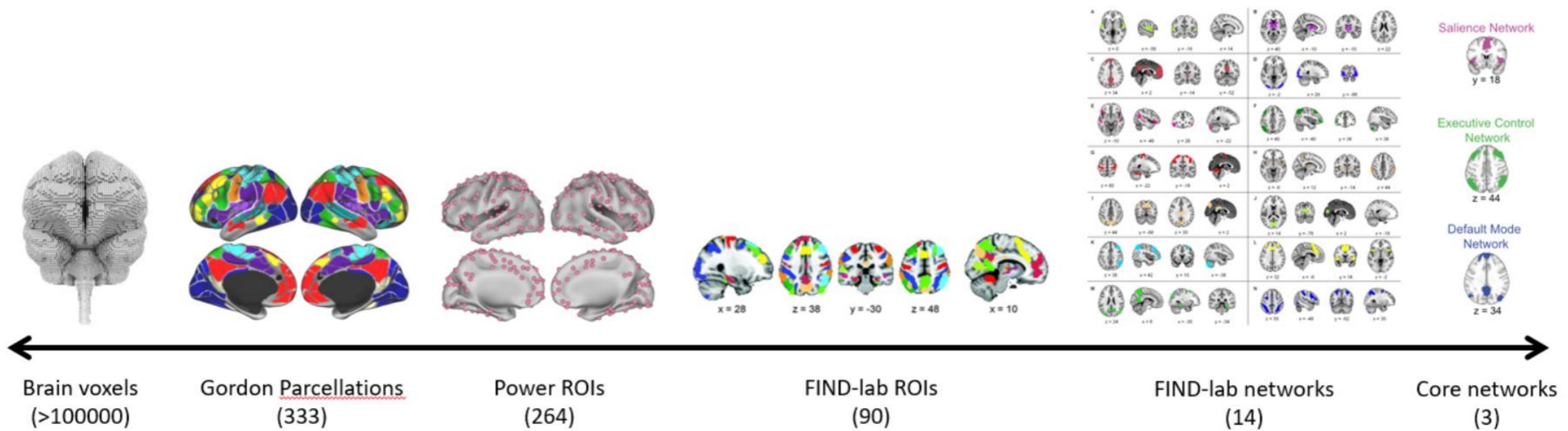
Dosenbach et al., 2010



Power et al., 2012, 2014



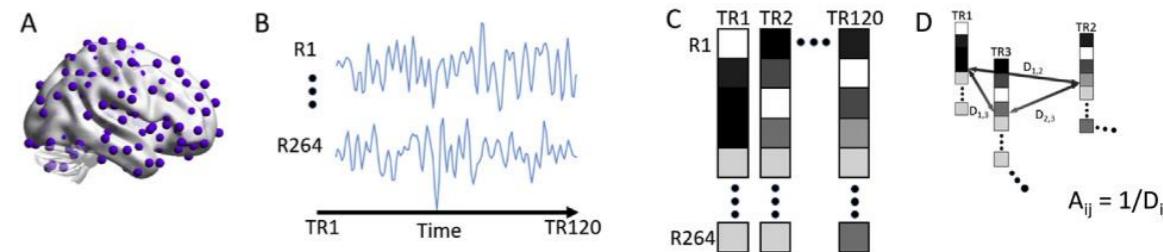
# How to sample a network/brain state?



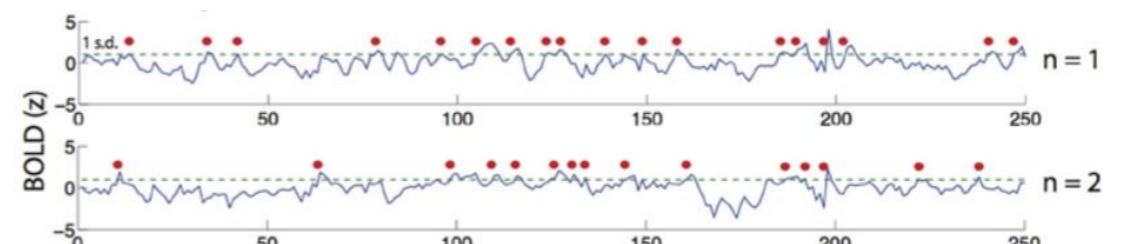
# How to define a network/brain state?

- **Current activity of all samples**

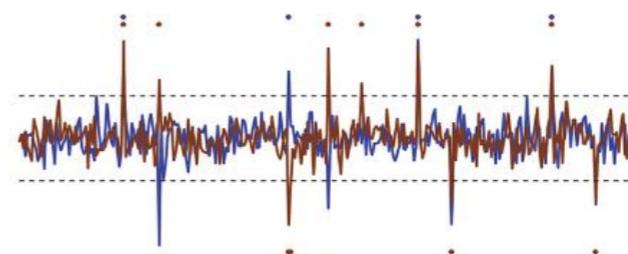
- **BOLD signal**  
(Medaglia et al., 2018)



- **Instantaneous activity**  
(Tagliazucchi et al., 2011)



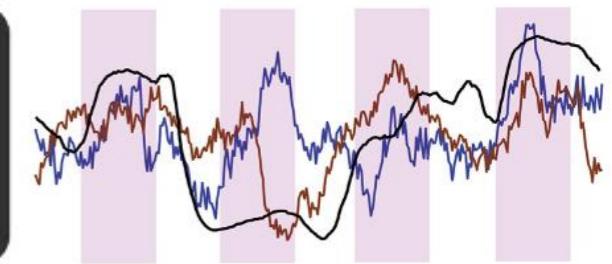
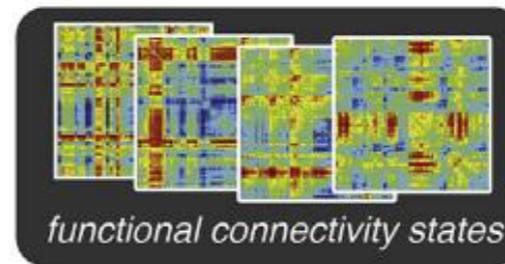
- **Transient activity**  
(Karahanoğlu et al., 2013)



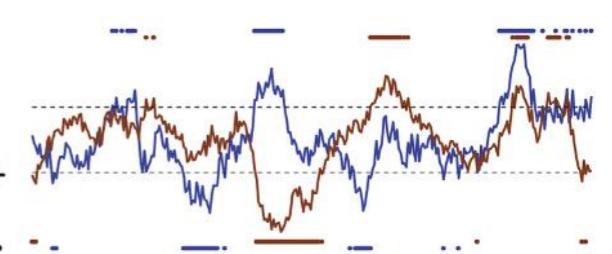
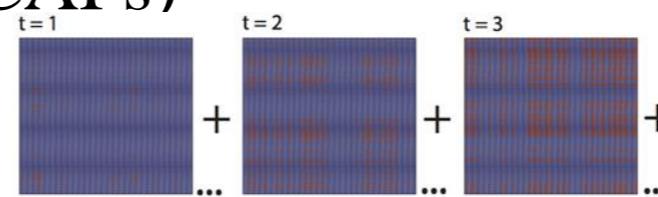
## How to define a network/brain state?

