Mathematical Modeling of Spontaneous Brain Activity and Psychiatry

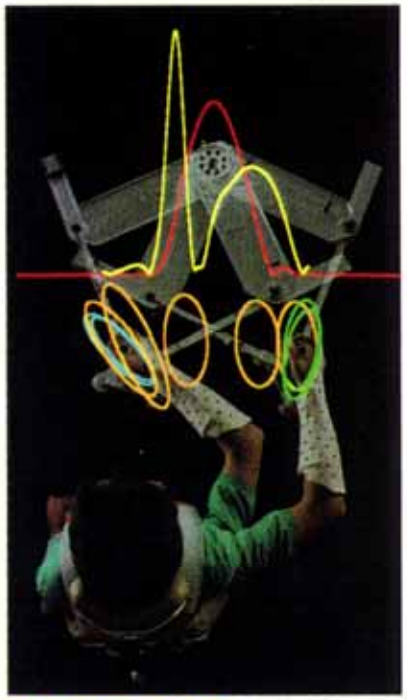
ATR Computational Neuroscience Labs

Mitsuo Kawato

Discovery Channel

ISSN 0036-8075
5 APRIL 1996
VOLUME 272
NUMBER 5258

SCIENCE



32 & 117
Arms control

NEWS & COMMENT

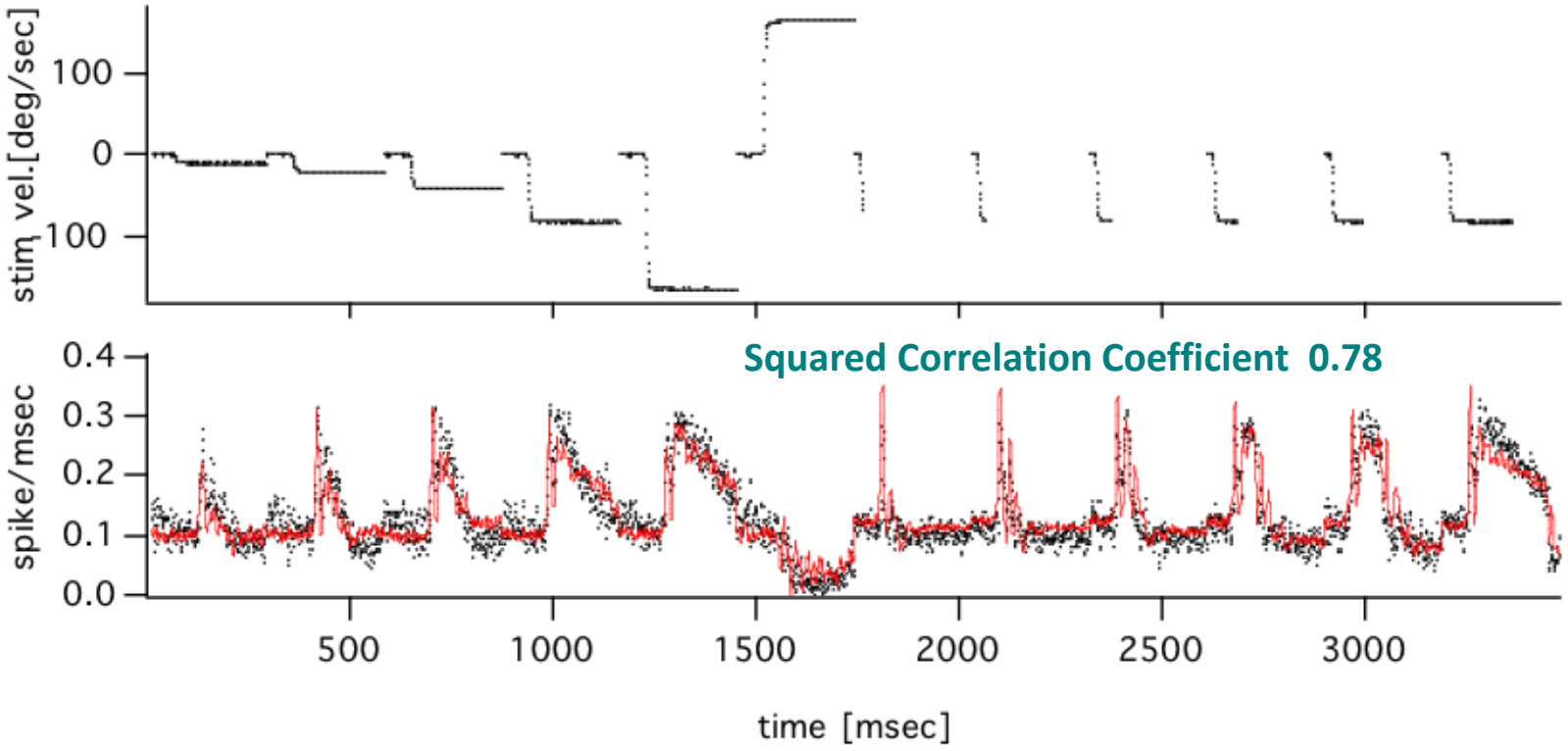
RESEARCH NEWS

Neuroscience: Tilting Against a Major Theory of Movement Control

Reconstruction of Firing Frequency for Different Stimulus Speeds and Duration

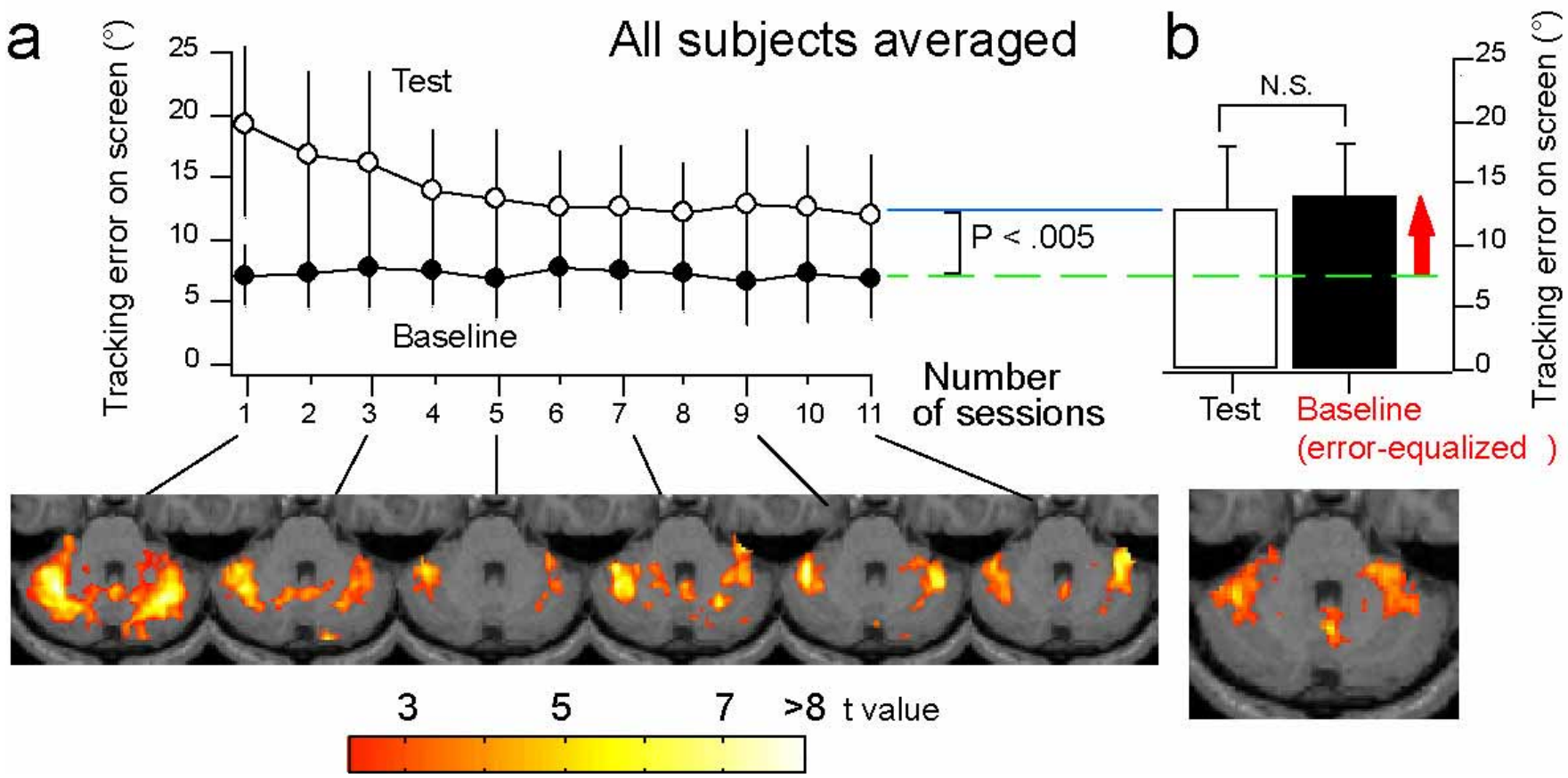
f(t): firing frequency *θ(t)*: eye movement

