Real-time fMRI and Neurofeedback

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Real-time fMRI

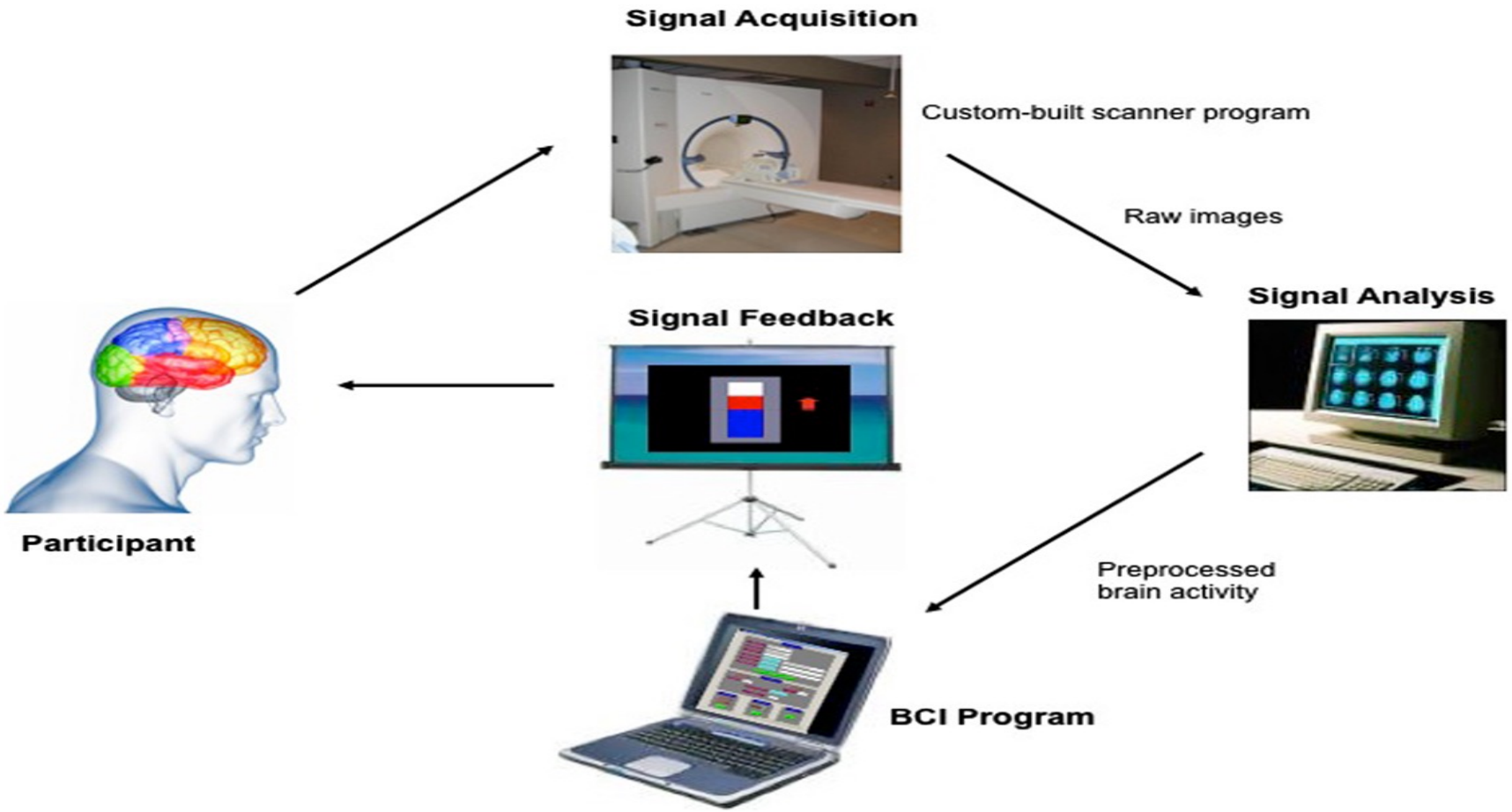
- Usually, fMRI data is processed post acquisition

- Real-time fMRI allows us to look at fMRI data online, during the scan

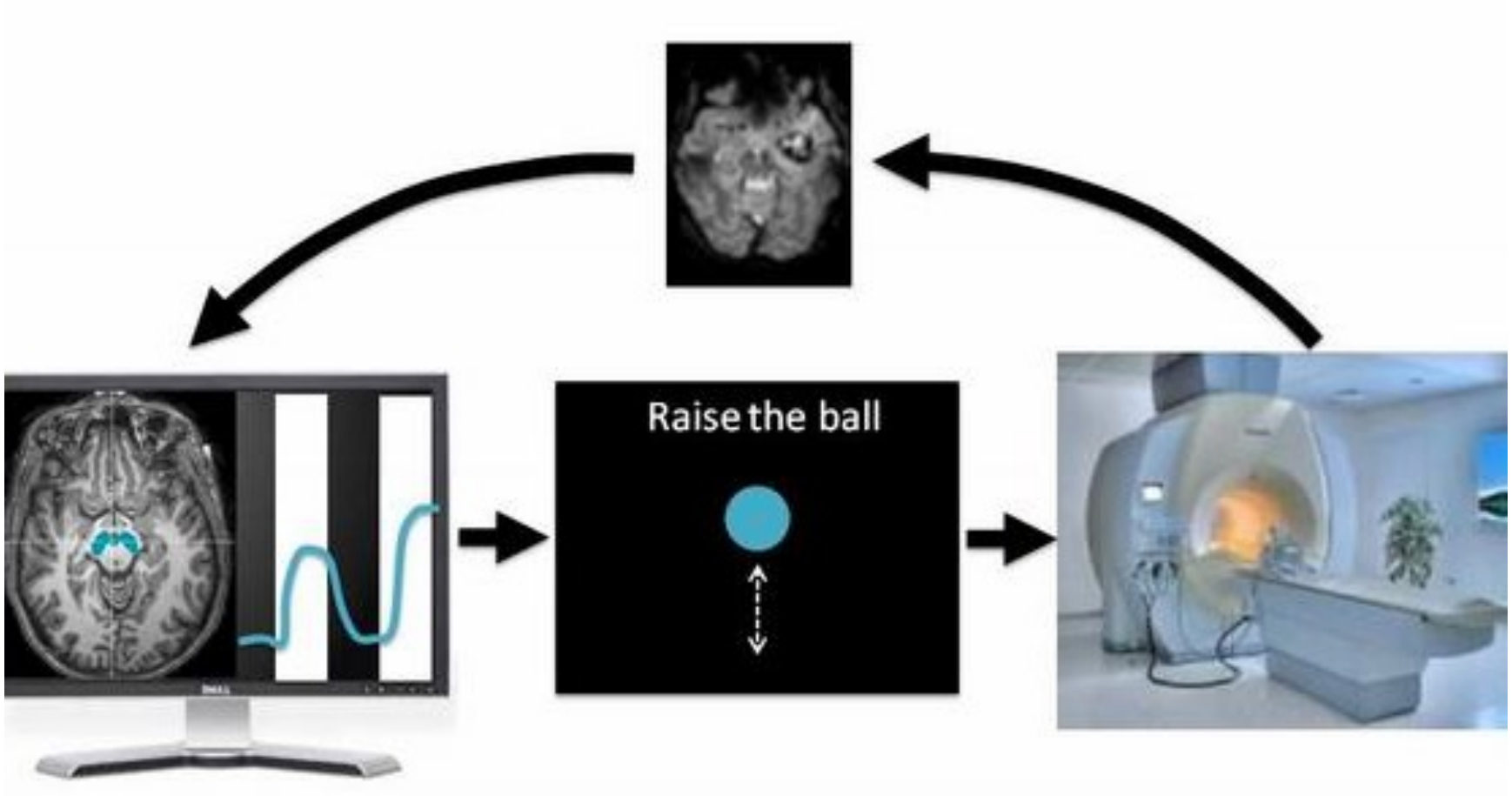
Neurofeedback

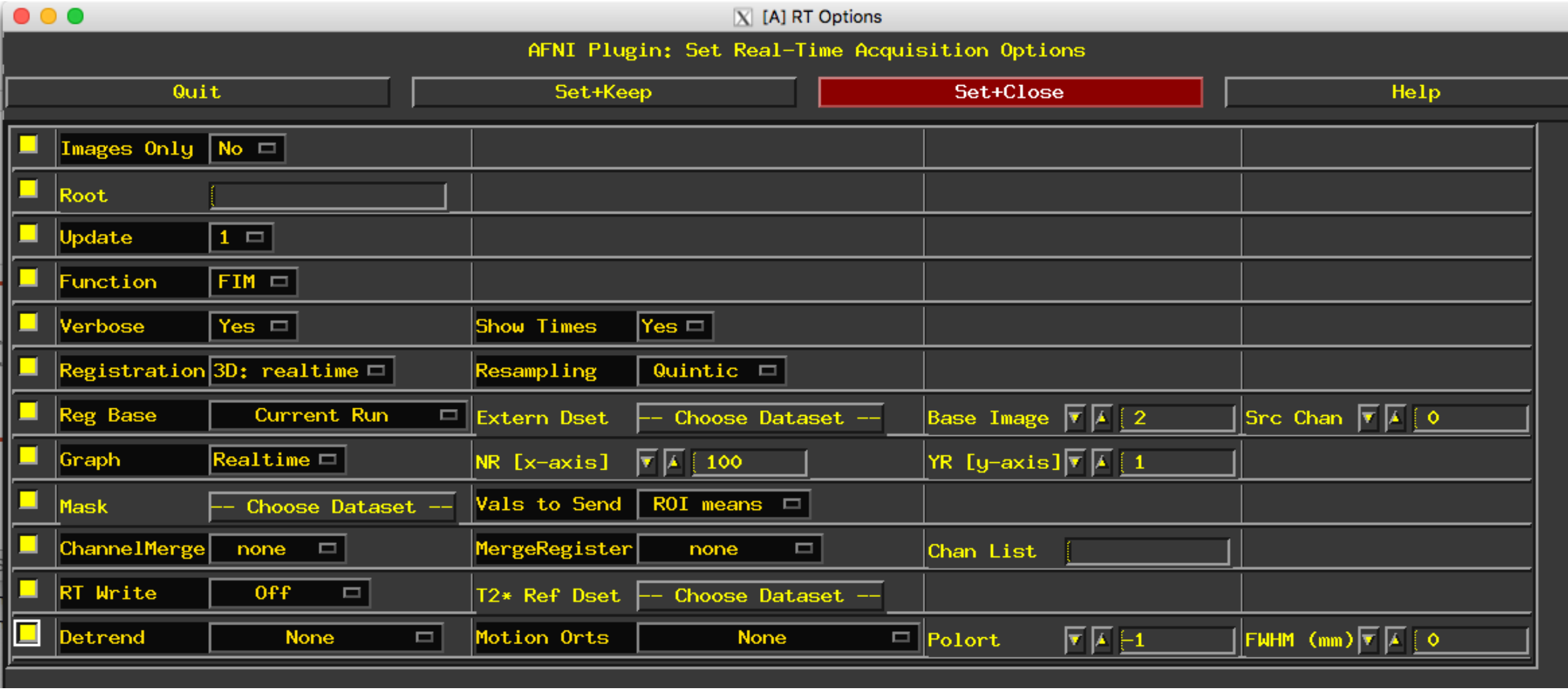
- Translating signals from the brain to a signal subjects can perceive (visual, auditory)
- Various recording techniques:
  - EEG
  - Invasive methods
  - Real time fMRI