- **Current functional connectivity between all samples**

- Sliding window correlations  
(Hutchison et al., 2012)

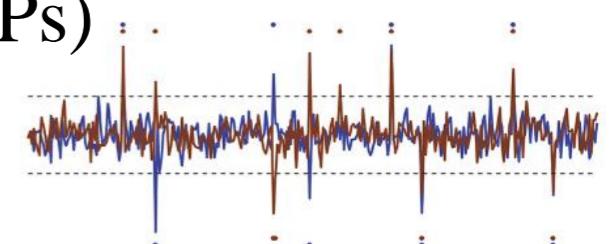


- Co-activation patterns (CAPs)  
(Liu & Duyn, 2013)

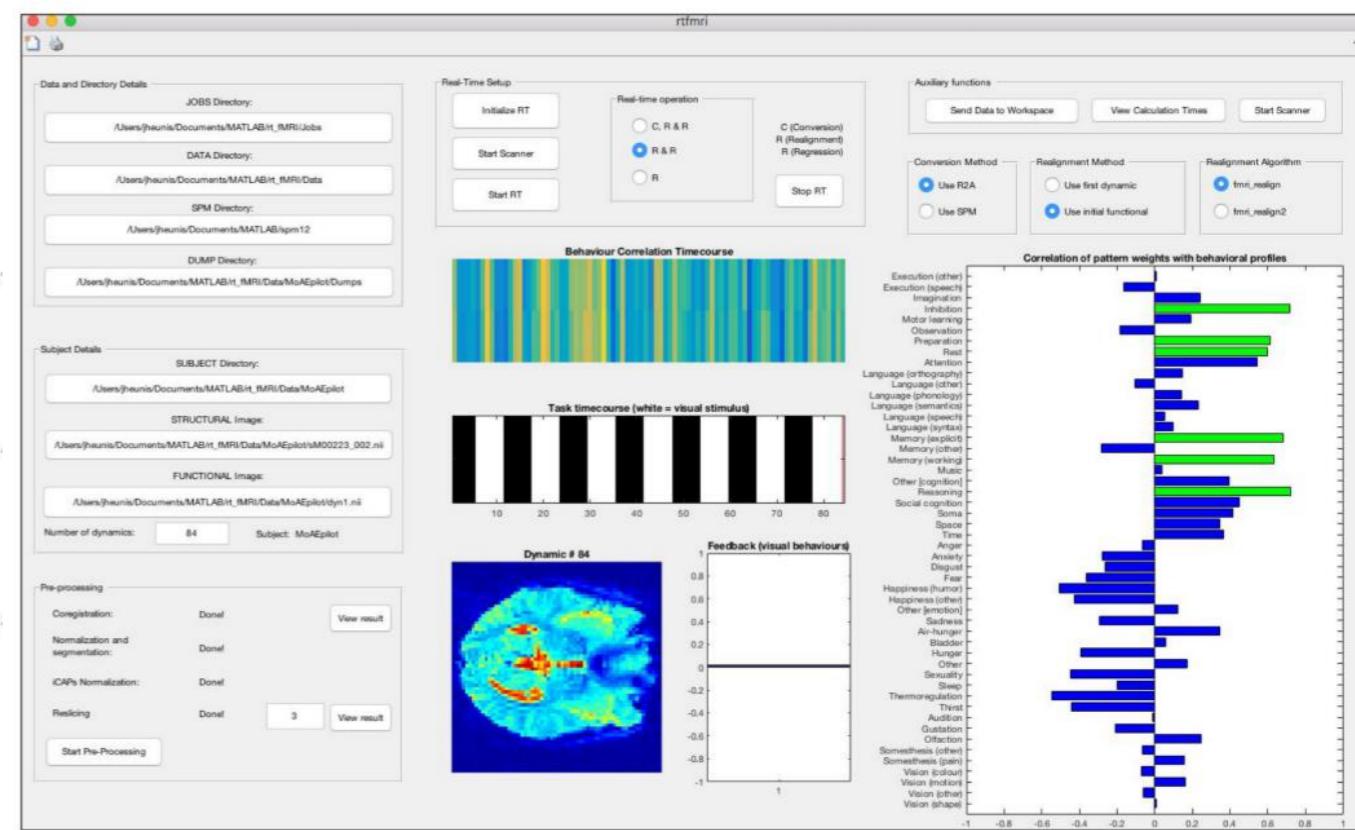
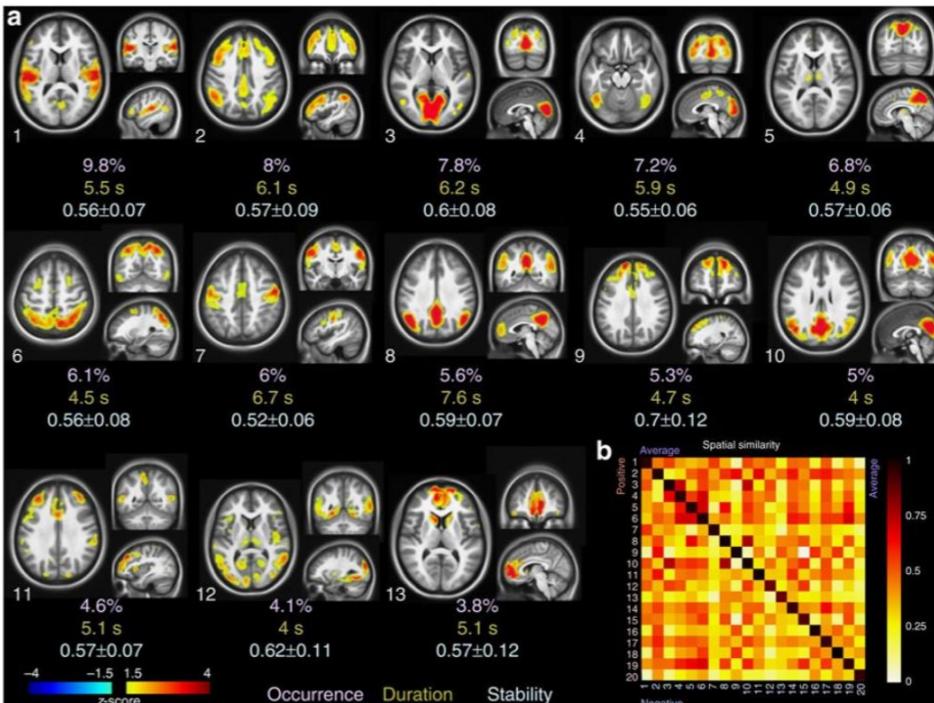
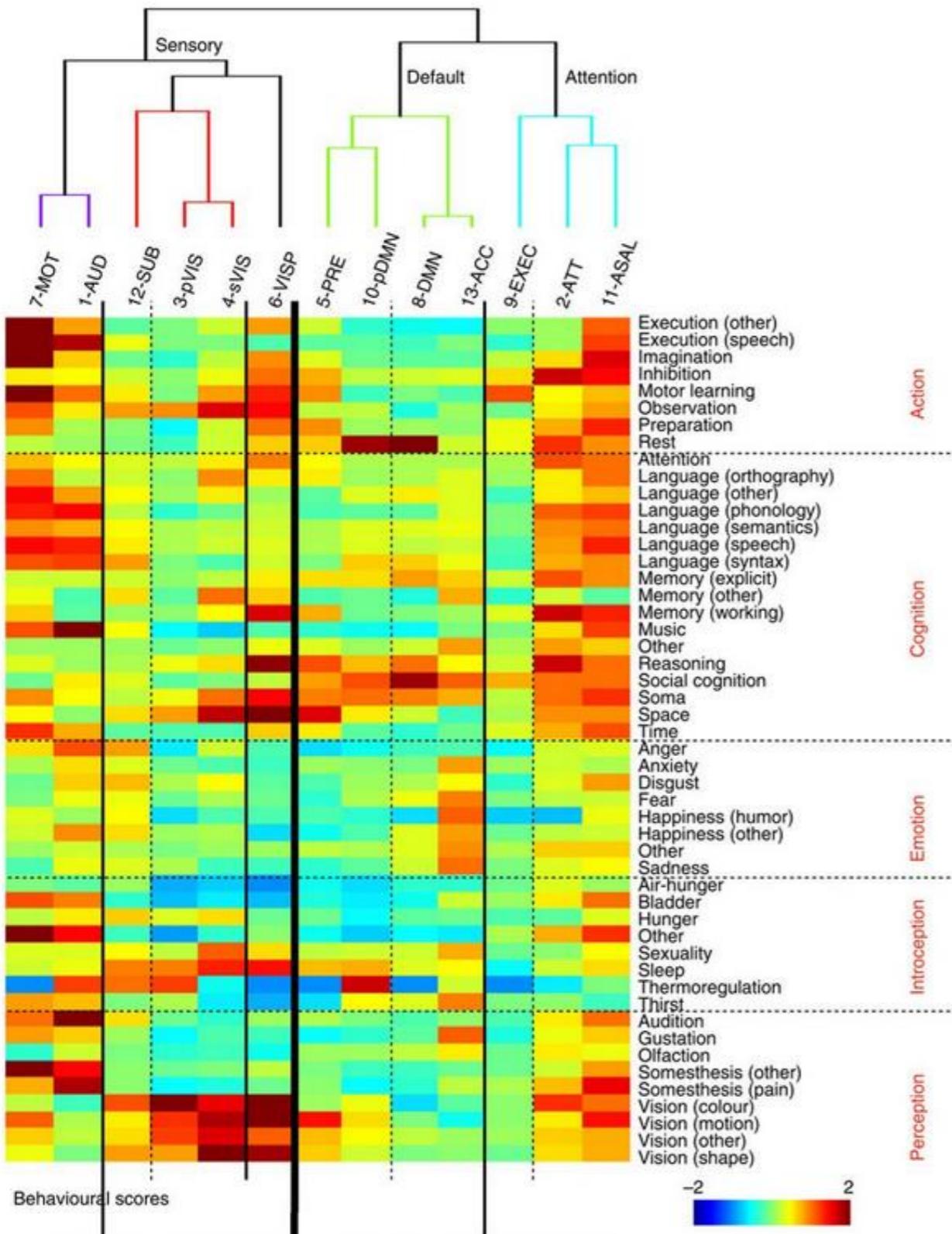