$$f(t) = M\ddot{\theta}(t+\delta) + B\dot{\theta}(t+\delta) + K\theta(t+\delta) + f_{bias}$$



Shidara M, Kawano K, Gomi H, Kawato M: Inverse-dynamics model eye movement control by purkinje cells in the cerebellum. *Nature*, **365**, 50-52 (1993).

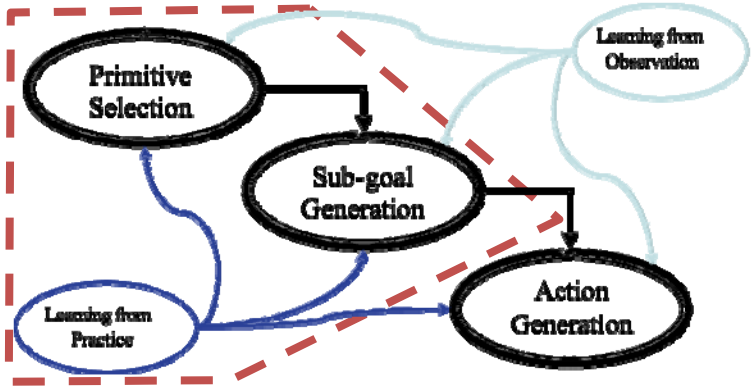
Behavioral and Imaging Data for Learning Sessions

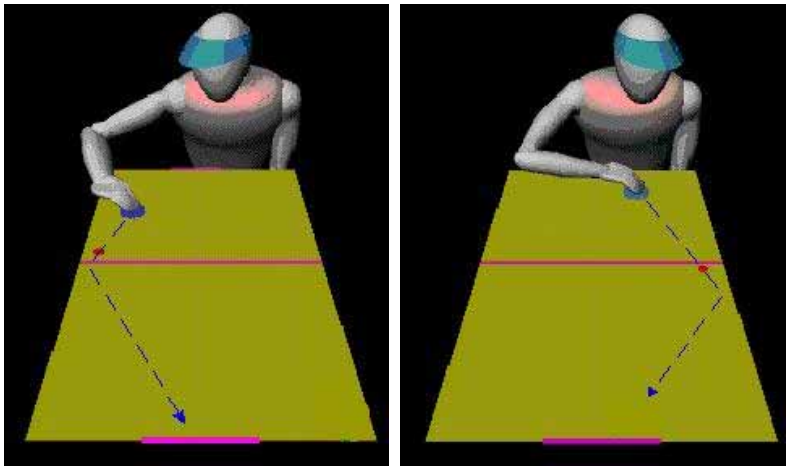


Imamizu H, Miyauchi S, Tamada T, Sasaki Y, Takino R, Puetz B, Yoshioka T, Kawato M: Human cerebellar activity reflecting an acquired internal model of a new tool. ***Nature* 403** 192-195(2000)

DB Air Hockey by Reinforcement Learning, Learning by Watching and Skill Learning

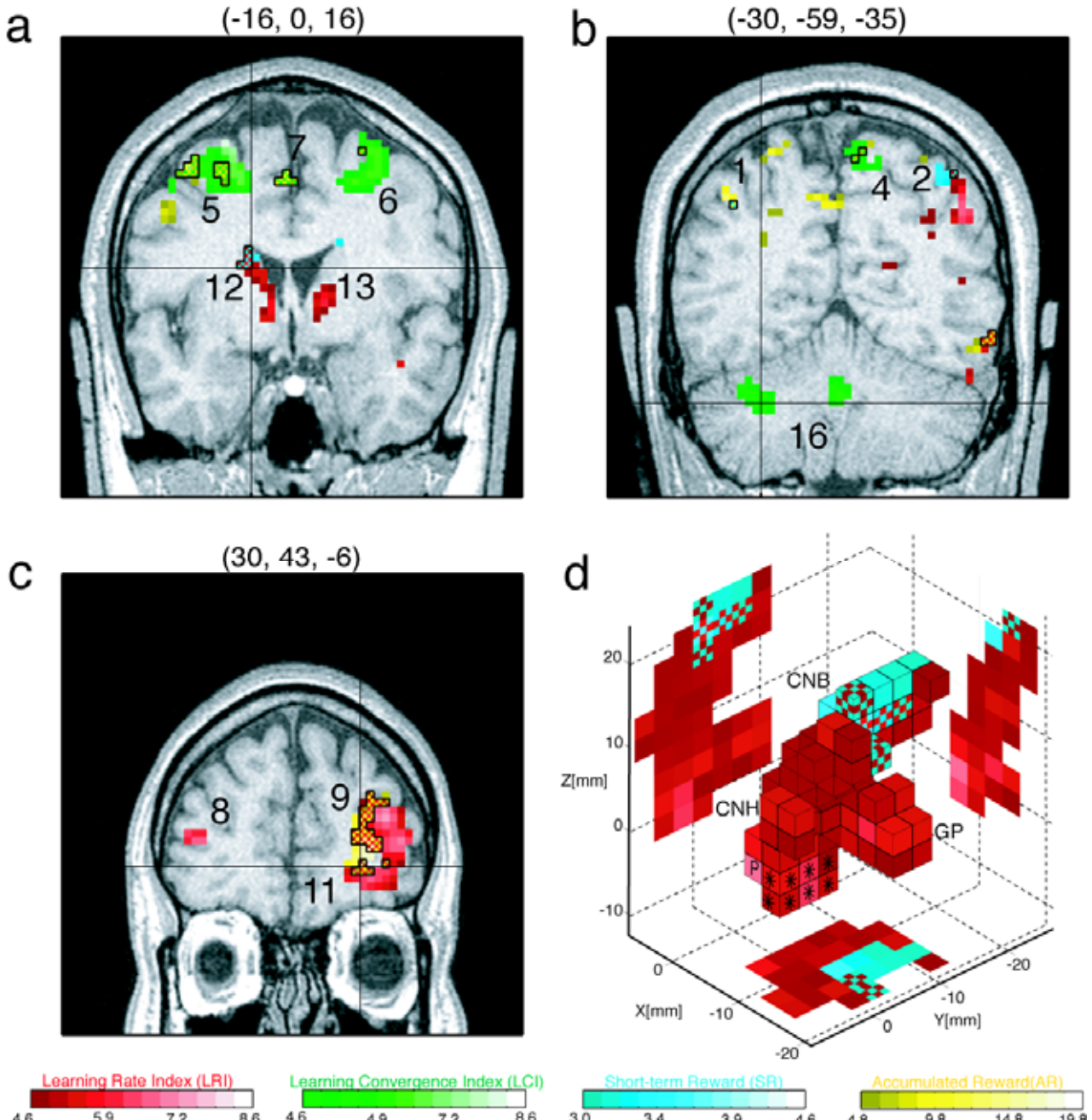
- Learn appropriate actions and sub-goals for the observed situation.
  - Database initialized with supervised data; observes human player.
  - Actions: Right bank shot, left bank shot, etc.
- Learn by adjusting the distance to the query point within the database.
  - Data is retrieved using locally weighted learning (LWL) techniques.
  - Weights are updated using Q learning techniques.
    - Agent receives feedback (reward and penalty) while playing.