Neurofeedback



Neurofeedback




[A] RT Options
AFNI Plugin: Set Real-Time Acquisition Options
Quit
Set+Keep
Set+Close
Help
Images Only
No
Root
Update
1
Function
FIM
Verbose
Yes
Show Times
Yes
Registration
3D: realtime
Resampling
Quintic
Reg Base
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Extern Dset
-- Choose Dataset --
Base Image
2
Src Chan
0
Graph
Realtime
NR [x-axis]
100
YR [y-axis]
1
Mask
-- Choose Dataset --
Vals to Send
ROI means
ChannelMerge
none
MergeRegister
none
Chan List
RT Write
Off
T2* Ref Dset
-- Choose Dataset --
Detrend
None
Motion Orts
None
Polort
-1
FWHM (mm)
0

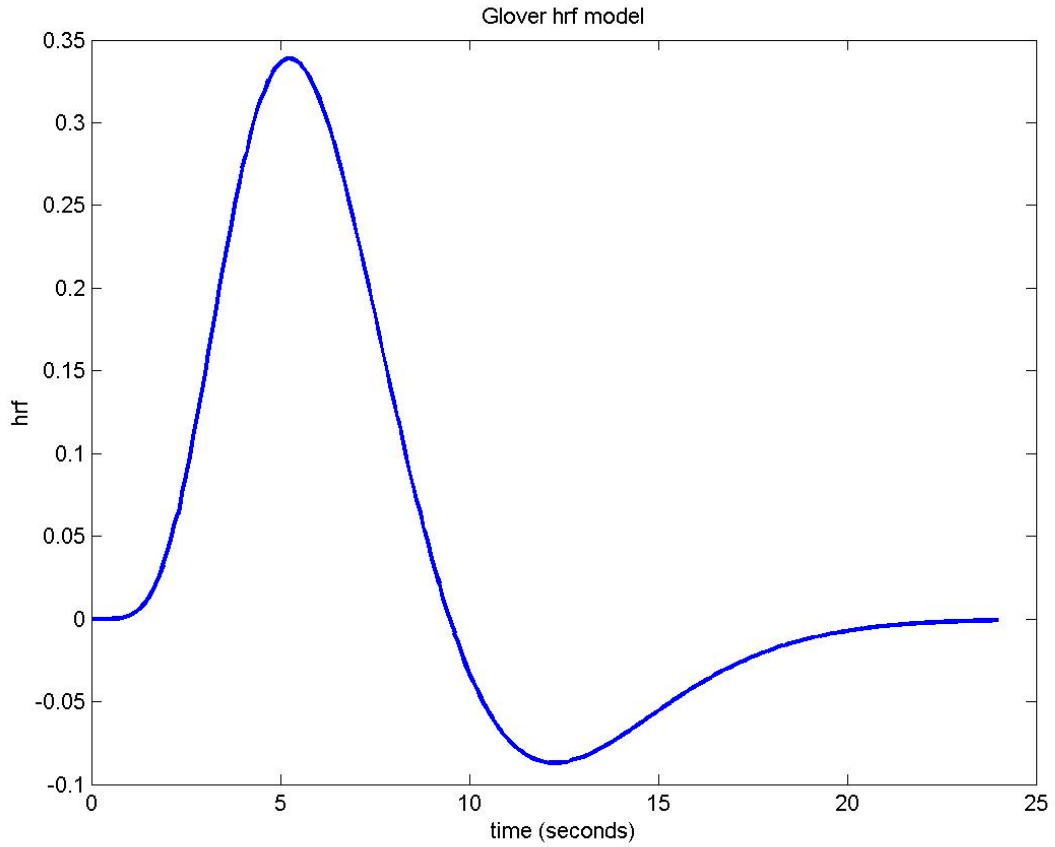
Preprocessing

- Register everything to a common space (anatomical and functional data, pre-defined regions of interest)
- Motion correction

- Physiological noise regression
- Detrending
- Optimally combined echoes

Limitations of the signal

- Processing can be fast, but the fMRI signal is slow
  - Slow acquisition
  - BOLD is slow



Limitations of the signal

- fMRI data is noisy!
- Global signal artifacts / real global signal

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Methods to detect, characterize, and remove motion artifact in resting state fMRI

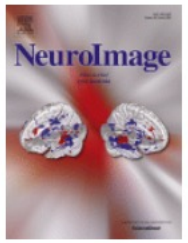
Jonathan D. Power [a,*], Anish Mitra [a], Timothy O. Laumann [a], Abraham Z. Snyder [a,b], Bradley L. Schlaggar [a,b,c,d], Steven E. Petersen [a,b,d,e,f,g]

What can we feedback?

- Single re

NeuroImage

Volume 88, March 2014, Pages 113-124



Research Articl

Self-regul

The righ

Self-regulation of the anterior insula: Reinforcement

Giuseppina R

Niels Birbaur

Self-Regulation of Amygdala Activation Using Real-Time fMRI Neurofeedback

Vadim Zotev, Frank Krueger, Raquel Phillips, Ruben P. Alvarez, W. Kyle Simmons, Patrick Bellgowan, Wayne C. Drevets, Jerzy Bodurka

Published: September 8, 2011 • https://doi.org/10.1371/journal.pone.0024522

What can we feedback?