- Innovation-driven co-activation patterns (iCAPs)  
(Karahanoğlu & Van De Ville, 2015)

→ iCAPs-based NF (Heunis et al. 2017)



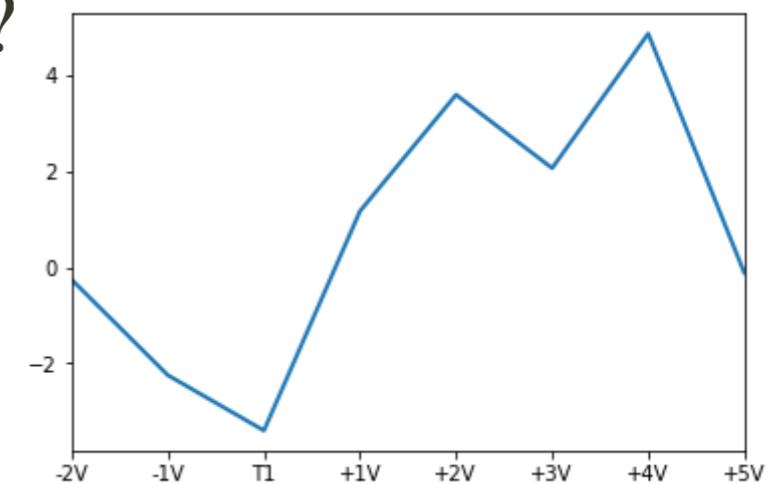
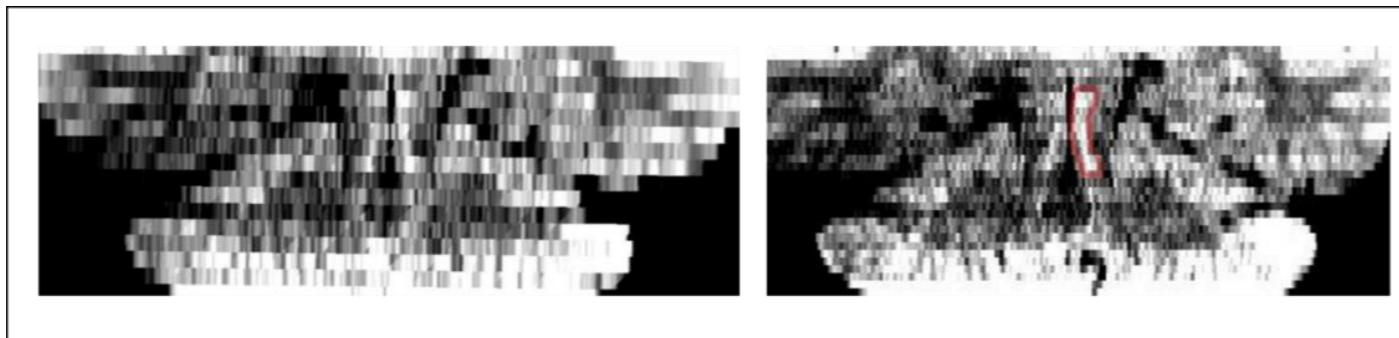
# Large-scale networks based behavioural profiles