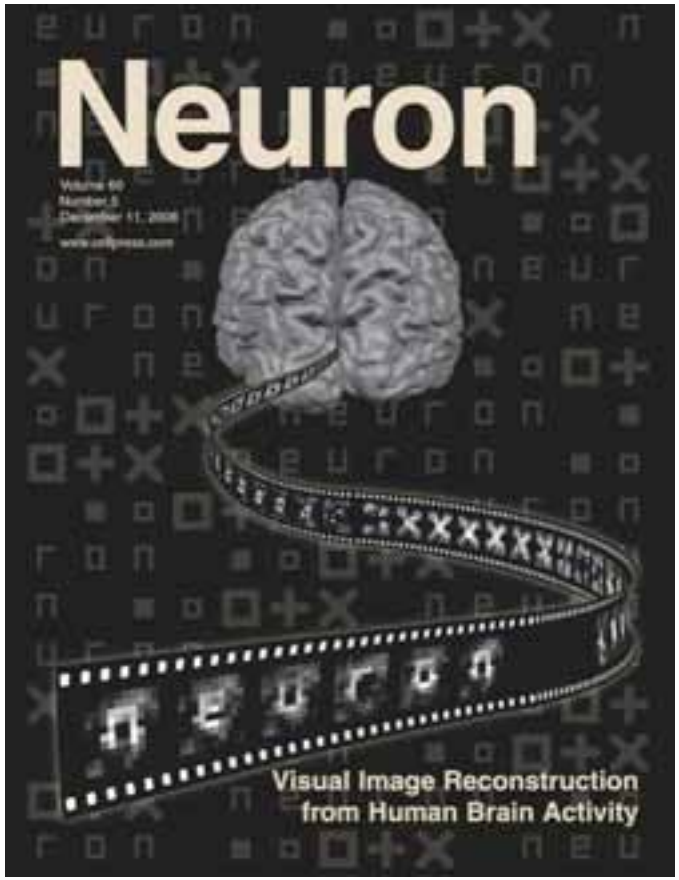
Air Hockey

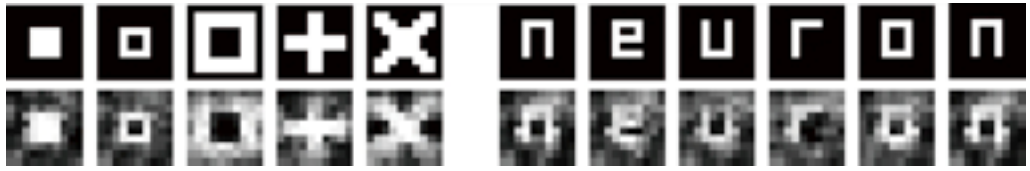
Darrin C. Bentivegna (darrin@atr.jp)

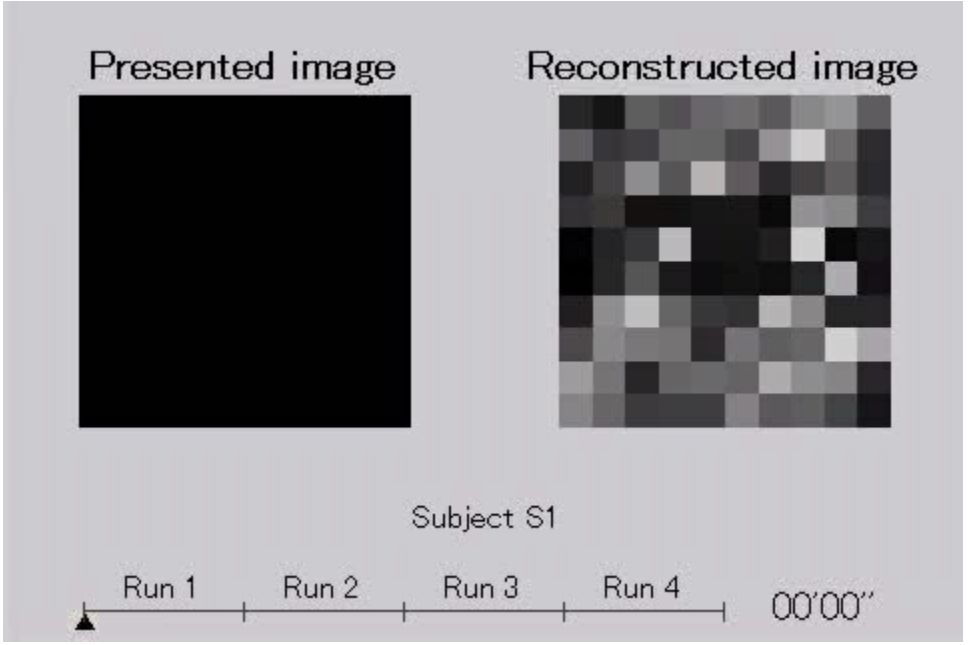


Haruno M, Kuroda T, Doya K, Toyama K, Kimura M, Samejima K, Imamizu H, Kawato M: A neural correlate of reward-based behavioral learning in caudate nucleus: a functional magnetic resonance imaging study of a stochastic decision task. *Journal of Neuroscience* **24**, 1660-1665 (2004)