- Classifier output

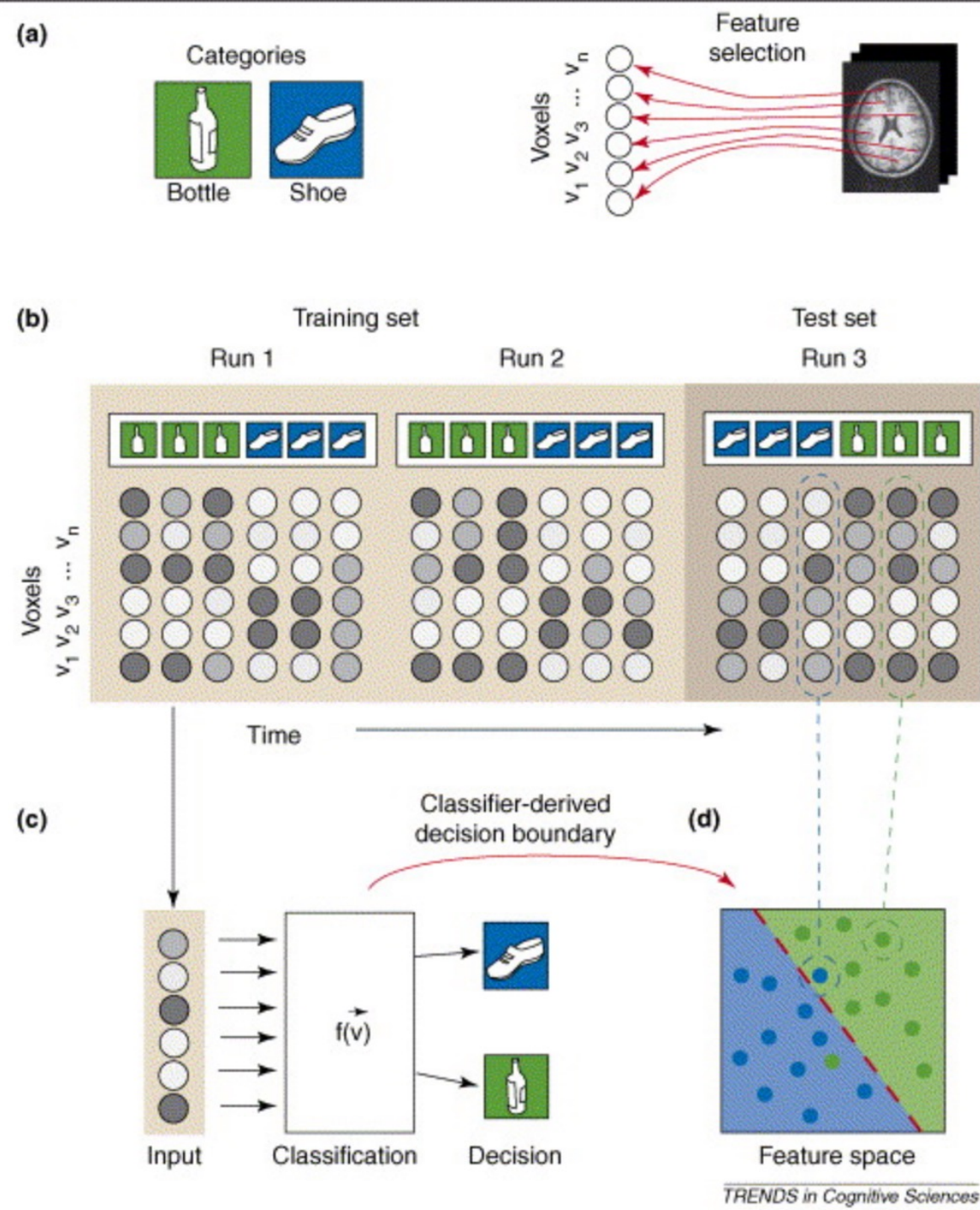
Trends in Cognitive Sciences

Volume 10, Issue 9, September 2006, Pages 424-430

Review

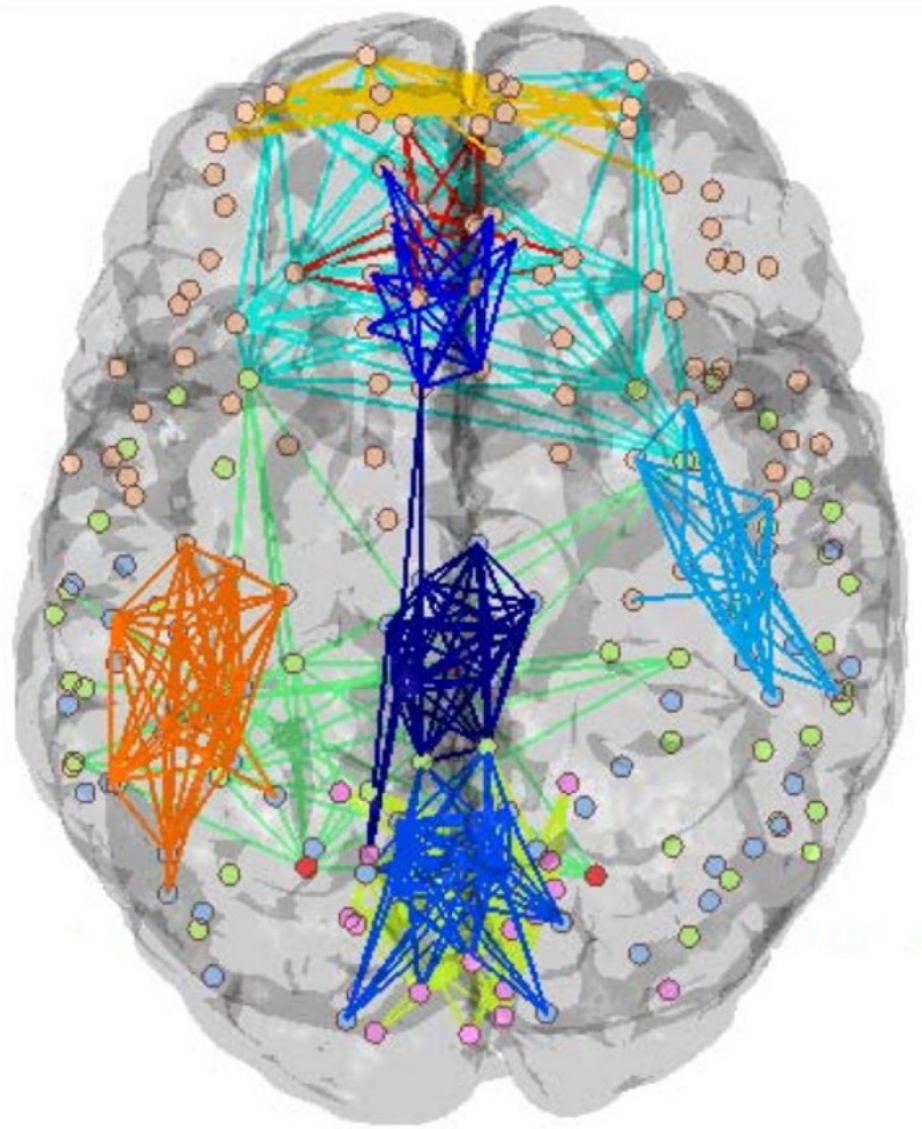
Beyond mind-reading: multi-voxel pattern analysis of fMRI data

Kenneth A. Norman [1] ✉, Sean M. Polyn [2], Greg J. Detre [1], James V. Haxby [1]


(a)
Categories
Bottle
Shoe
Feature selection
Voxels
v_1 v_2 v_3 ... v_n
(b)
Training set
Test set
Run 1
Run 2
Run 3
Voxels
v_1 v_2 v_3 ... v_n
Time
(c)
Classifier-derived decision boundary
(d)
f(v)
Input
Classification
Decision
Feature space
TRENDS in Cognitive Sciences

What can we feedback?

- Correlations between regions
- Not trivial – calculating correlations takes time



Goals of neurofeedback

- Clinical applications
- Enhance performance

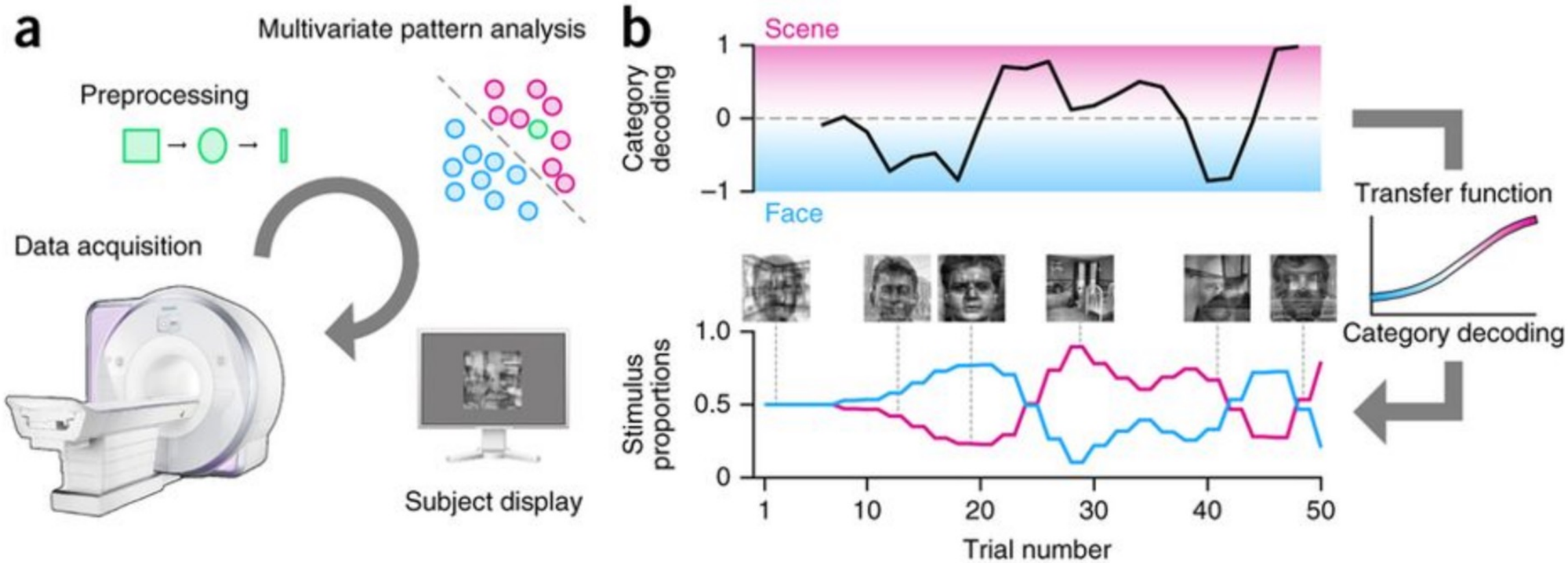
nature neuroscience

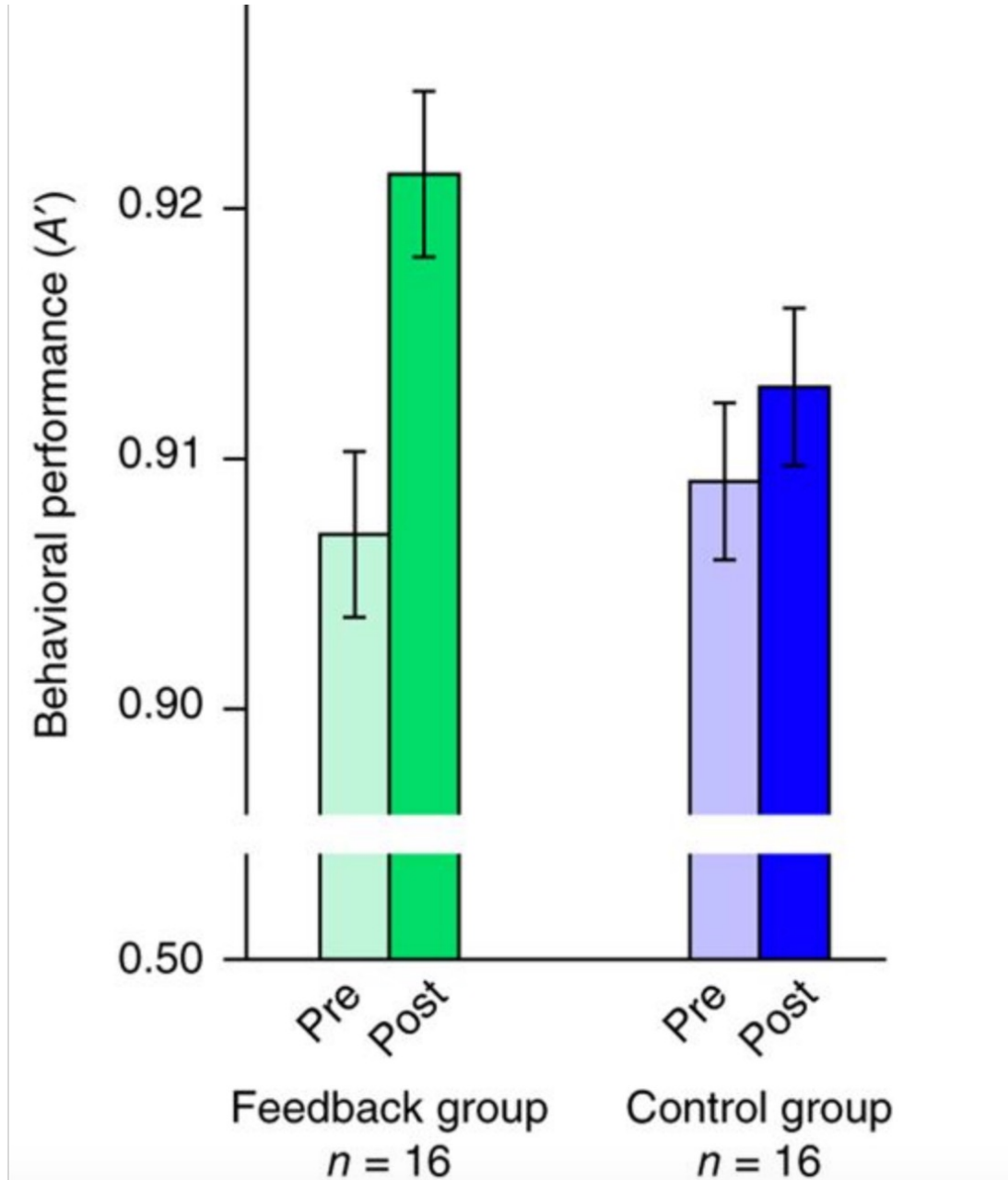
Article | Published: 09 February 2015

Closed-loop training of attention with real-time brain imaging

Megan T deBettencourt, Jonathan D Cohen, Ray F Lee, Kenneth A Norman & Nicholas B Turk-Browne