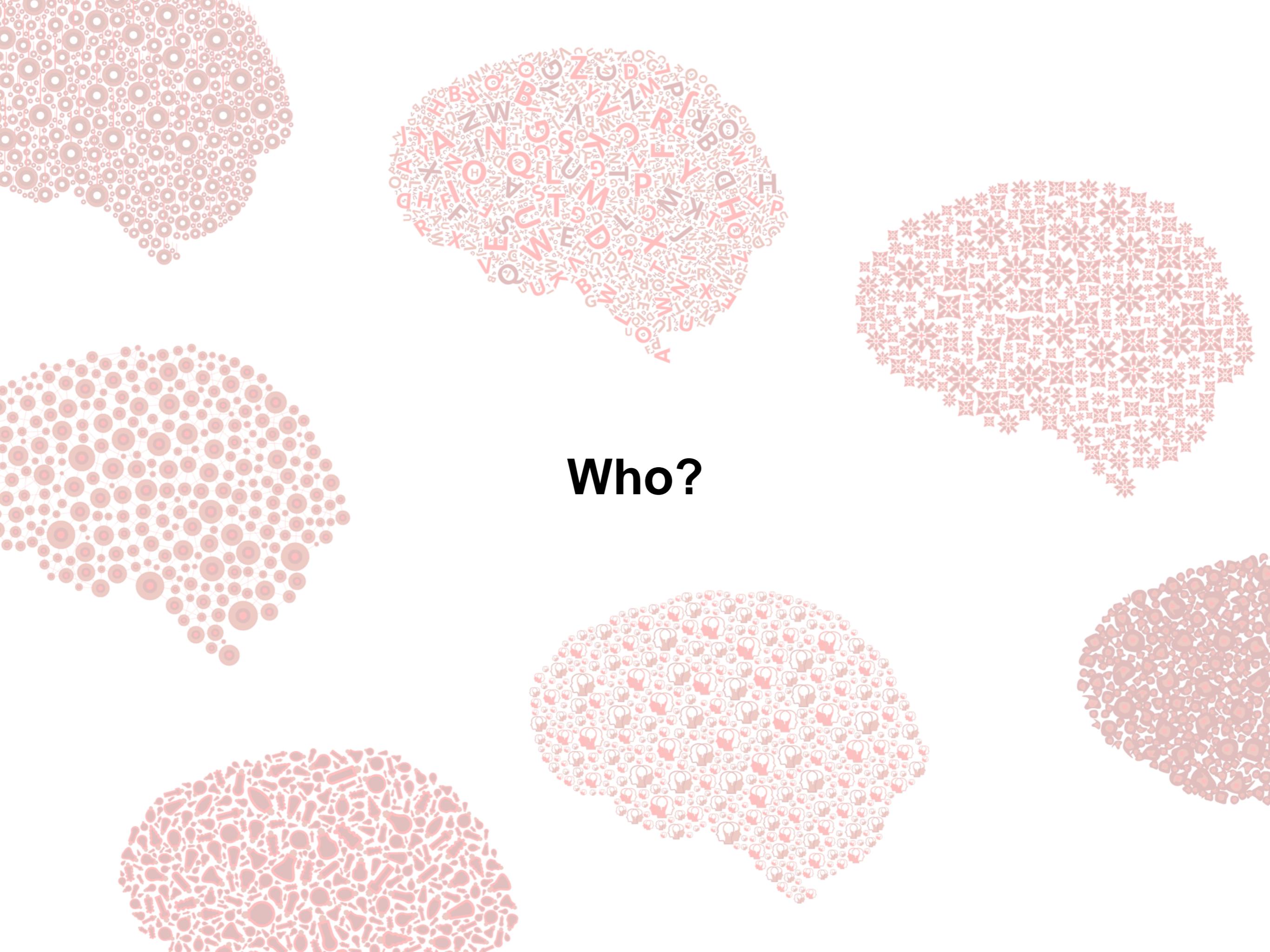




## Subcortical regions?

- Amygdala
- Insula
- Brainstem nuclei (e.g. locus coeruleus)?





Who?



## BCI illiteracy

- Current state of most NF applications:
  - It **can** work well, but not in everyone
  - Some individuals (up to 30%) do not seem to be able to do NF
  - Unclear whether this is a domain-general issue
- Two ways to go:
  1. Find a way to predict who will be able to benefit from NF
  2. Support the others better, such that they can benefit, too



# Predicting NF training outcome

- Potential targets for predictors:
  - Specific strategies
  - Individual traits
  - Behavioural/cognitive patterns in experimental tasks
  - Brain activity



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Can we predict real-time fMRI neurofeedback learning success  
from pretraining brain activity?

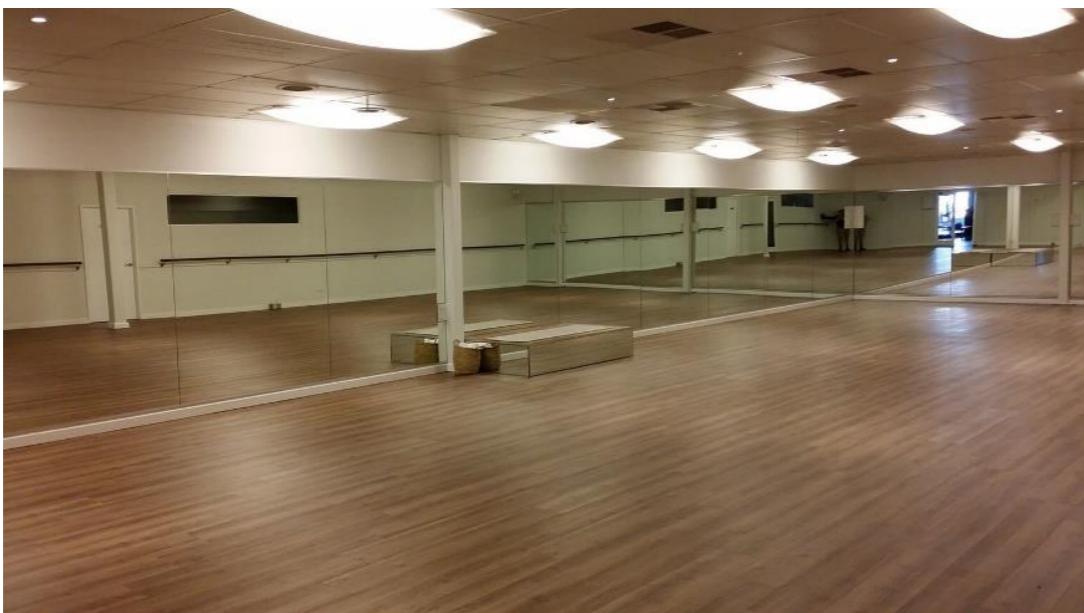
Amelie Haugg Ronald Sladky, Stavros Skouras, Amalia McDonald, Cameron Craddock, Matthias Kirschner, Marcus Herdener, Yury Koush, Marina Papoutsis, Jackob N. Keynan ... [See all authors](#)

- Large NF samples needed!



## Improve NF training

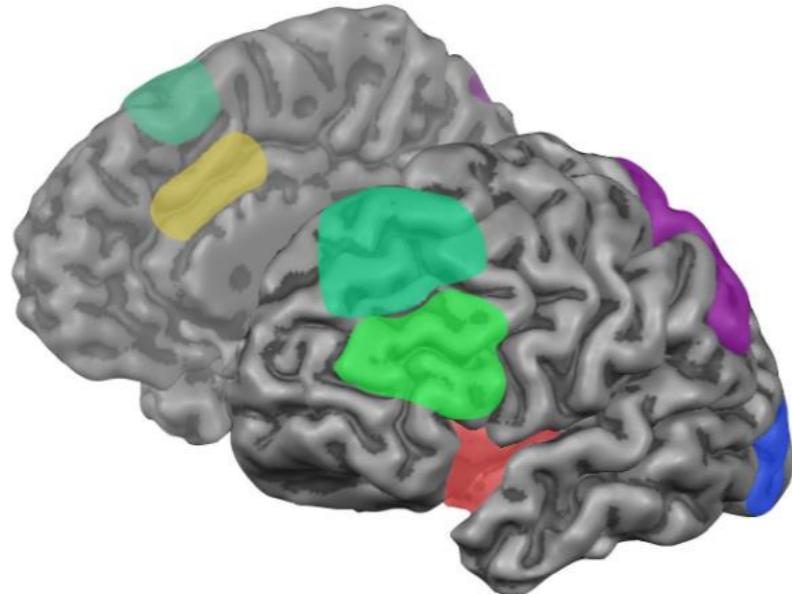
- How do individuals learn a new skill?
  - Getting feedback is only half of the story
  - The other half is external support



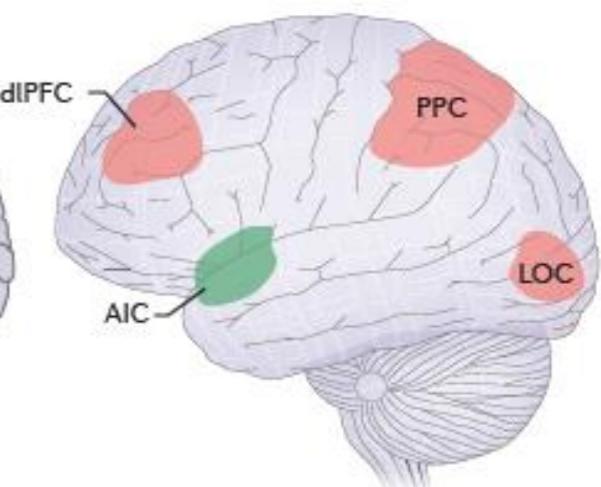
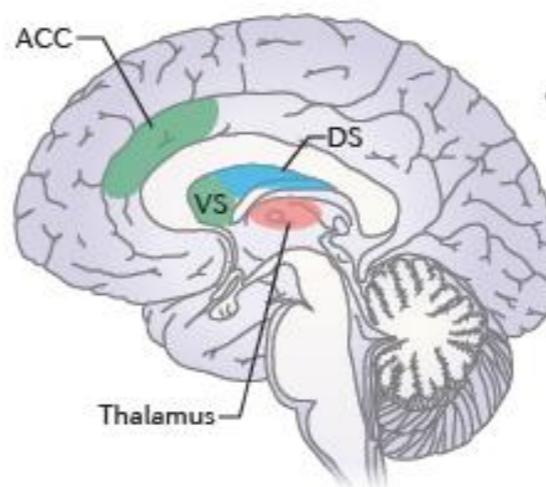