Reconstruction of Black and White General Images from V1 fMRI Signal





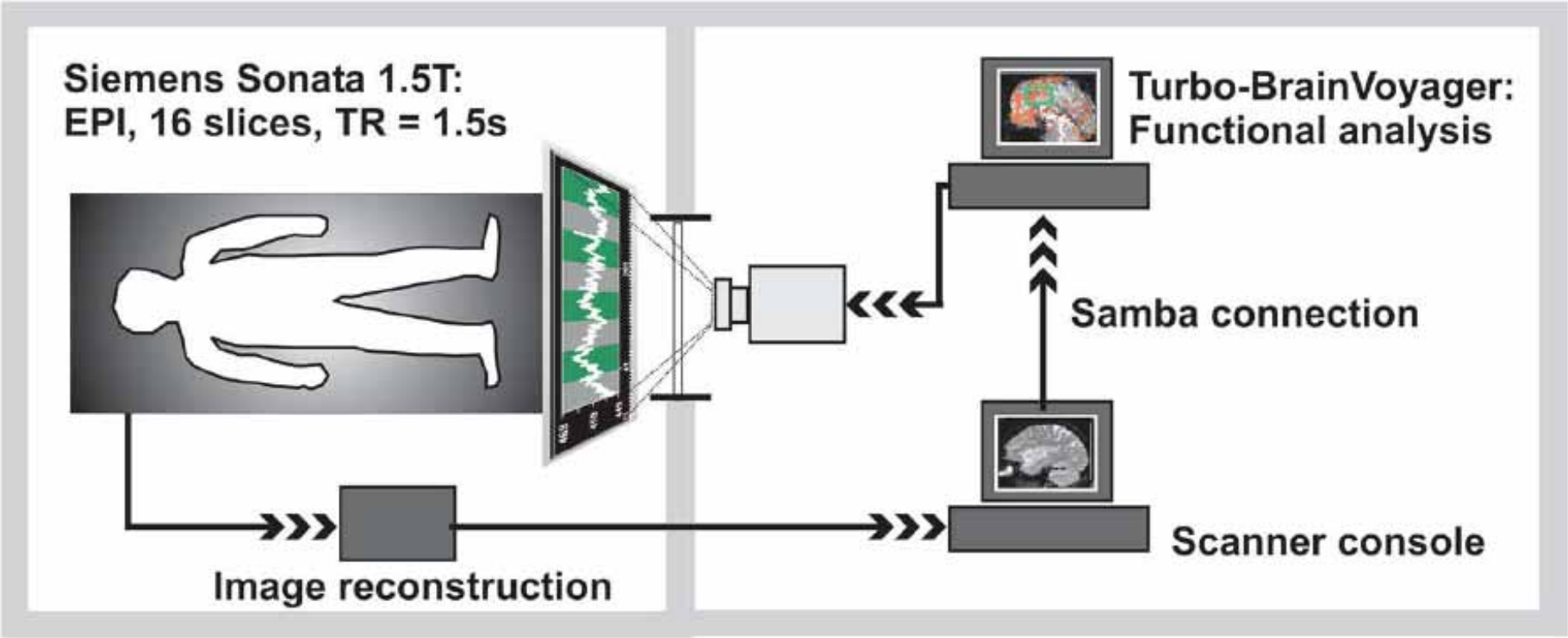


Miyawaki, Uchida, Yamashita, Sato, Tanabe, Sadato, Kamitani *Neuron* (2008)

Dream Reading

Neural decoding of visual imagery during sleep. T. Horikawa, M. Tamaki, Y. Miyawaki, Y. Kamitani, *Science*, **340**, 639-642 (2013)

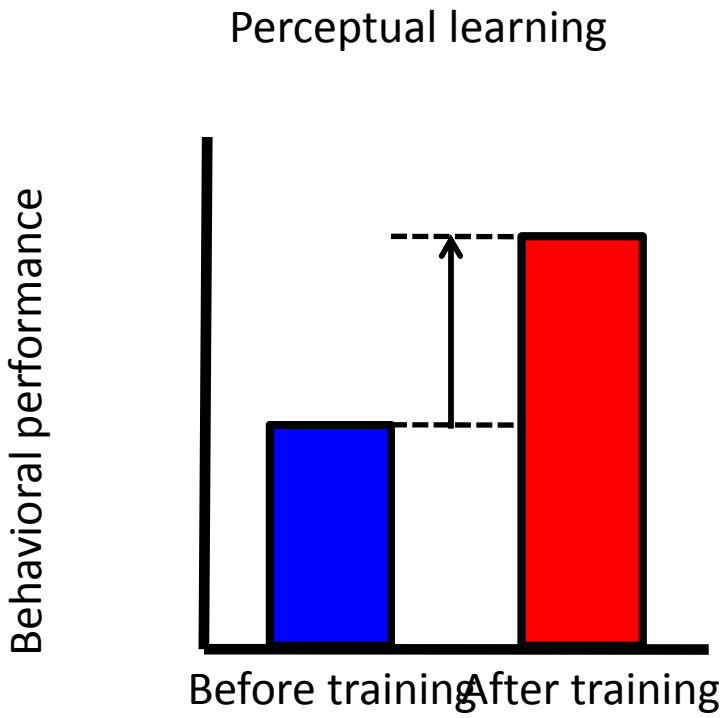
ROI fMRI real-time neurofeedback; pain, Parkinson's disease, anxiety



NeuroImage. 2003 Jul;19(3):577-86.**Physiological self-regulation of regional brain activity using real-time functional magnetic resonance imaging (fMRI): methodology and exemplary data . Weiskopf N, Veit R, Erb M, Mathiak K, Grodd W, Goebel R, Birbaumer N.**

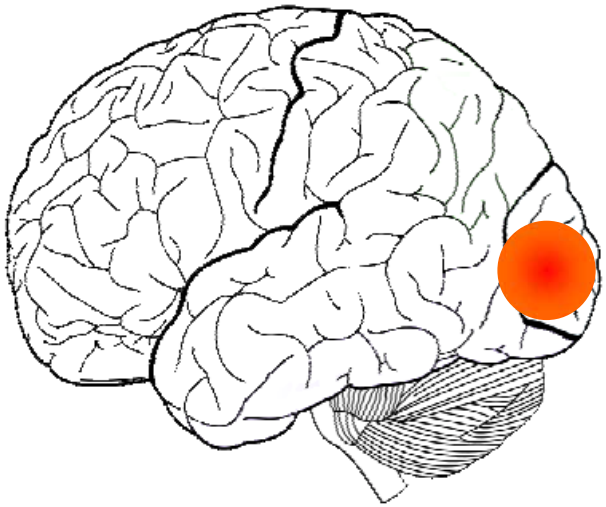
ACC for Pain; De Charms RC *et al.* (2005) *PNAS* **102**, 18626
SMA for Parkinson; Subramanian L. *et al.* (2011) *J Neurosci*. **31**, 16309
OFC for OCD; Scheinost D*, et al.* (2013) *Translational psychiatry* **3**:e250.

Are V1/V2 plastic enough to accommodate visual perceptual learning?



Conventional way:
Correlation

Our goal:
Causality



Shibata K, Watanabe T, Sasaki Y, Kawato M: Perceptual learning incepted by decoded fMRI neurofeedback without stimulus presentation. *Science*, **334** 1413-1415 (2011)

