Real-time fMRI / fMRI Neurofeedback

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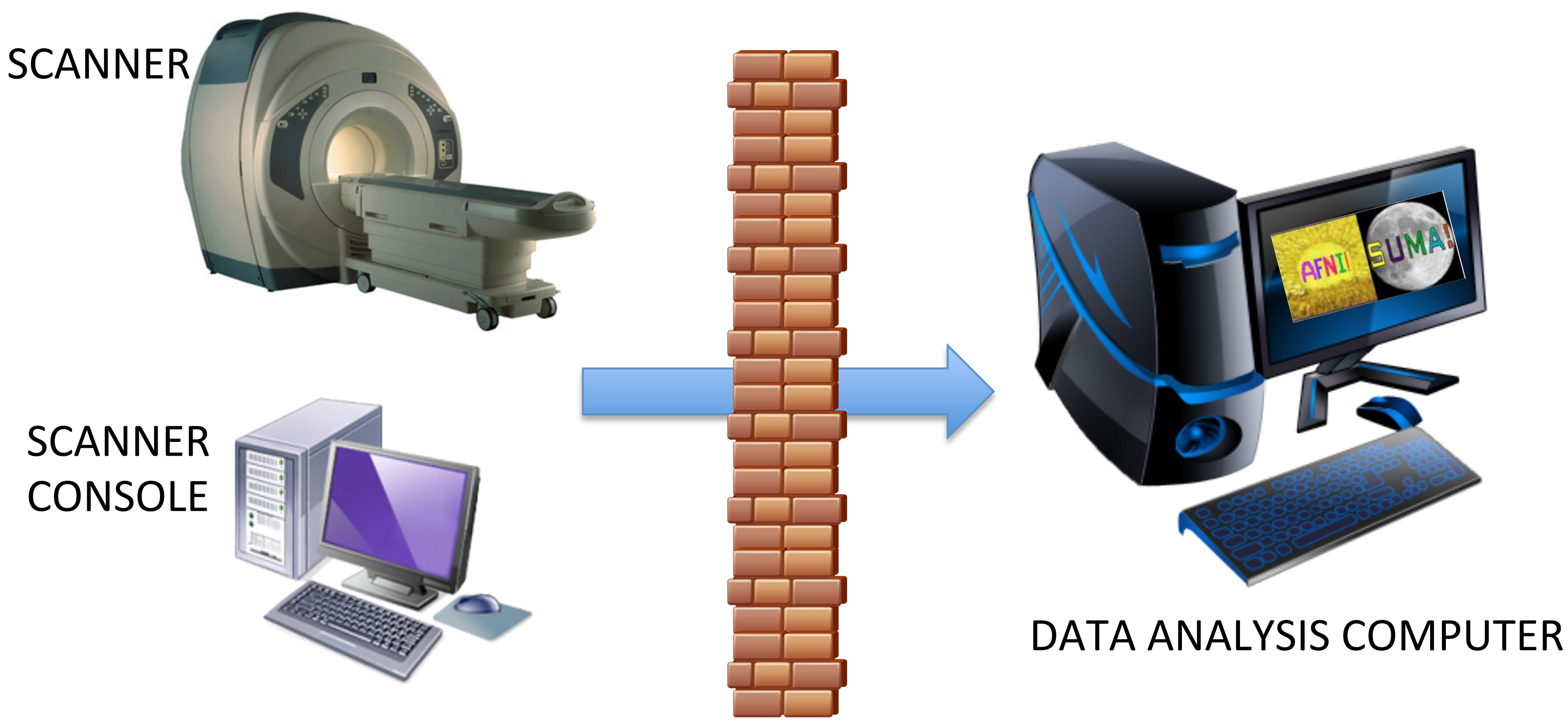
Outline

- What is “REALTIME fMRI”?
- Specific Example: NIH/AFNI Real-time fMRI System.
- Most Common Applications
  - Automatic On-line Data Quality Control
  - On-line Computation of Functional Localizations Maps
  - Neurofeedback / Brain-Computer Interfaces
- What do we know from these early experiments/prototypes
- Considerations when designing your own real-time fMRI studies