Nature Neuroscience **18**, 470–475 (2015) | Download Citation


a
Multivariate pattern analysis
Preprocessing
Data acquisition
Subject display
b
Scene
Face
Category decoding
1
0
−1
Transfer function
Category decoding
Stimulus proportions
1.0
0.5
0
1
10
20
30
40
50
Trial number

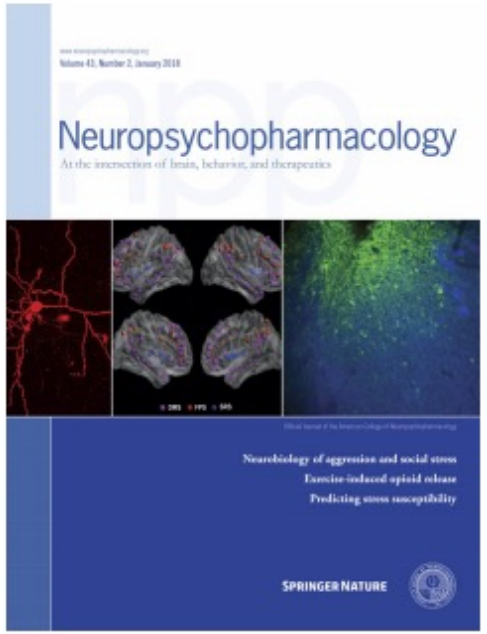

Behavioral performance (A')
0.92
0.91
0.90
0.50
Pre
Post
Pre
Post
Feedback group
n = 16
Control group
n = 16

Goals of neurofeedback

- Clinical applications
- Enhance performance
- Investigate causality, understand the relationships between networks and behavior

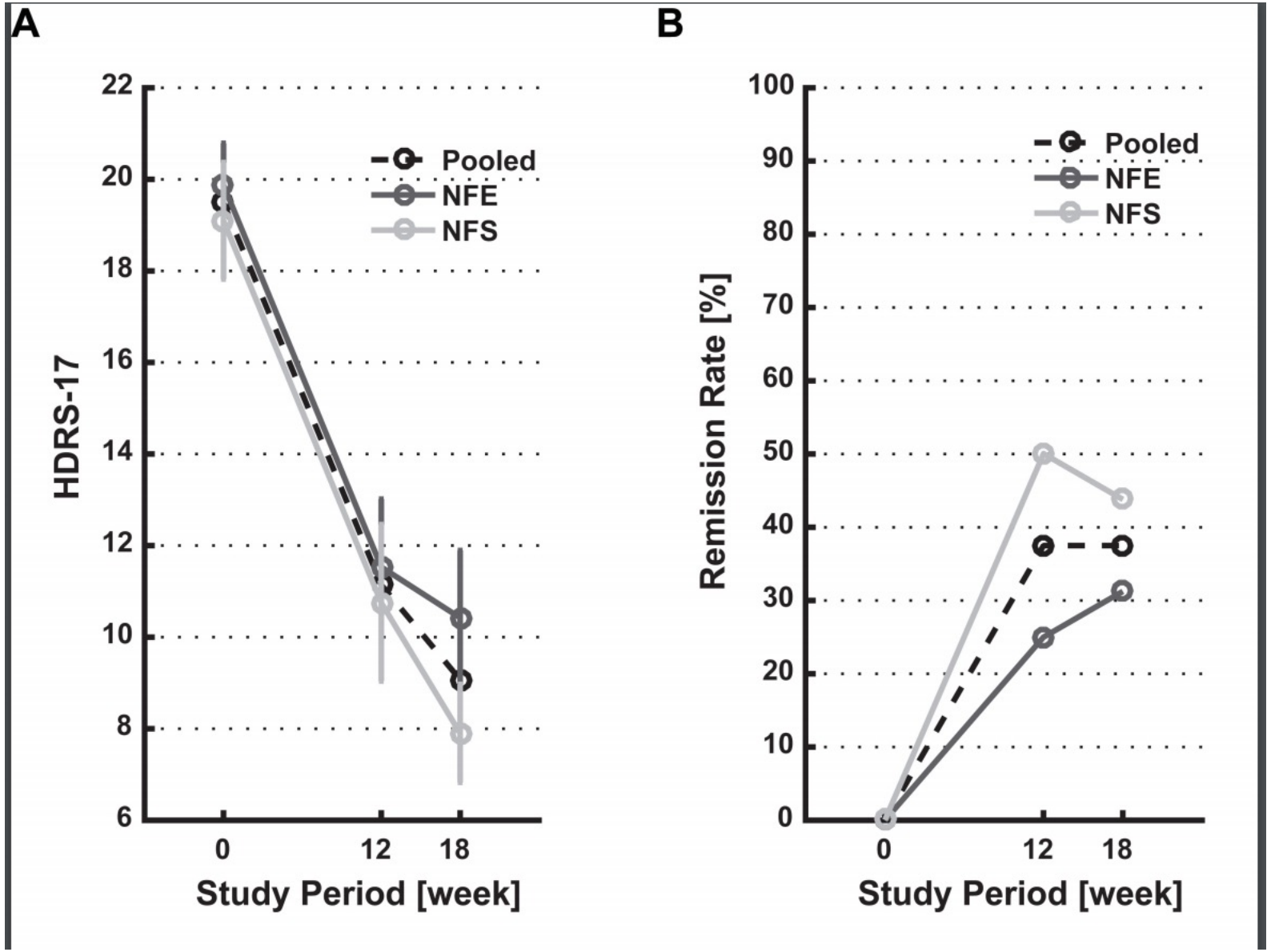
- Do you need neurofeedback to answer your question?
- Does your planned neurofeedback experiment answer your question?

Interpreting changes following neurofeedback



Targeting the affective brain - A Randomized Controlled Trial of real-time fMRI neurofeedback in patients with depression

David M. A. Mehler, Moses O. Sokunbi, Isabelle Habes, Kali Barawi, Leena Subramanian, Maxence Range, John Evans, Kerenza Hood, Michael Lührs, Paul Keedwell, Rainer Goebel, David E. J. Linden


A
HDRS-17
22
20
18
16
14
12
10
8
6
Pooled
NFE
NFS
0
12
18
Study Period [week]
B
Remission Rate [%]
100
90
80
70
60
50
40
30
20
10
0
Pooled
NFE
NFS
0
12
18
Study Period [week]

Caveats of task-based Neurofeedback

- Doesn’t bypass behavior, cannot address the question of causality
- Difficult to disentangle the effects of the task from the effects of the neurofeedback
- Limited in scope, inflexible
- Potentially underestimates the extent of plasticity
- Does not necessarily require a piece of equipment as expensive as an MRI machine

Implicit training – covert neurofeedback

- What if we don’t give subjects a strategy?

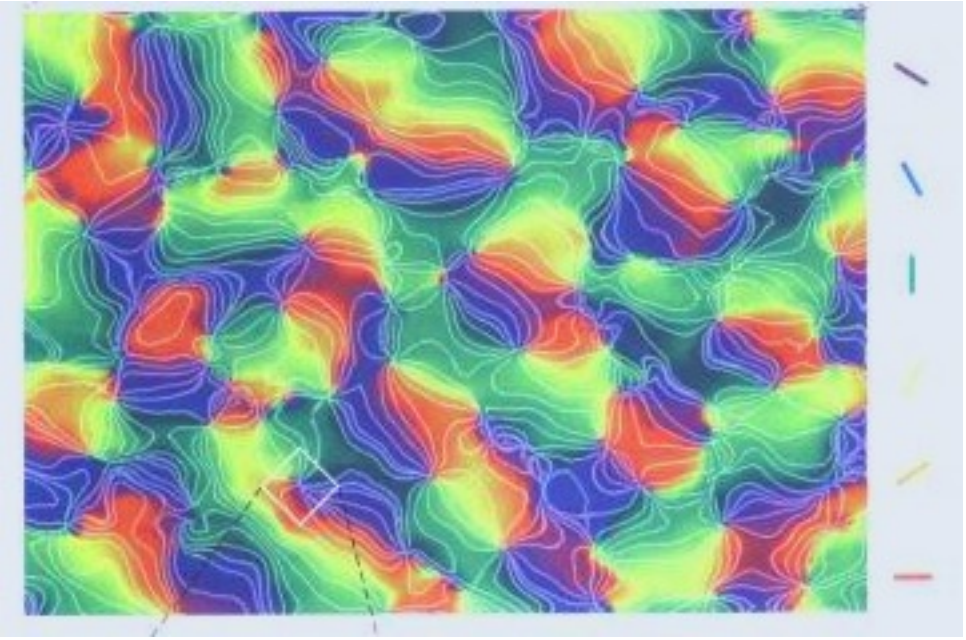
Background – Visual Perceptual Learning

- Practice or training in a particular task often substantially improves perceptual performance. This is known as perceptual learning. Examples:
  - Distinguishing between two musical notes
  - Finding the ripe berries on the bush
  - Reading
  - Finding a tumor on an imaging scan
- Perceptual learning is often restricted to a particular task or stimulus
- Visual perceptual learning (VPL) often correlates with changes in visual areas, but this does not prove causation, and studies have been divided on whether these changes are in early or high order visual cortex