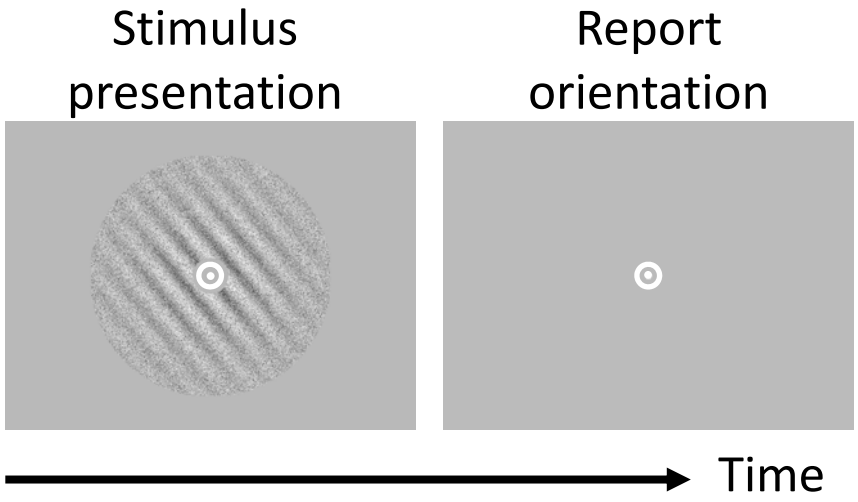
Behavioral pre- and post-test

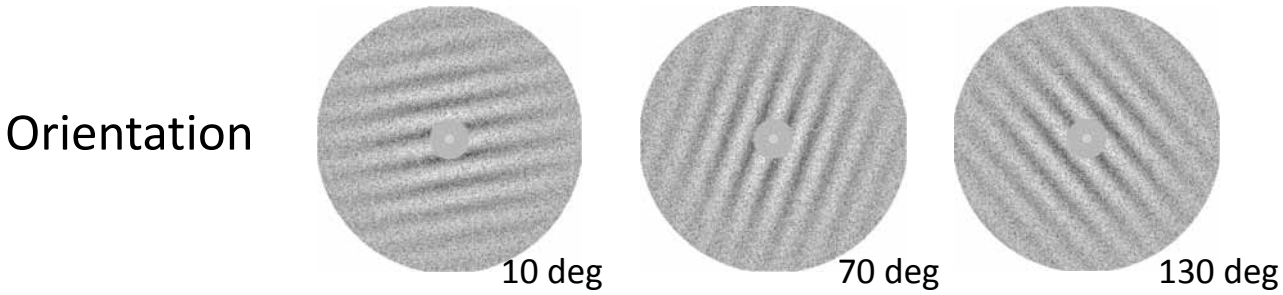
Behavioral pre-test

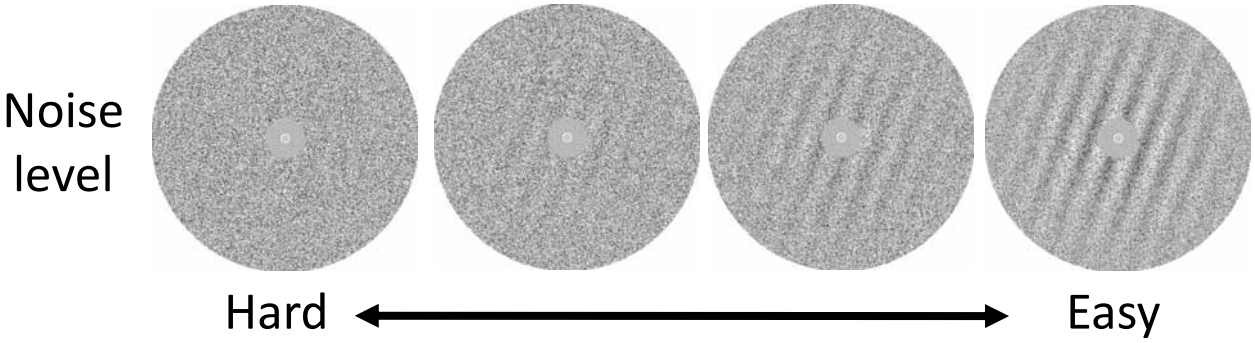
FMRI Decoder construction

Decoded fMRI neurofeedback

Behavioral Post-test







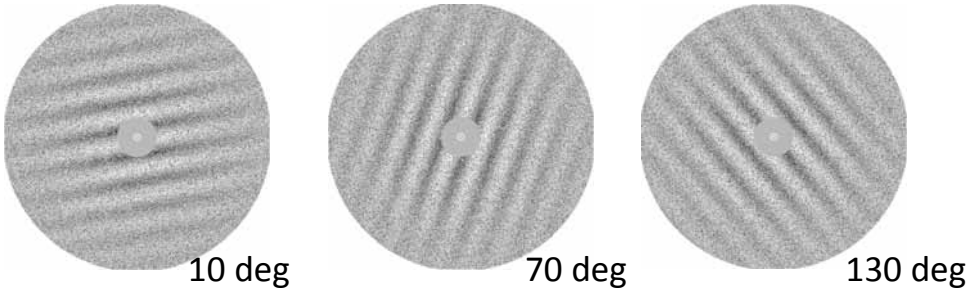
fMRI decoder construction

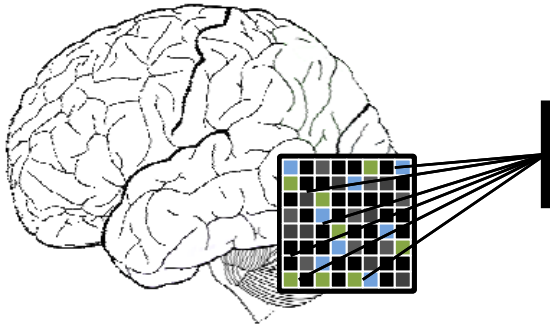
Behavioral pre-test

FMRI Decoder construction

Decoded fMRI neurofeedback

Behavioral Post-test





Decoder

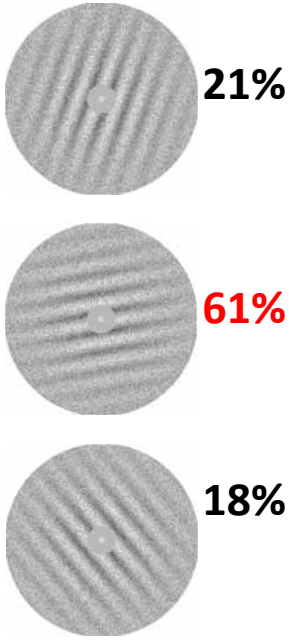
Multinomial

Sparse

Logistic

Regression

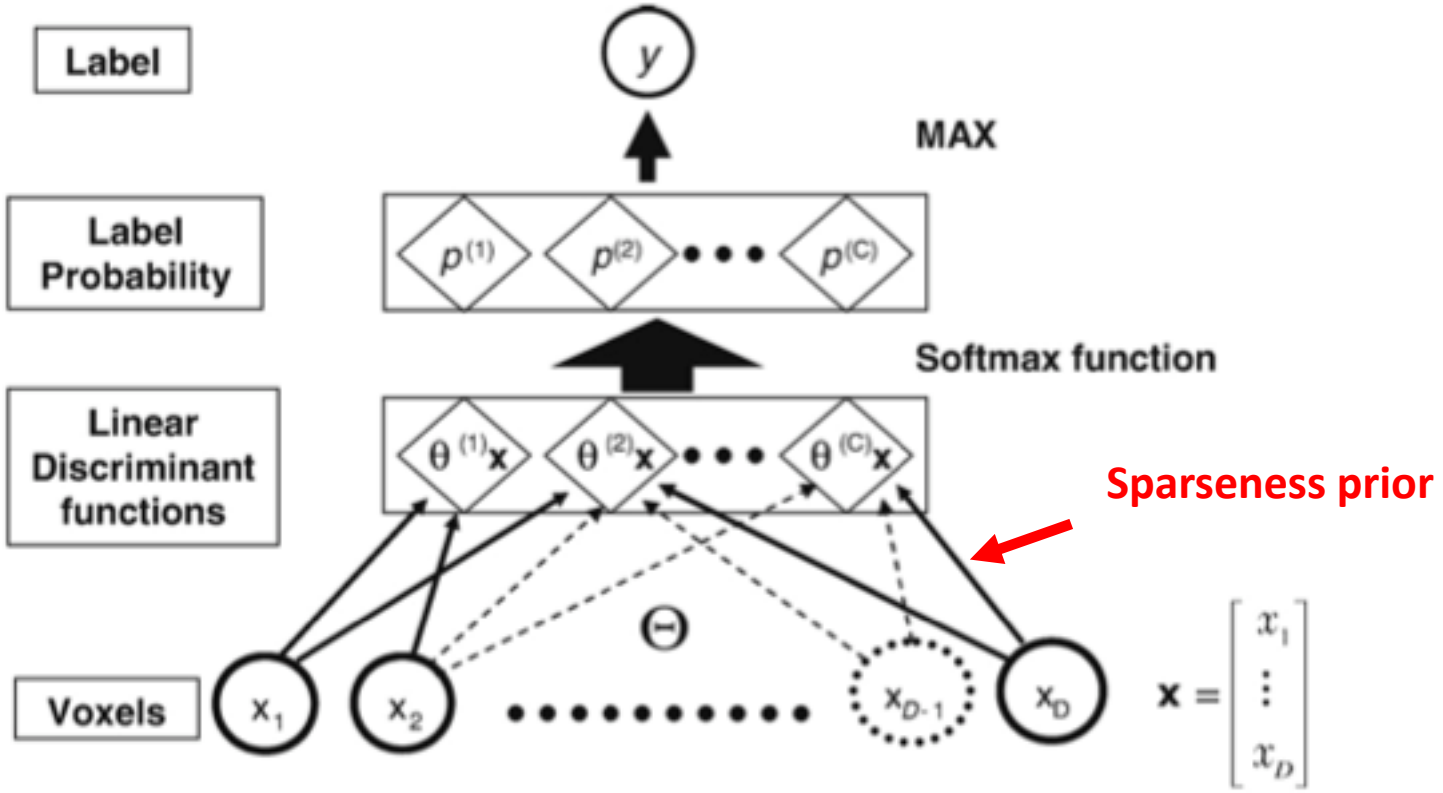
Likelihoods



Multinomial Sparse Logistic Regression

Yamashita et al., *NeuroImage*, 2008

$$f_c\left(\mathbf{x};\boldsymbol{\theta}^{(c)}\right)=\sum_{d=1}^{D}\theta_d^{(c)}x_d+\theta_0^{(c)}\quad c=1,\ldots,C,\qquad P(S_c|\mathbf{x})=\frac{\exp\left(f_c\left(\mathbf{x};\boldsymbol{\theta}^{(c)}\right)\right)}{\sum_{k=1}^{C}\exp\left(f_k\left(\mathbf{x};\boldsymbol{\theta}^{(k)}\right)\right)}\quad c=1,\ldots,C.$$