Traditional fMRI

fim.nimh.nih.gov

1 – 2 Hours	1 – 2 Days
DATA ACQUISITION	DATA ANALYSIS

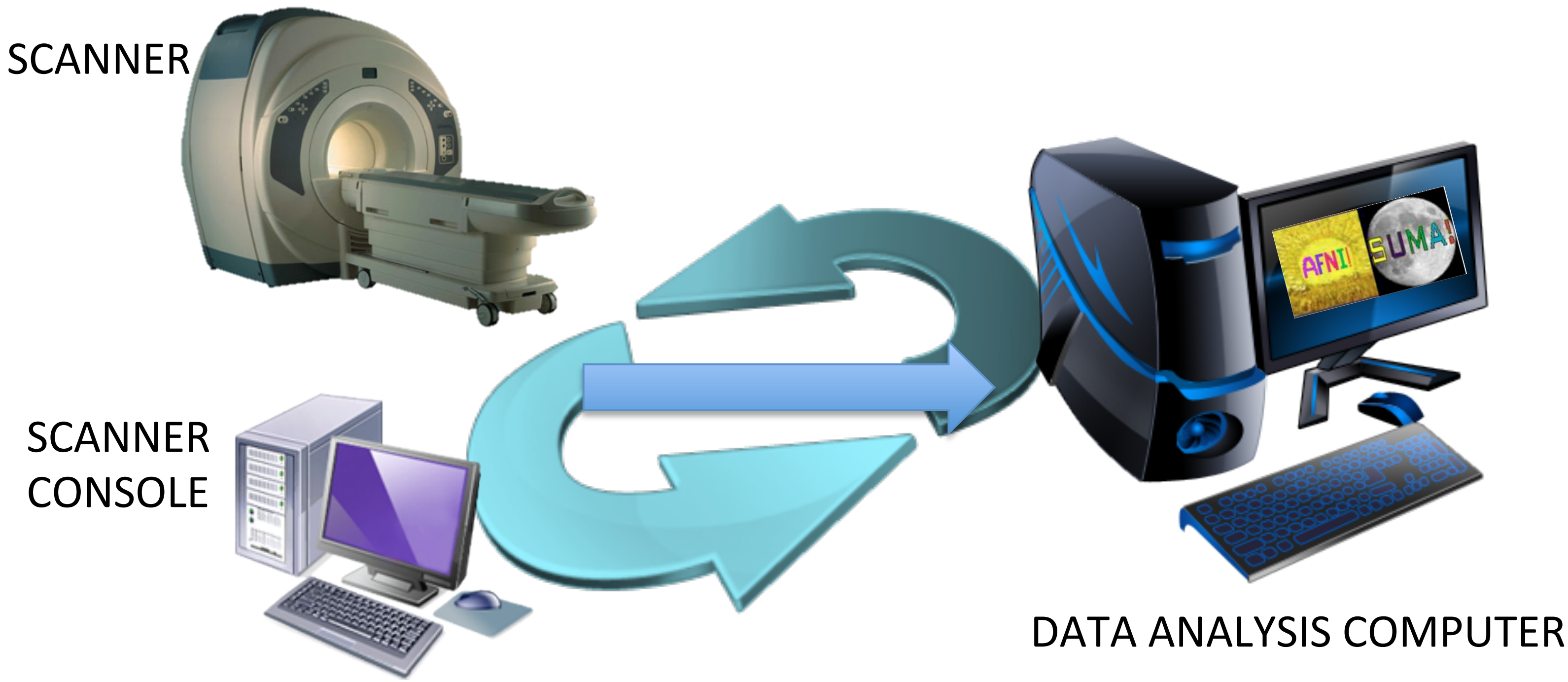


Real-time fMRI

fim.nimh.nih.gov

1 – 2 Hours

DATA ACQUISITION AND ANALYSIS



Real-time fMRI: Original Work

fim.nimh.nih.gov

Real-Time Functional Magnetic Resonance Imaging

Robert W. Cox, Andrzej Jesmanowicz, James S. Hyde   MRM 33(2); 1995