# Use brain stimulation to support NF learning?

## 1. Target domain-general NF areas



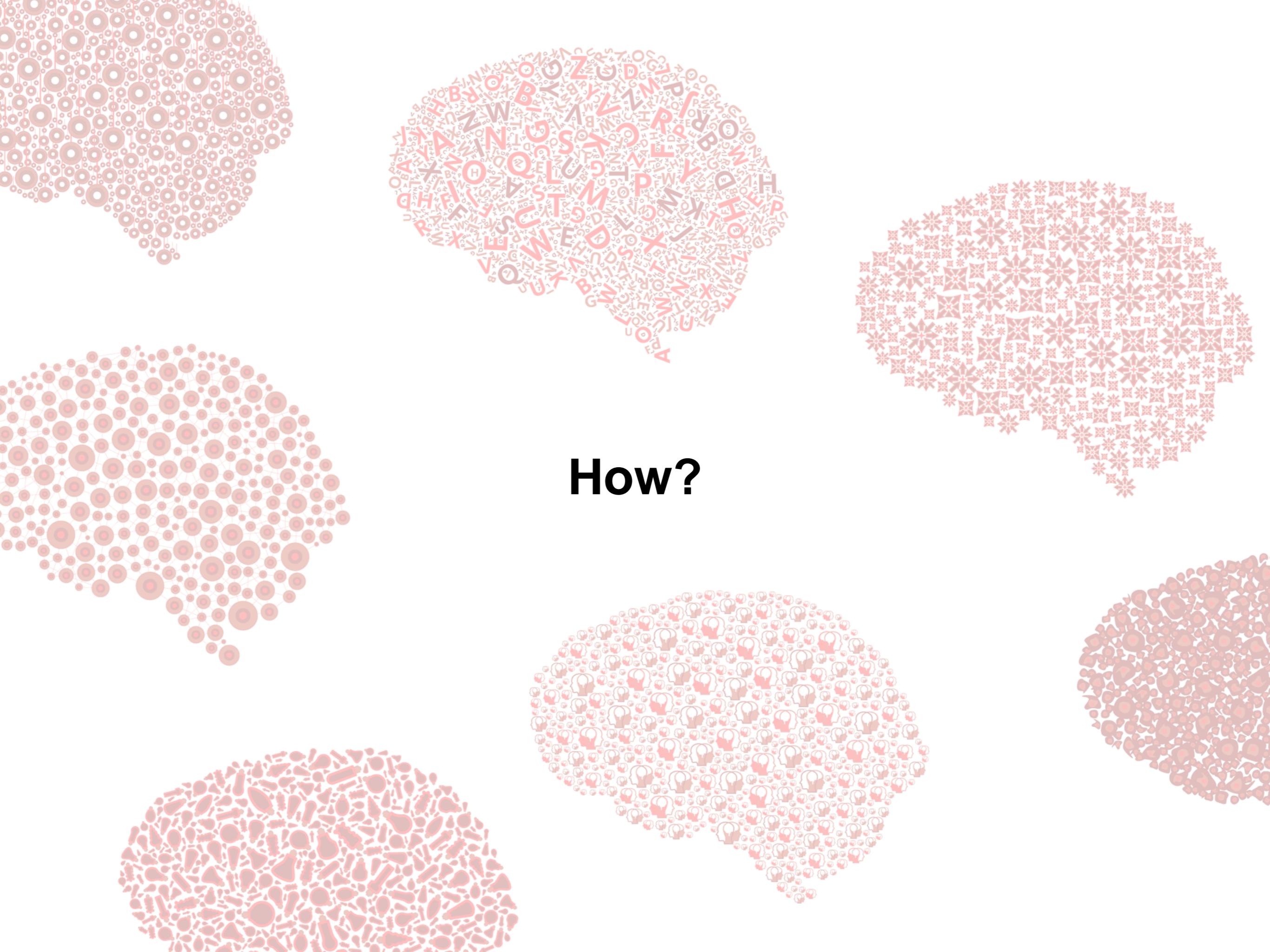
Emmert et al., 2016



■ Neurofeedback control   ■ Neurofeedback learning   ■ Neurofeedback reward processing

Sitaram et al., 2017

## 2. Stimulate domain-specific network nodes during first NF attempts



How?

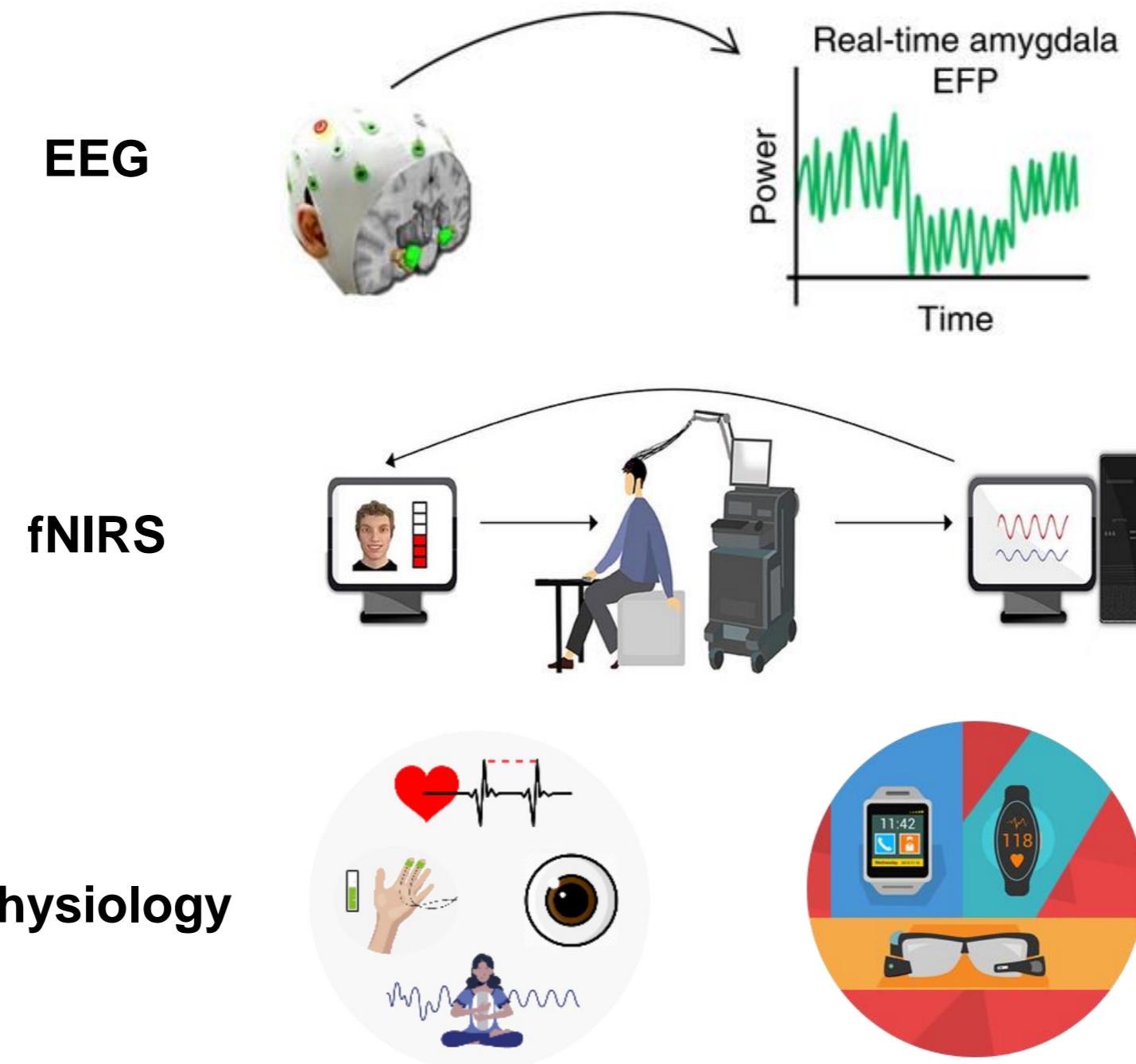


## Better understand the training parameters

- How to optimize designs?
- How long to train individuals?
- How lasting are the learned skills?
- (How) do they translate to clinical populations?