10-day Decoded fMRI neurofeedback

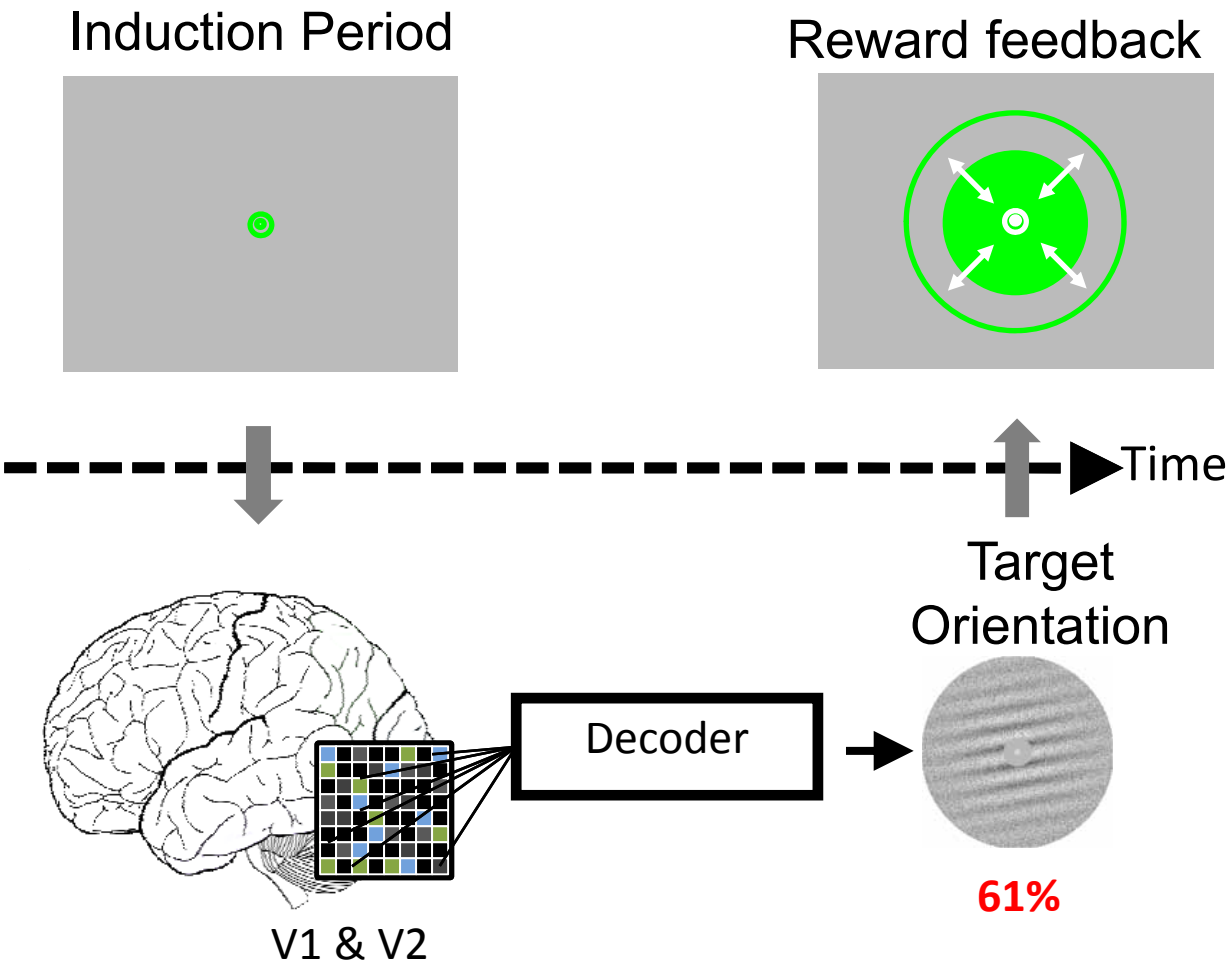
Behavioral pre-test

FMRI Decoder construction

Decoded fMRI neurofeedback

Behavioral Post-test

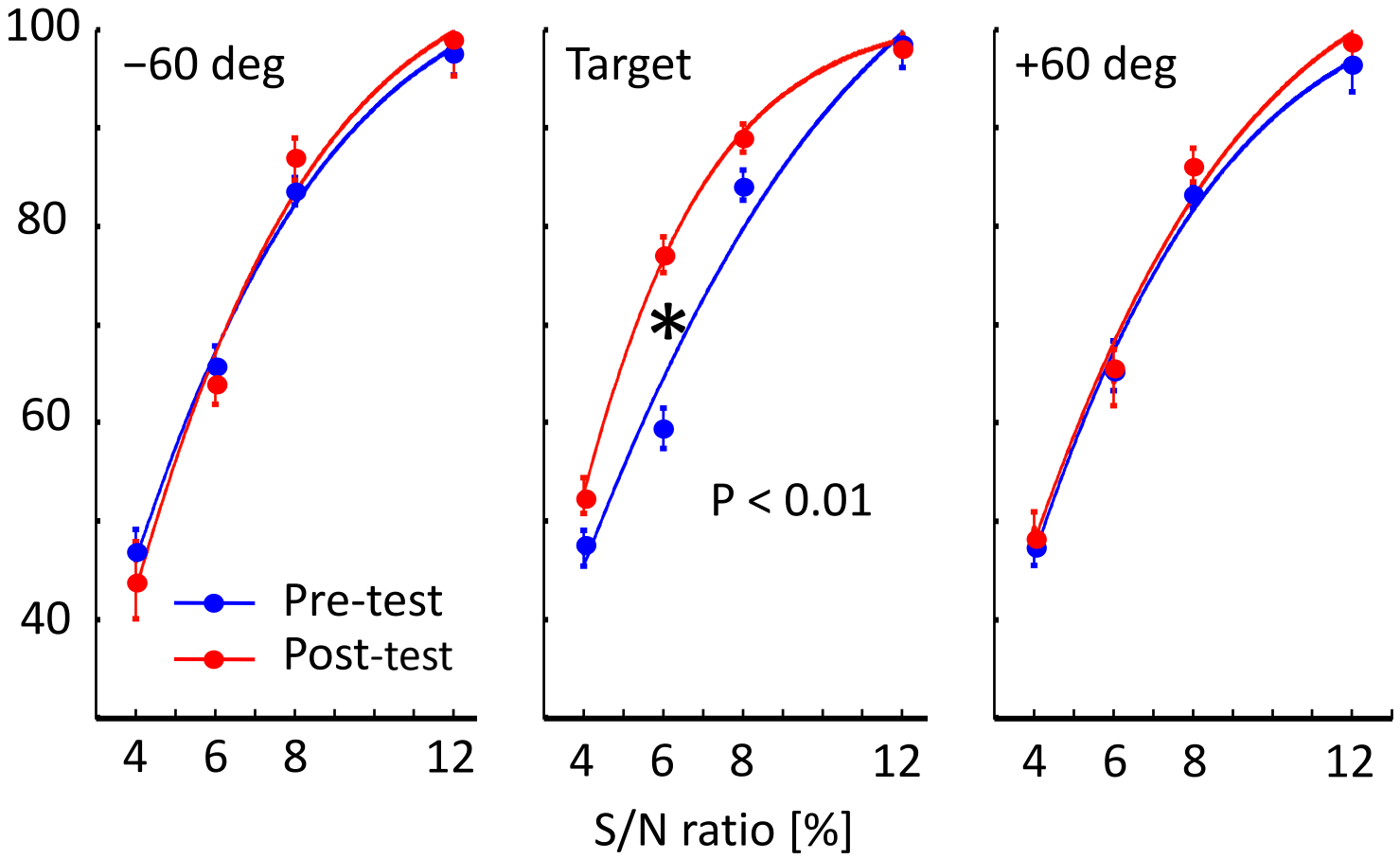
Visual stimulus to subjects



Neurofeedback system

Accuracies only in target orientation improved in post-tests compared with pre-tests

3-way ANOVA: Day * Orientation * S/N ratio, P = 0.02

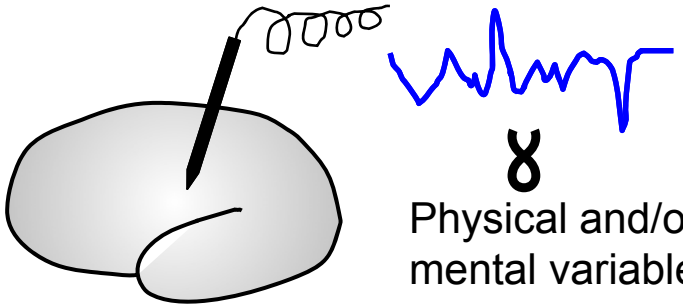


Conclusions of Perceptual Learning induced by decoded Neurofeedback

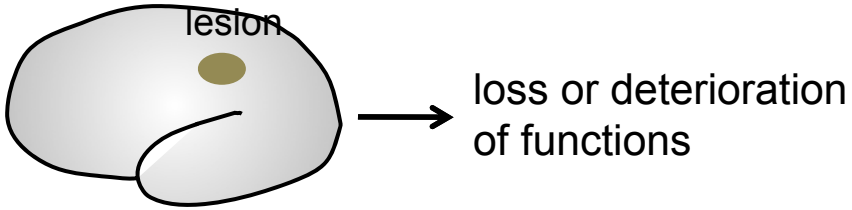