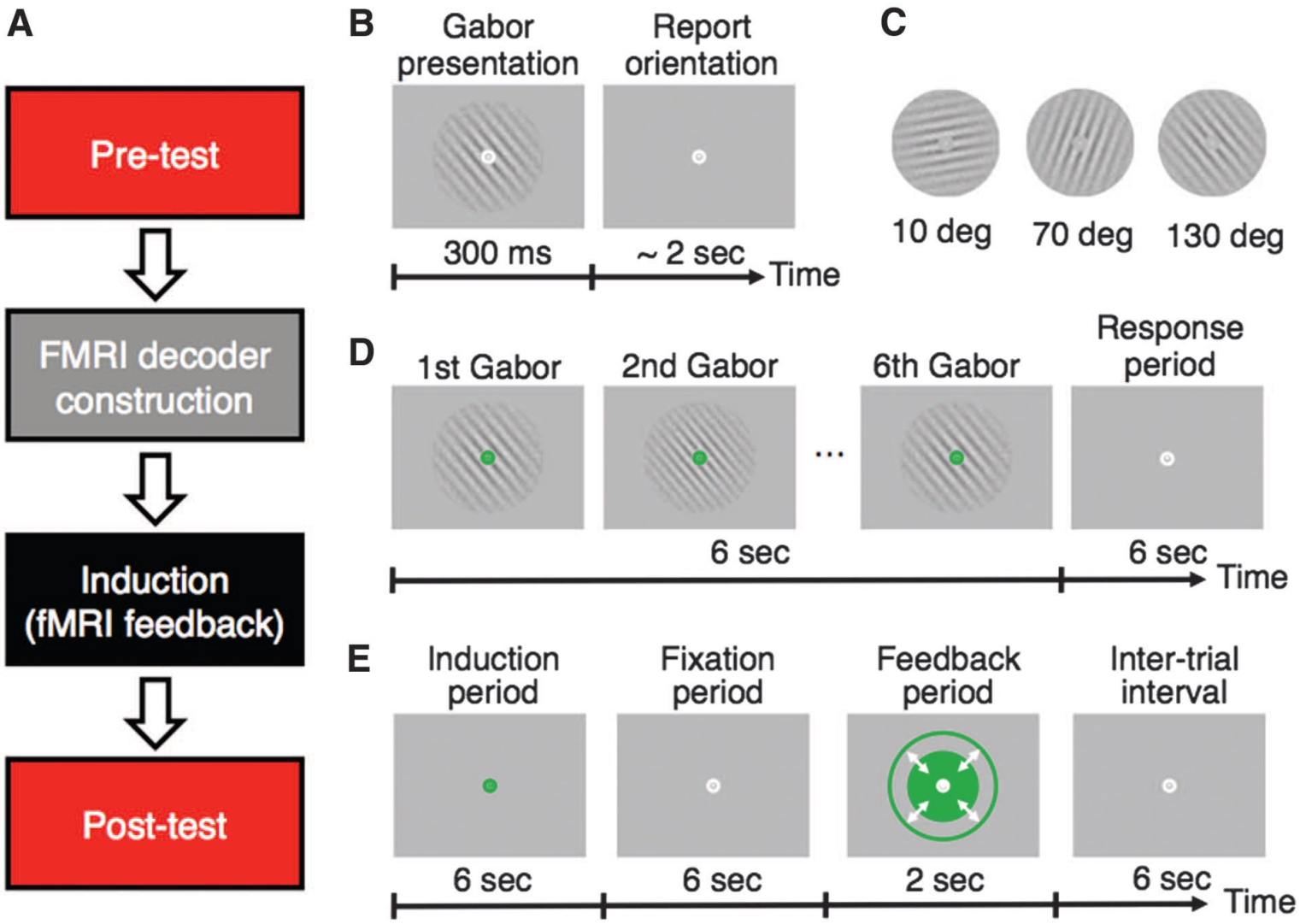
Example

Question

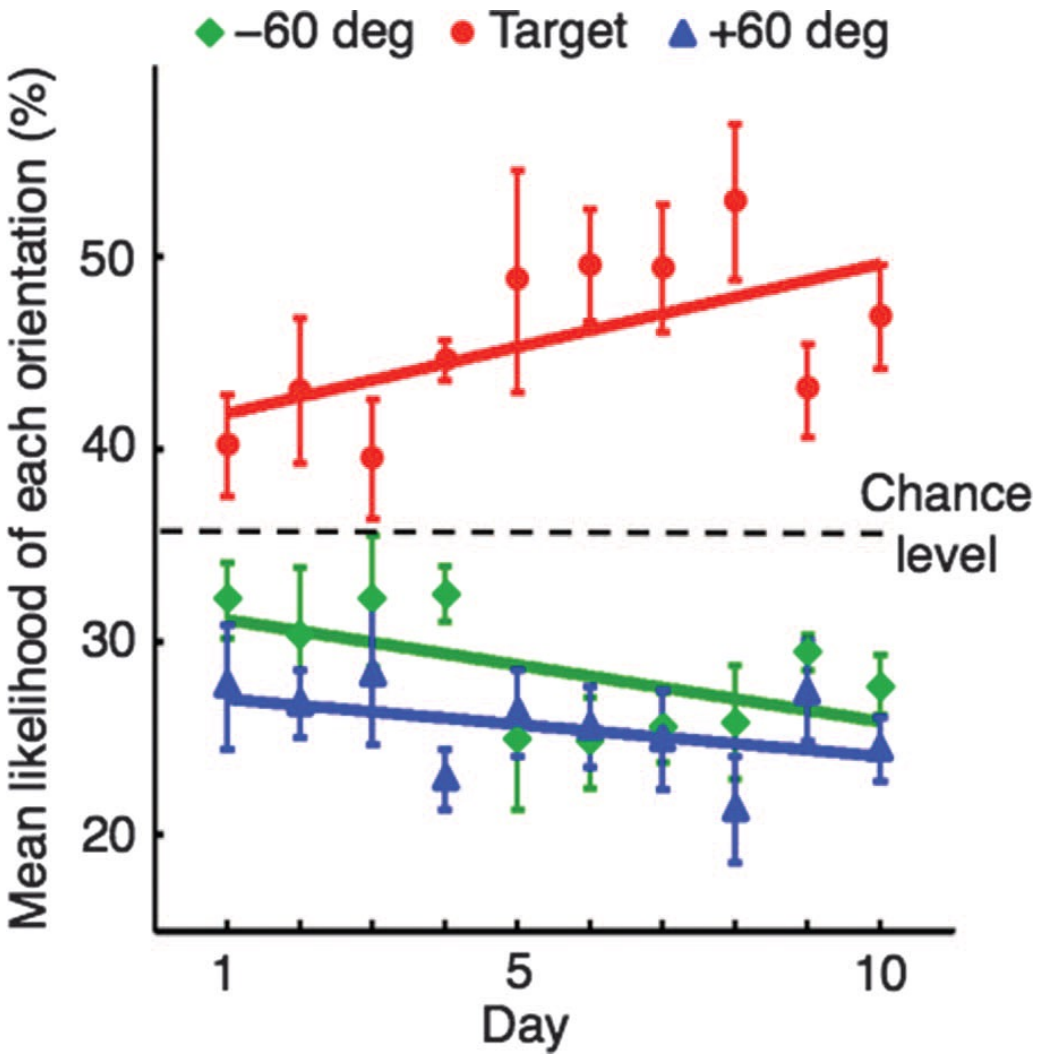
- Is early visual cortex plastic enough to cause VPL?
- Induce change in a very specific manner in early visual cortex, without exposing to the visual stimulus this pattern represents