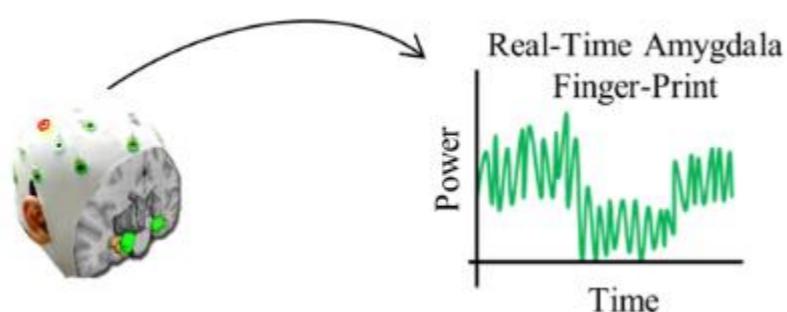


# Transfer technologies



# EEG

- Spatially very unspecific
- Great temporal resolution
- Can be (sort of) mobile
- Temporal fingerprinting of subcortical areas?



Keynan et al., 2019



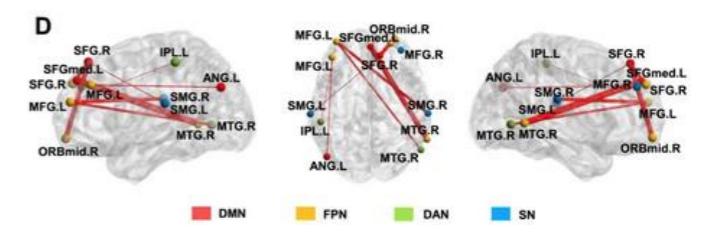
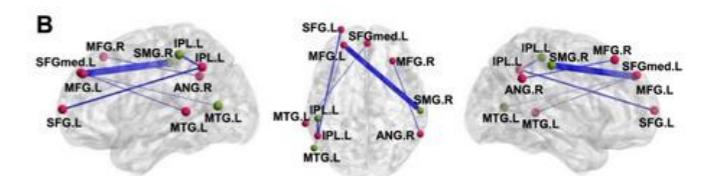
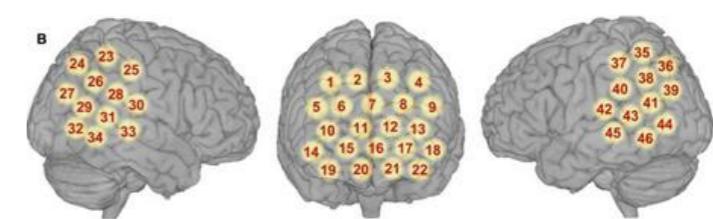
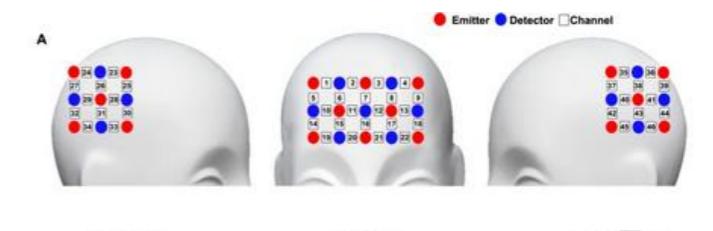
## fNIRS

- Also hemodynamic signal
- Can be quite spatially specific
- Network neurofeedback (surface areas)?

**Intrinsic organization of cortical networks predicts state anxiety: an functional near-infrared spectroscopy (fNIRS) study**

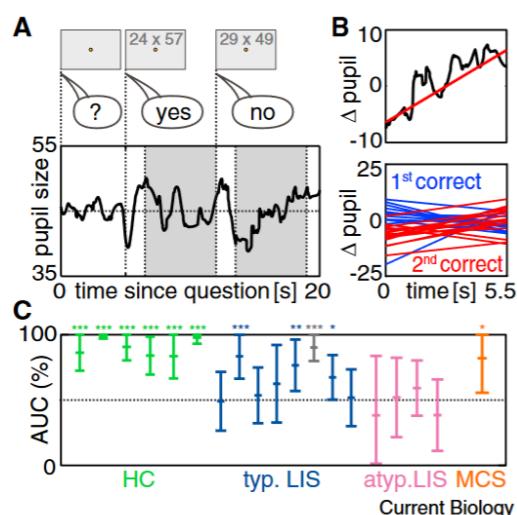
Lian Duan, Nicholas T. Van Dam, Hui Ai & Pengfei Xu

*Translational Psychiatry* 10, Article number: 402 (2020) | [Cite this article](#)

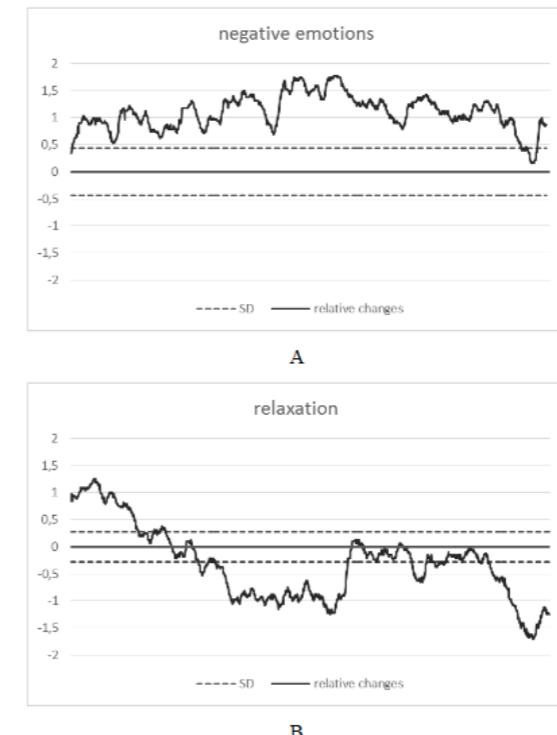
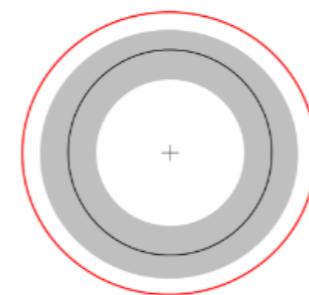


# Physiology

- Very interesting given surge in wearable devices!
- Pupil size biofeedback as proxy for LC activity?