- Mere induction of spatial pattern of neural activity is sufficient to cause visual perceptual learning without visual stimulus presentation.
- V1/V2 are locus of visual perceptual learning: demonstrating V1/V2 plasticity in adulthood
- Subjects were not aware of what the neurofeedback signal represents and which is the target orientation.
- Minimal information leak outside V1/V2

Correlation vs Cause-and-Effect; From neural codes to mind

(1) Correlation (fMRI, unit activity)

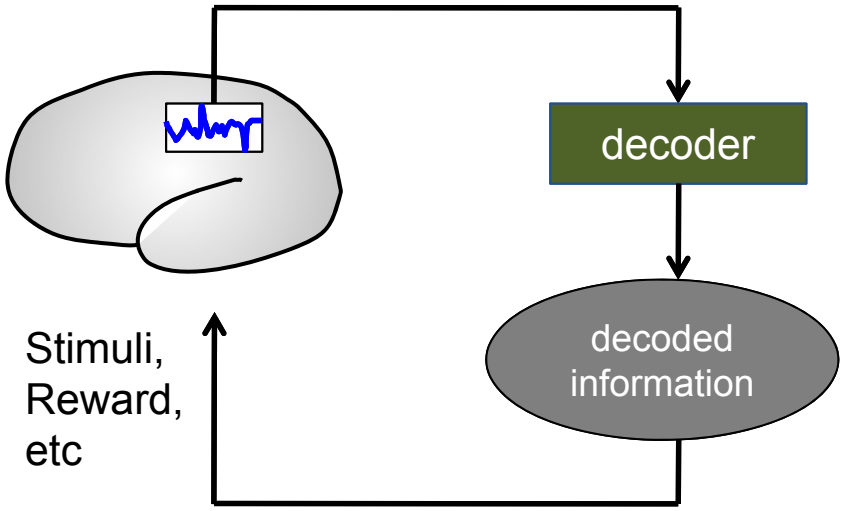


(2) Lesion (Patient, pharmacological, TMS)