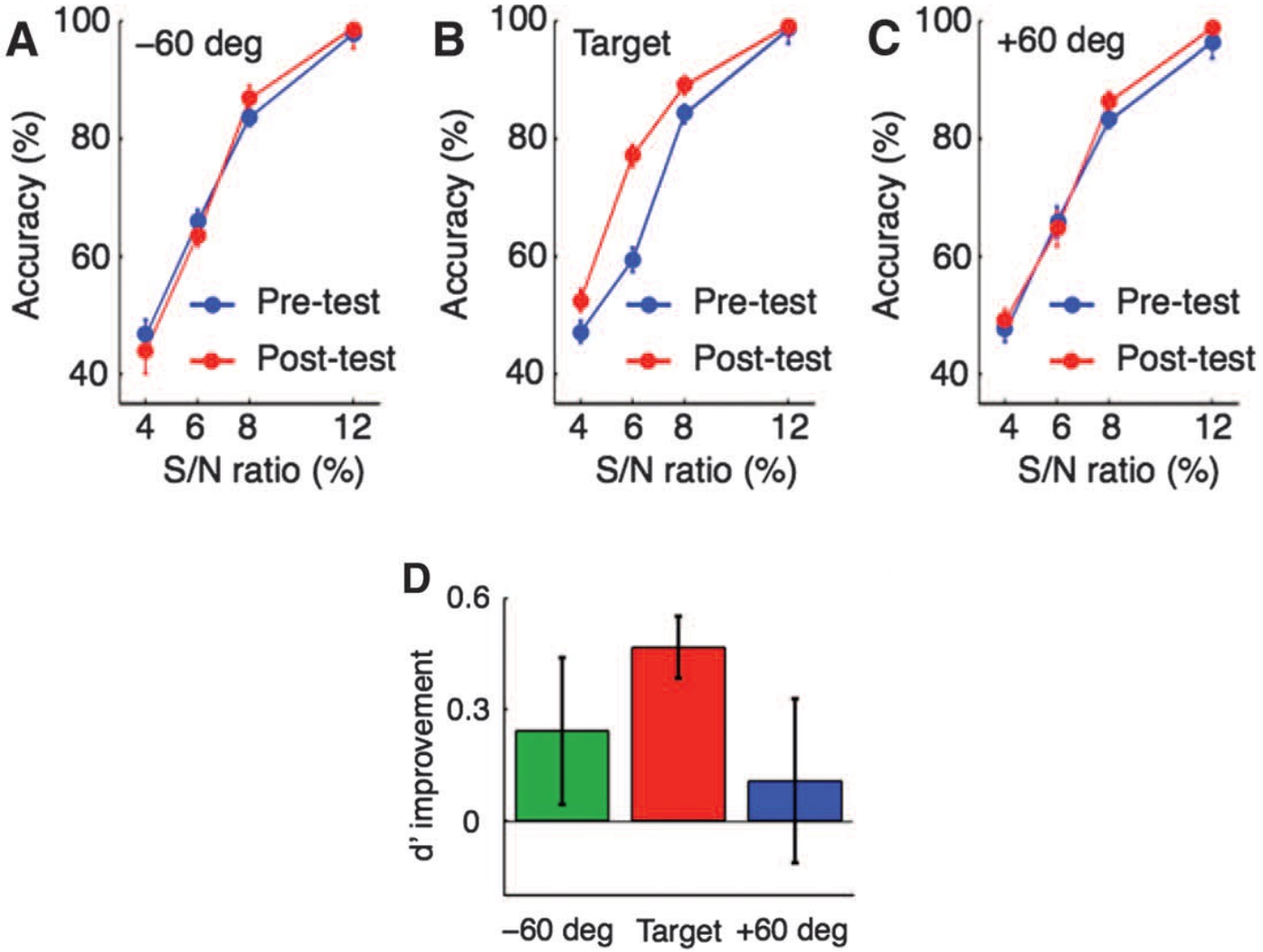
Experimental design



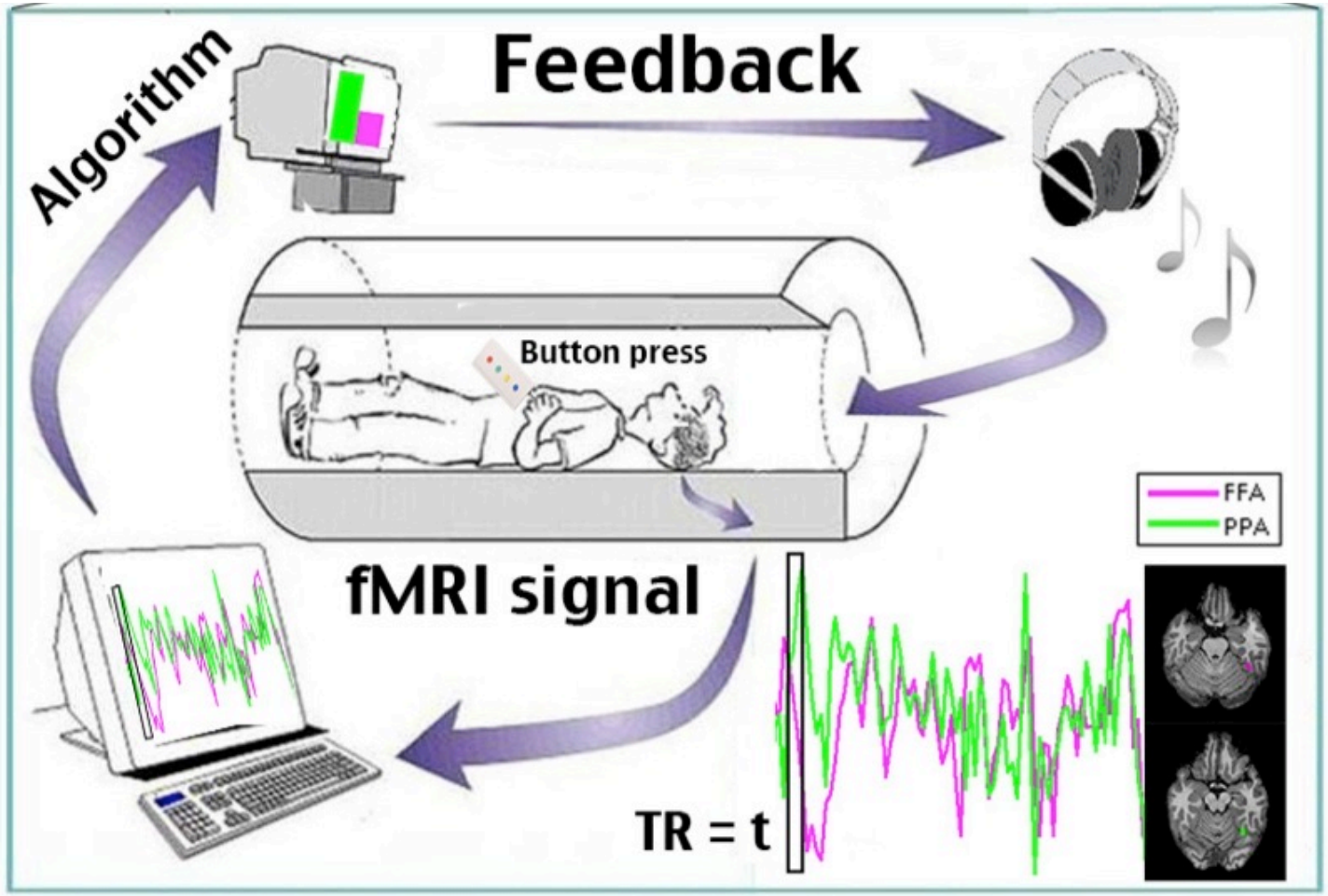
Results – changes in fMRI signal



Perceptual learning



Does learning have to be conscious?