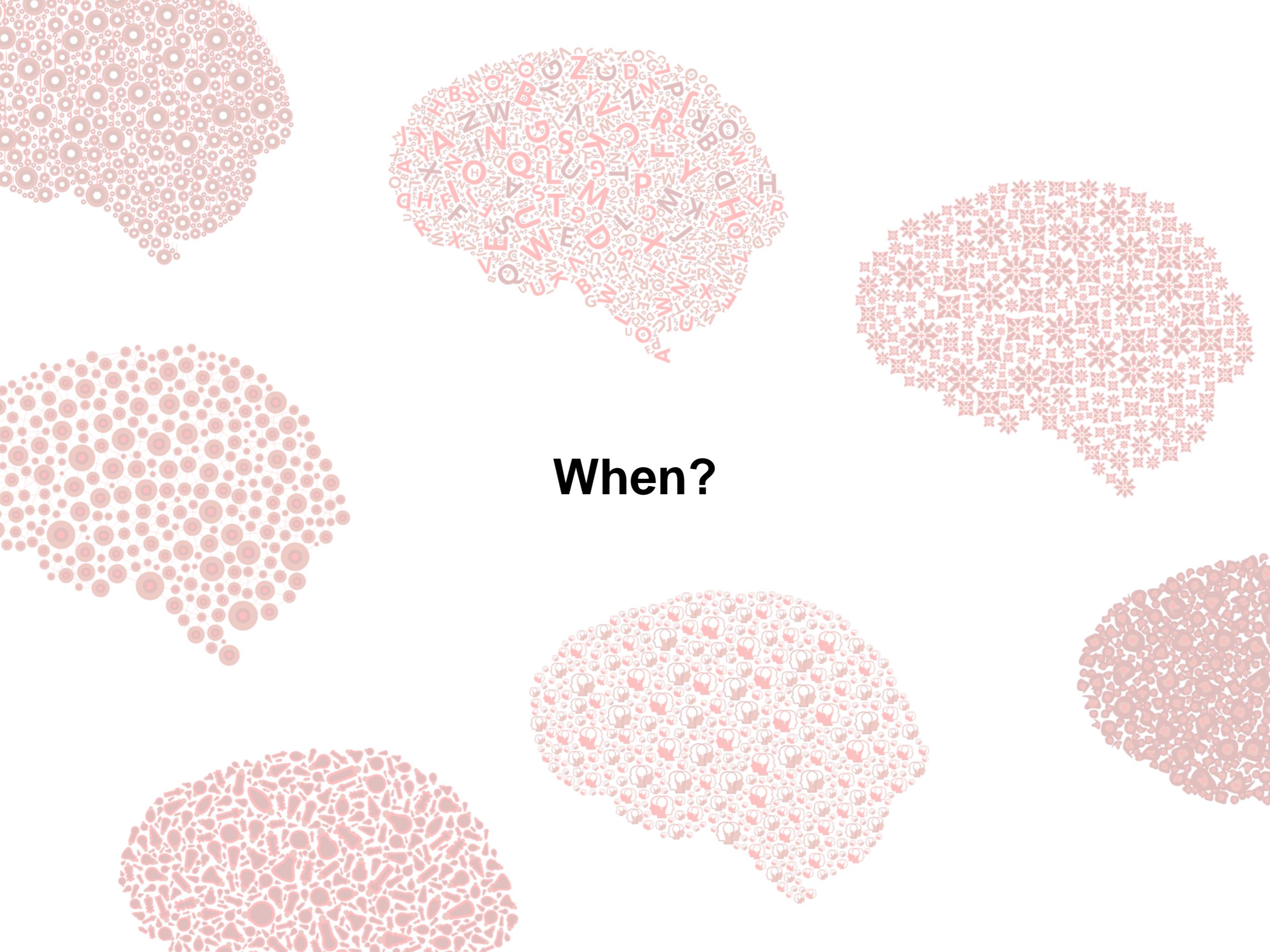


Stoll et al., 2013



Elehrs et al., 2014

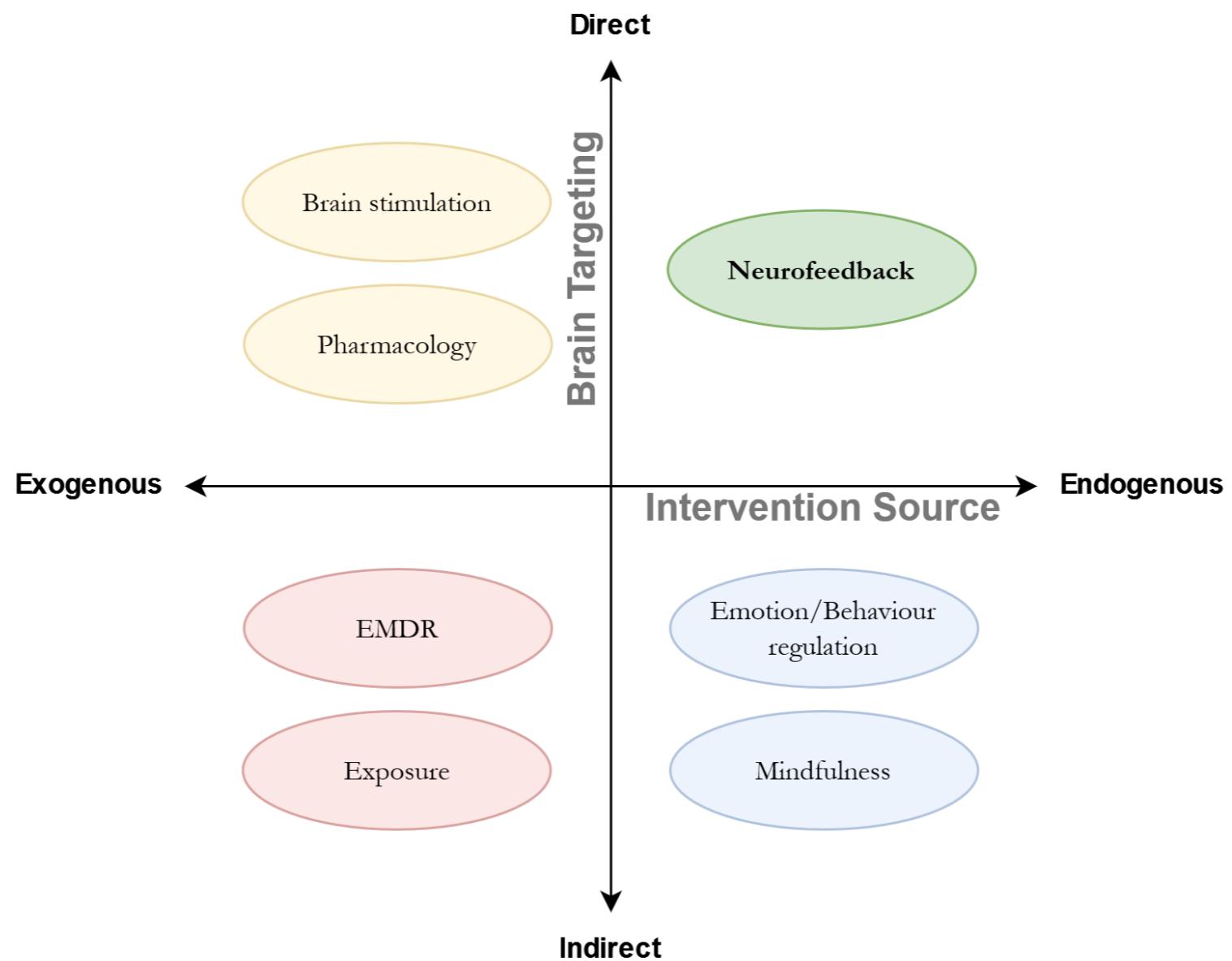
B



When?