- **Necessary condition**
- **No neural code examined**

(3) Decoded neurofeedback



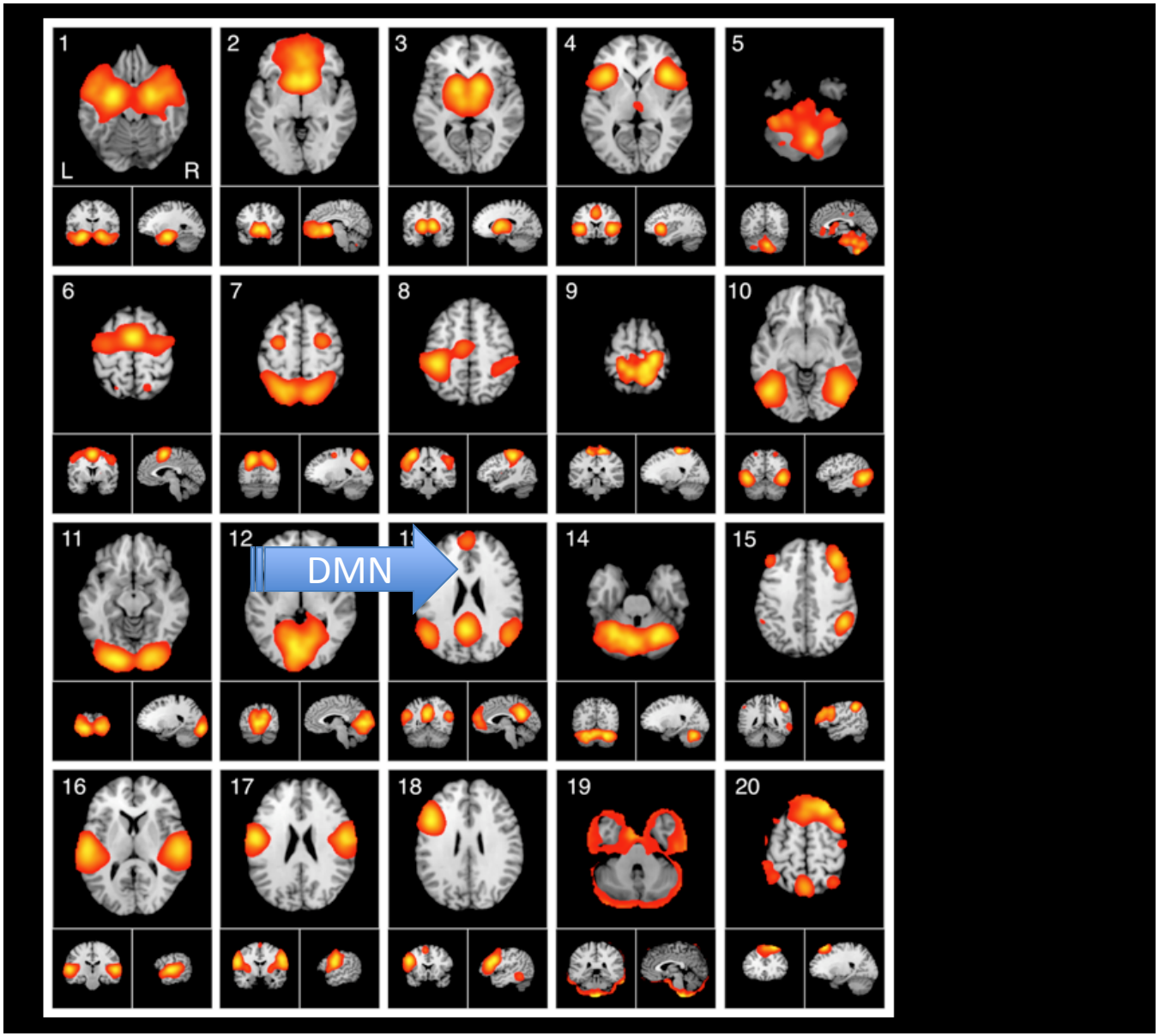
Induction of a specific neural code is sufficient to cause a specific function

Kawato M: From "understanding the brain by creating the brain" toward manipulative neuroscience. *Philosophical Transactions of the Royal Society B*, **363**, 2201-2214 (2008)

Why DecNef works out?

- Brain activity always fluctuates.
- If activity happens to fluctuate in a desired direction, the decoder detects it and a reward feedback is given to a subject and the brain.
- Synaptic plasticity is induced dependent on neuromodulators such as dopamine.
- Reinforcement learning without action but essentially the same as that for sensorymotor learning occurs in basal ganglia and cerebellum.
- Billions of synapses and millions of neurons fluctuate their activities to induce voxel fluctuation.
- Activated synapses in conjunction with reward may be potentiated, and depressed with penalty.

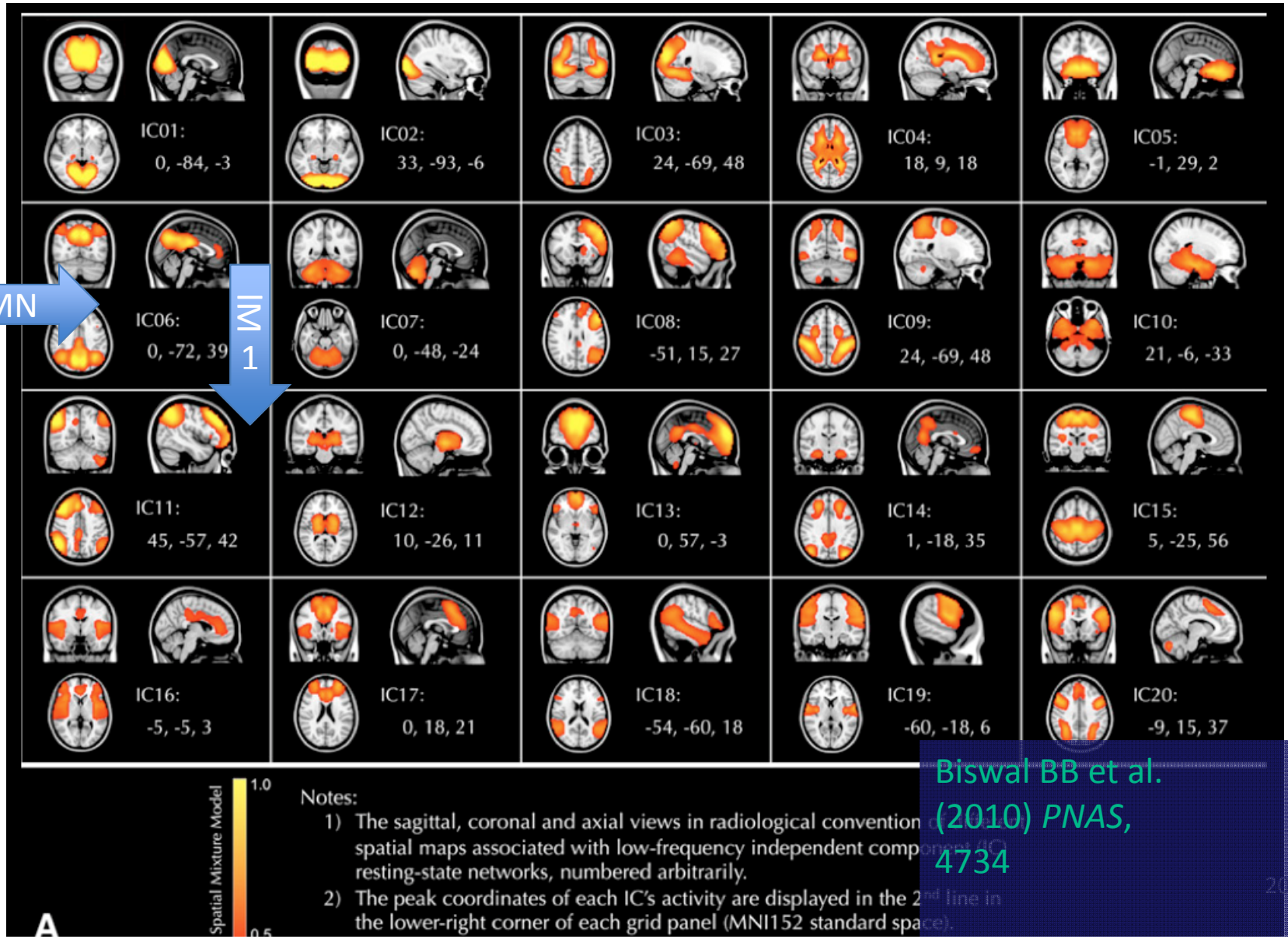
Independent Component Analysis of Big Data (30,000 sub., 10,000 exp., and 2,000 papers)



Laird AR et al.(2011) J. Cog. Neurosci. 4022

16 components out of 18 correspond well to those obtained from resting states

ICA from resting state activity of 306 subjects; rs-fcMRI



Biswal BB et al. (2010) *PNAS*, 4734