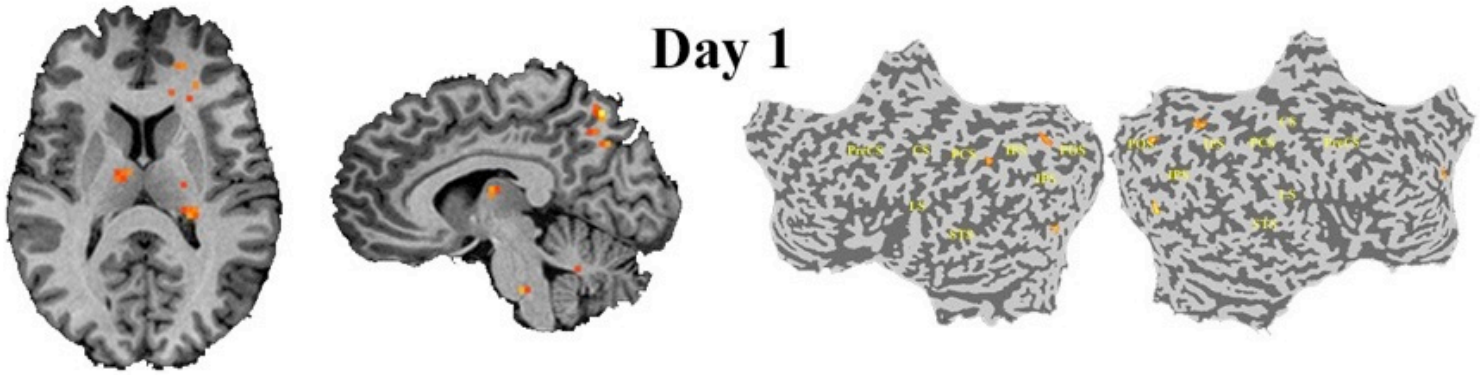


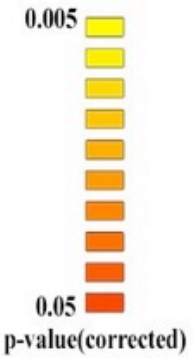
Good

Bad

Voxels significantly more correlated to good>bad ROI, during NF

Day 1

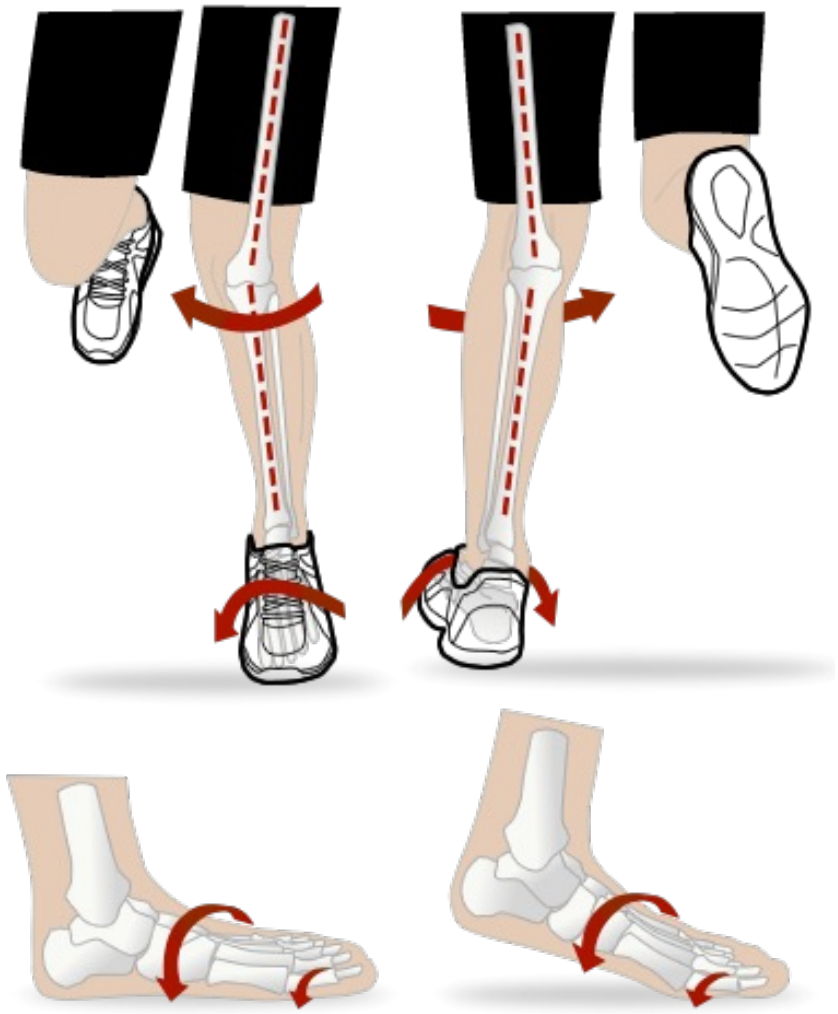




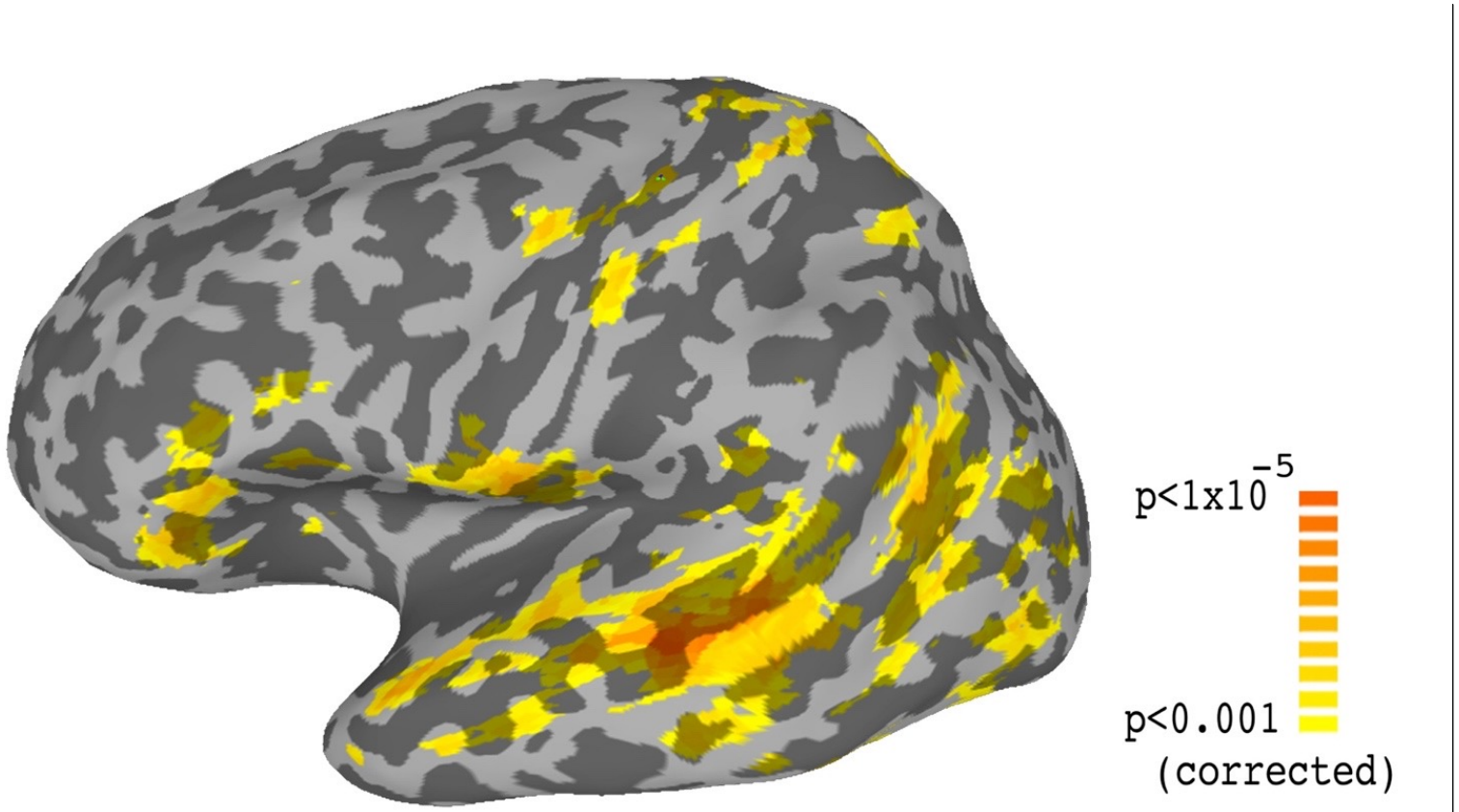
Ramot et al., PNAS 2016

Limits of explicit training

- If networks are aberrant, mere repetition of stimuli is akin to strengthening the wrong “muscles”