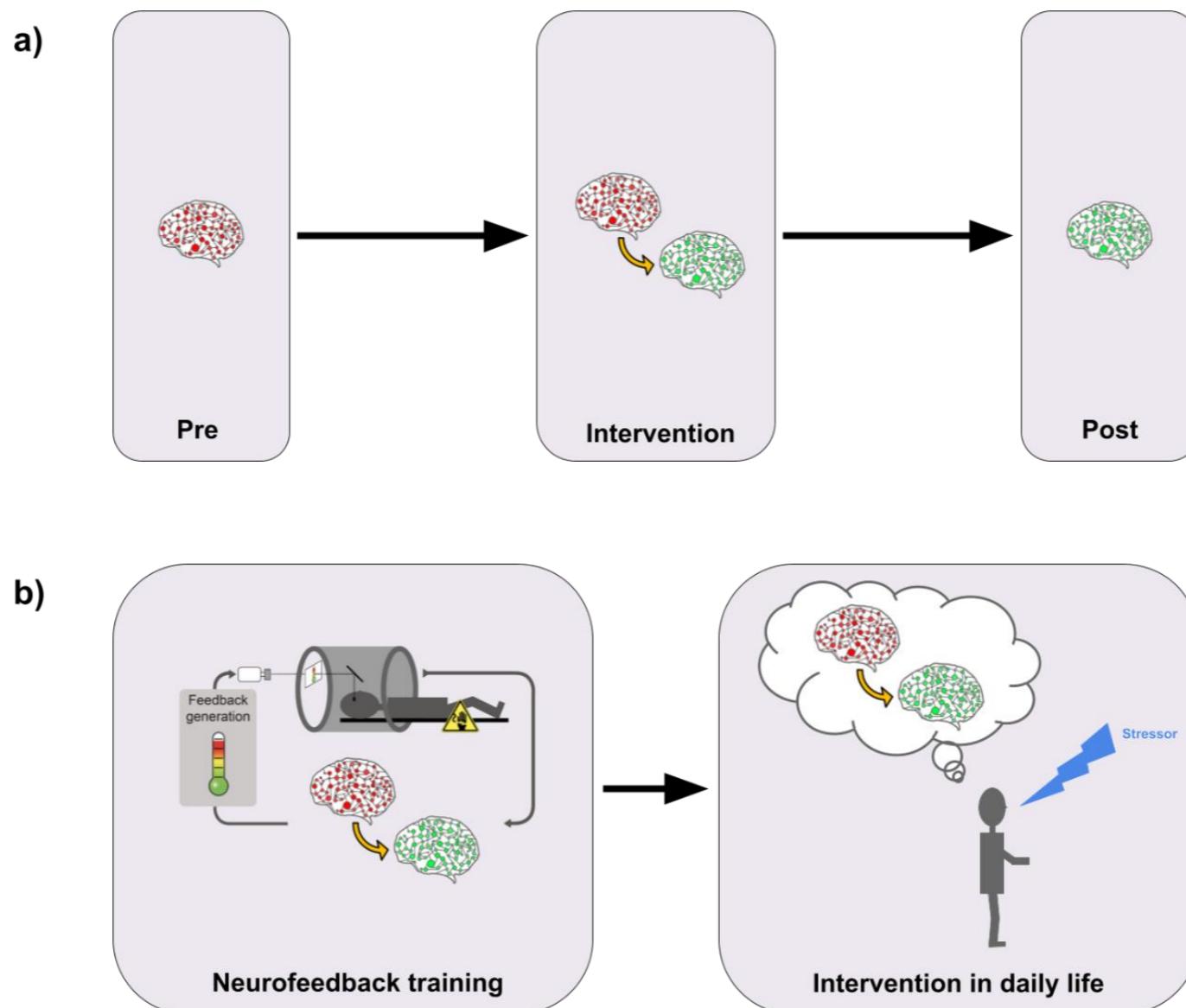
# Endogenous Neuromodulation

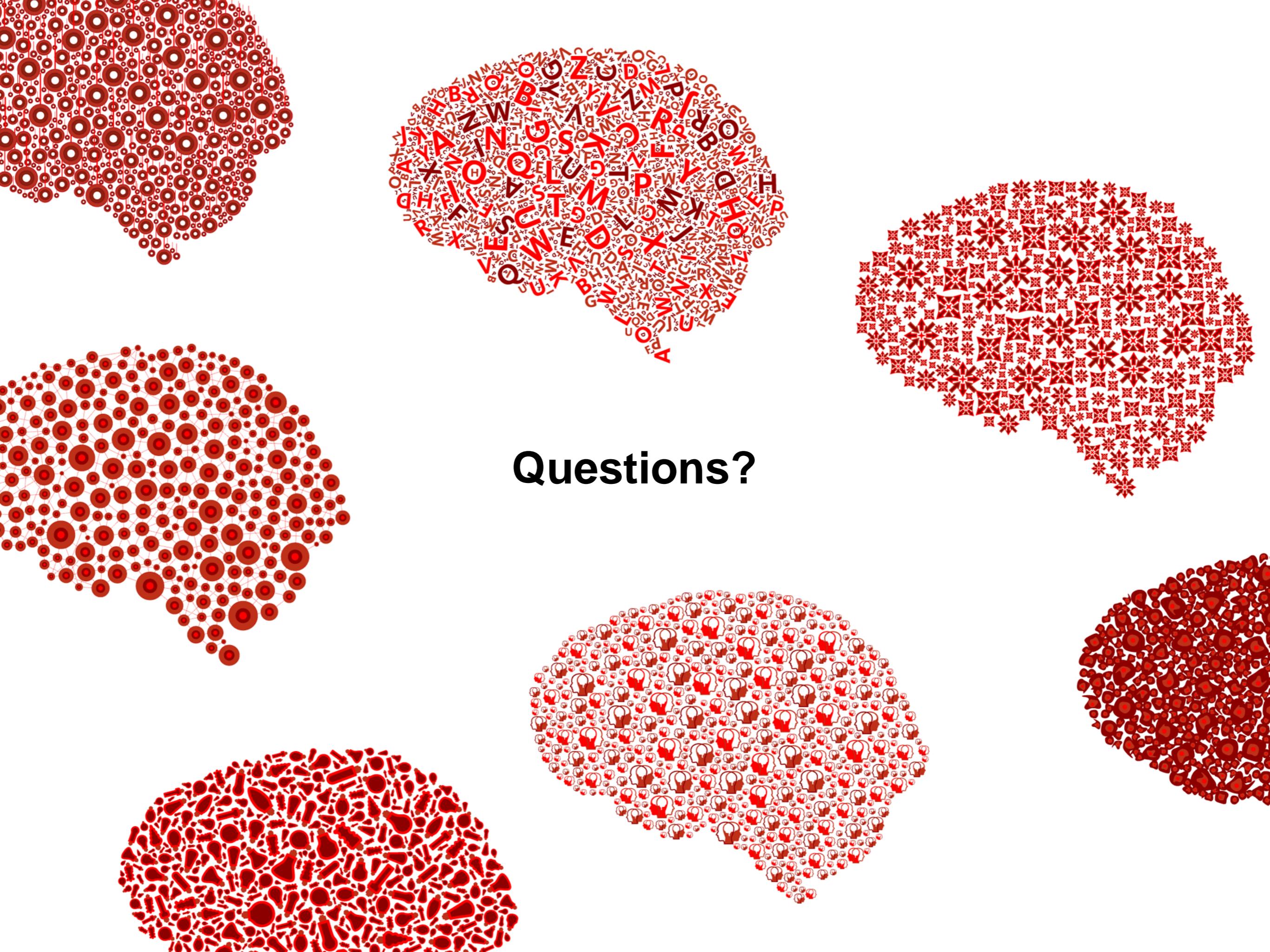




# Real-life time-dependent neuromodulation

- Unlike other neuromodulation, *NF self-regulation is a learned skill that can later be applied at will outside the lab*





Questions?