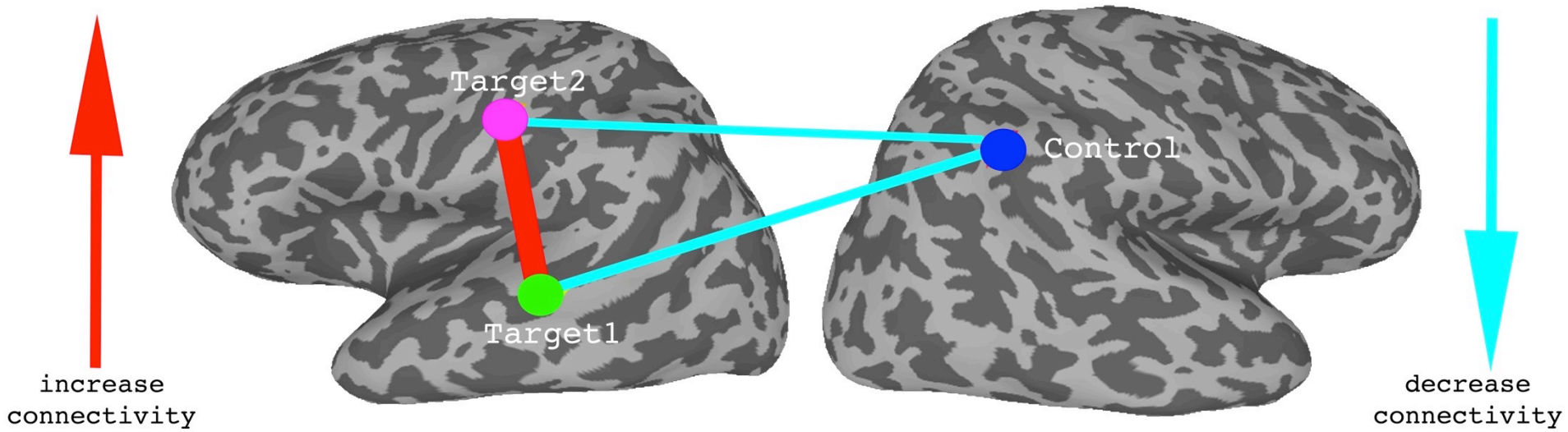


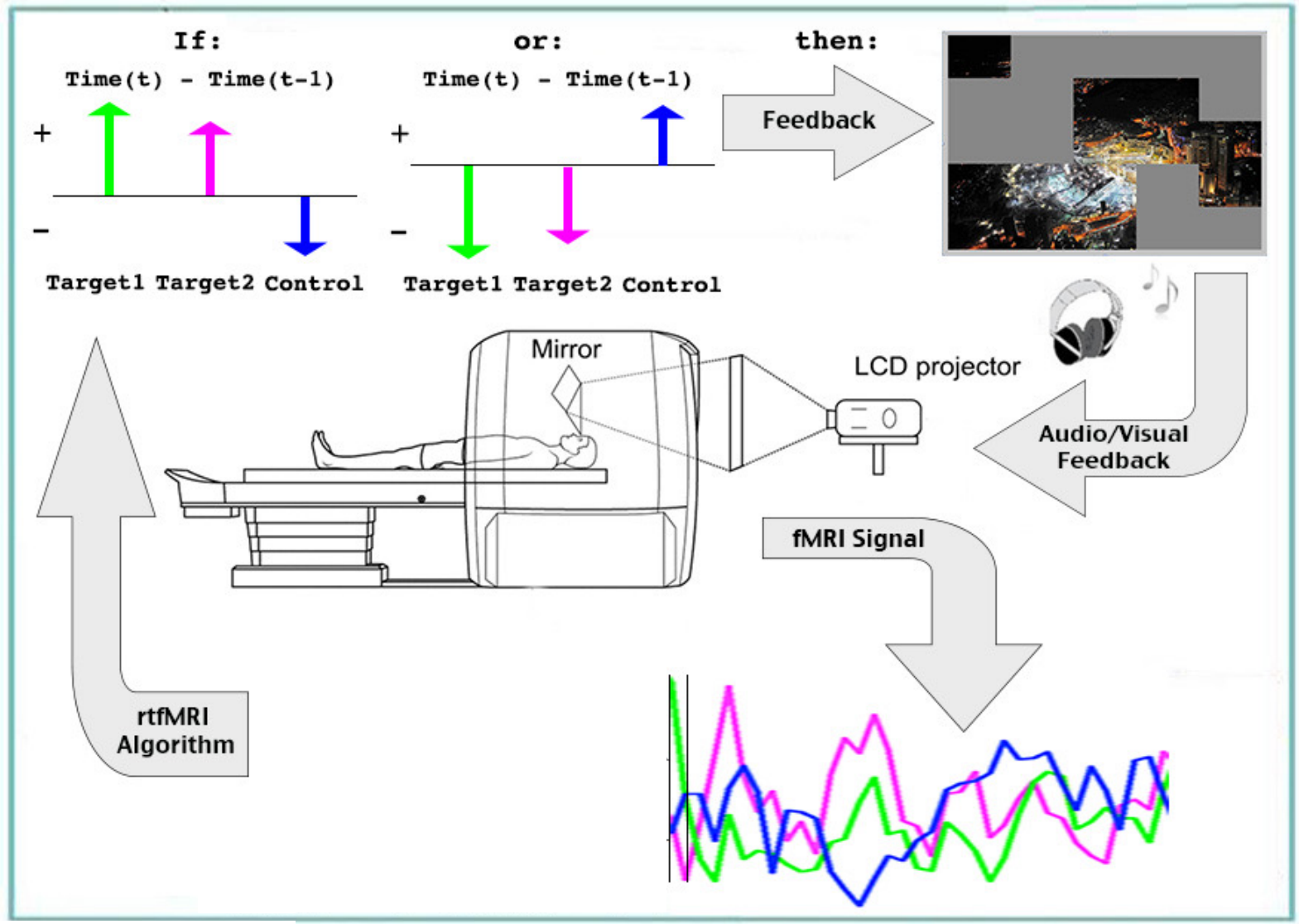
Aberrant networks in autism

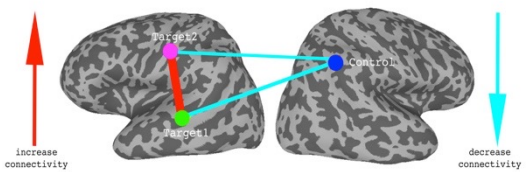


Gotts et al., Brain 2013

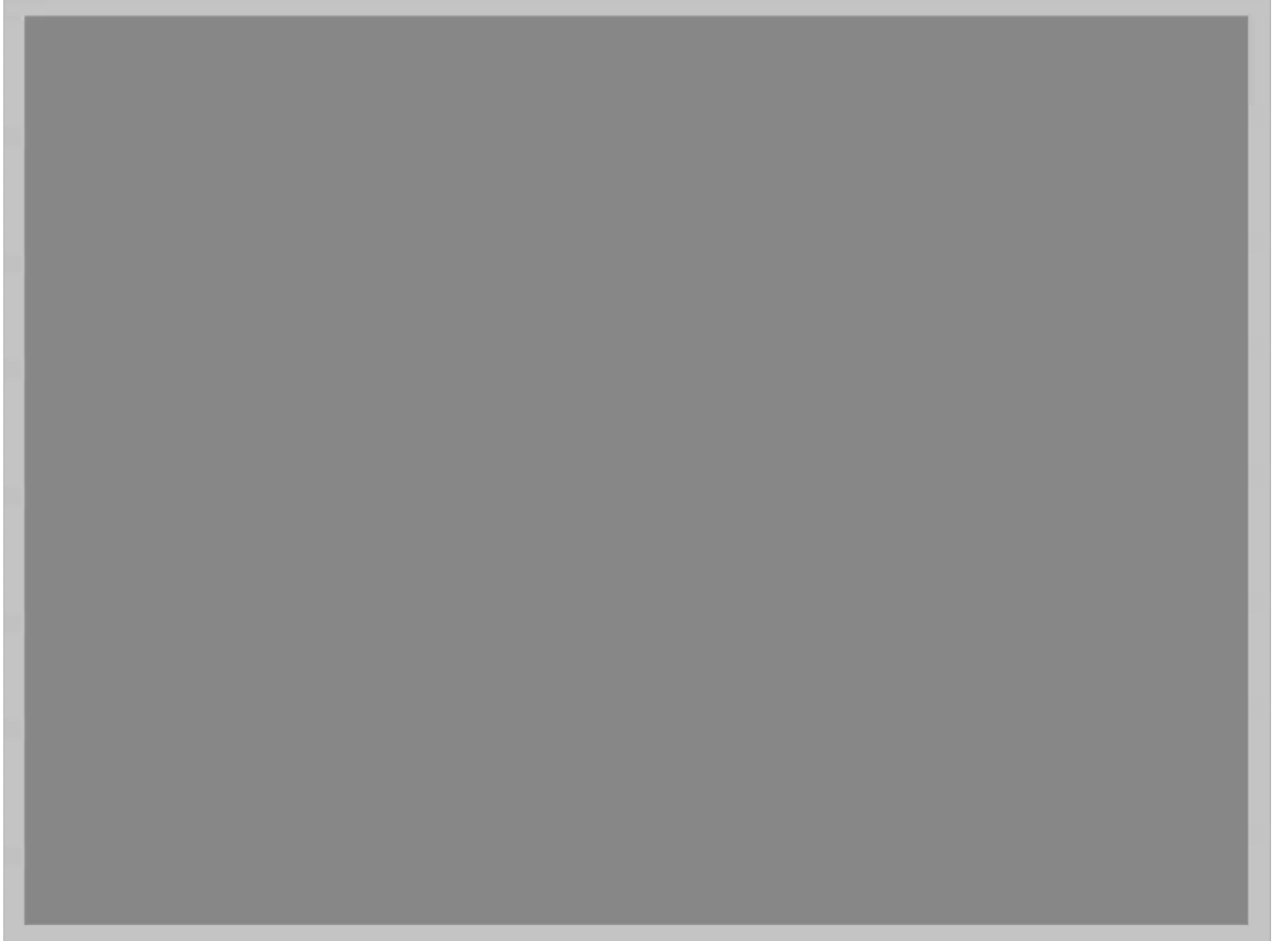
Goal


Target2
Control
Target1
increase
connectivity
decrease
connectivity

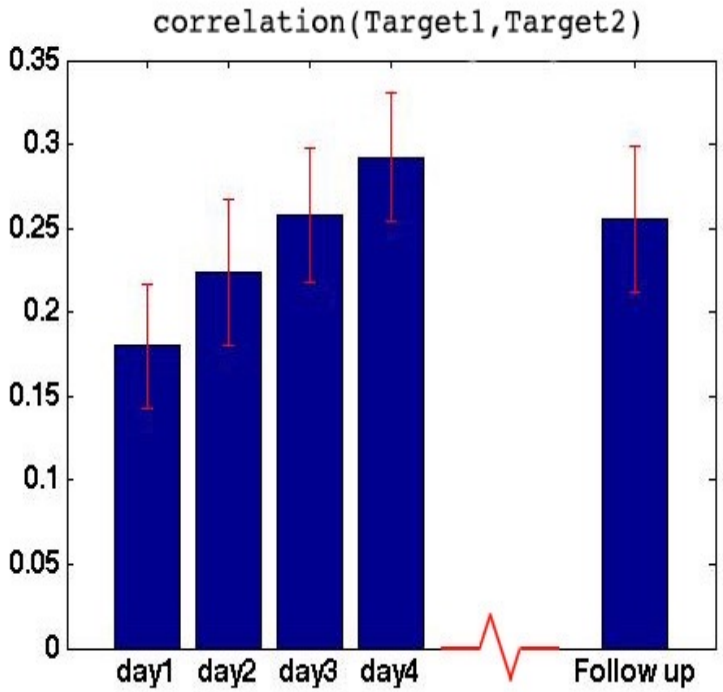


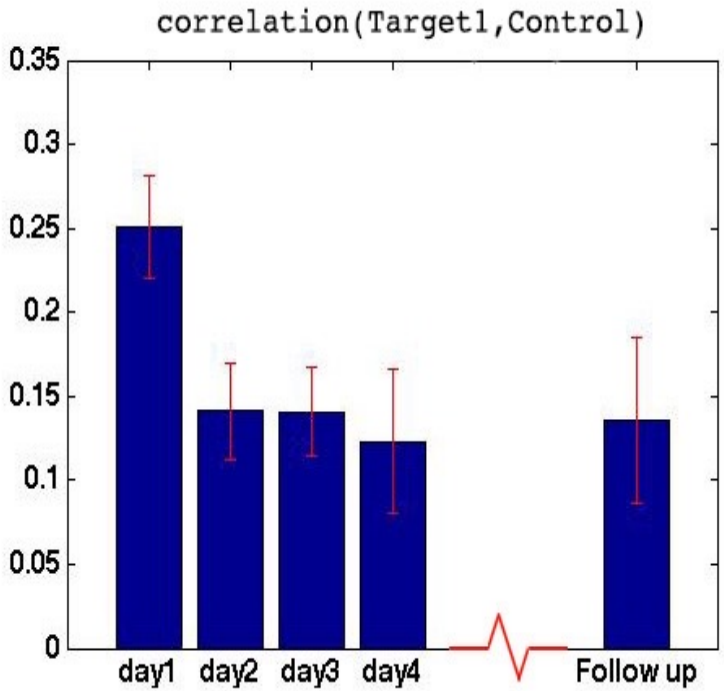


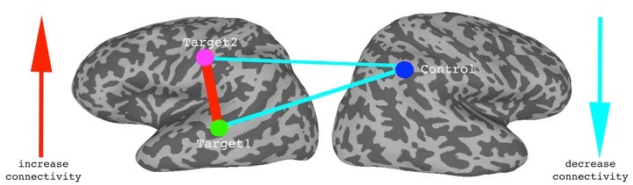
Ramot et al., eLife 2017



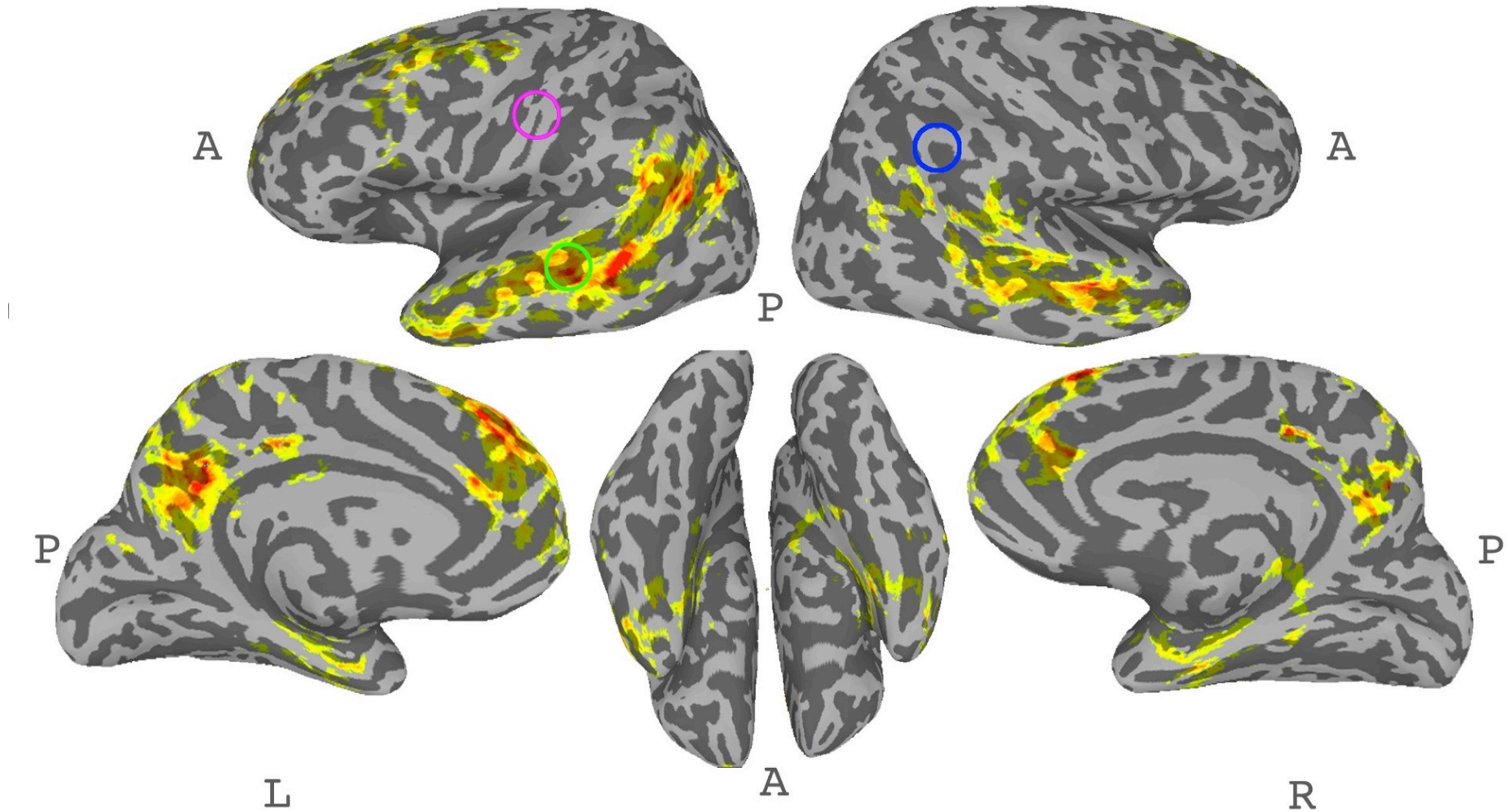
Long term changes







Target 2 minus Control, day 4 minus day 1



Conclusions

- Real-time fMRI neurofeedback is a potentially powerful tool
- Neurofeedback can change networks, even when it is implicit
- Caution must be used in the design of neurofeedback studies, and the interpretation of their results

Open questions

- How does changing the networks change behavior?
- Can you train any network, given the right feedback / enough time?
- What is the mechanism for neurofeedback learning?
- Which factors influence variability between subjects?
- What is the optimal network size / complexity to train?
- What is the optimal network feature to train?
- What is the optimal training technique / level of consciousness?