- <u>WHY NEAR-REAL-TIME VIEWING OF FMRI ACTIVATION IS DESIRABLE:</u>

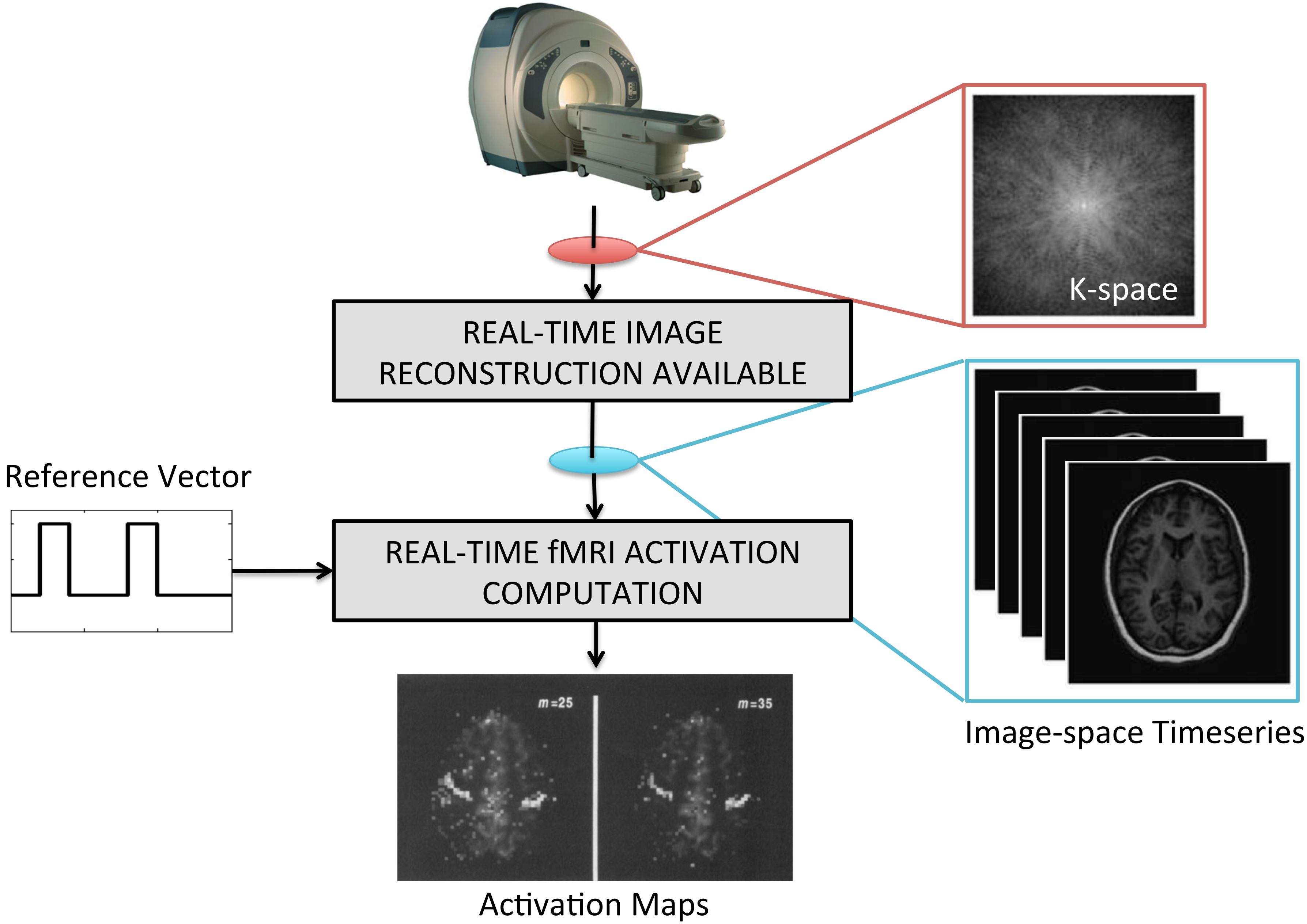
  1. Data Quality may be monitored as experiment progresses.
  2. Develop new task & stimulus protocols more quickly than offline analysis.
  3. Interactive experimental paradigms may be created.

- <u>FAST ALGORITHM TO RECURSIVELY COMPUTE:</u>

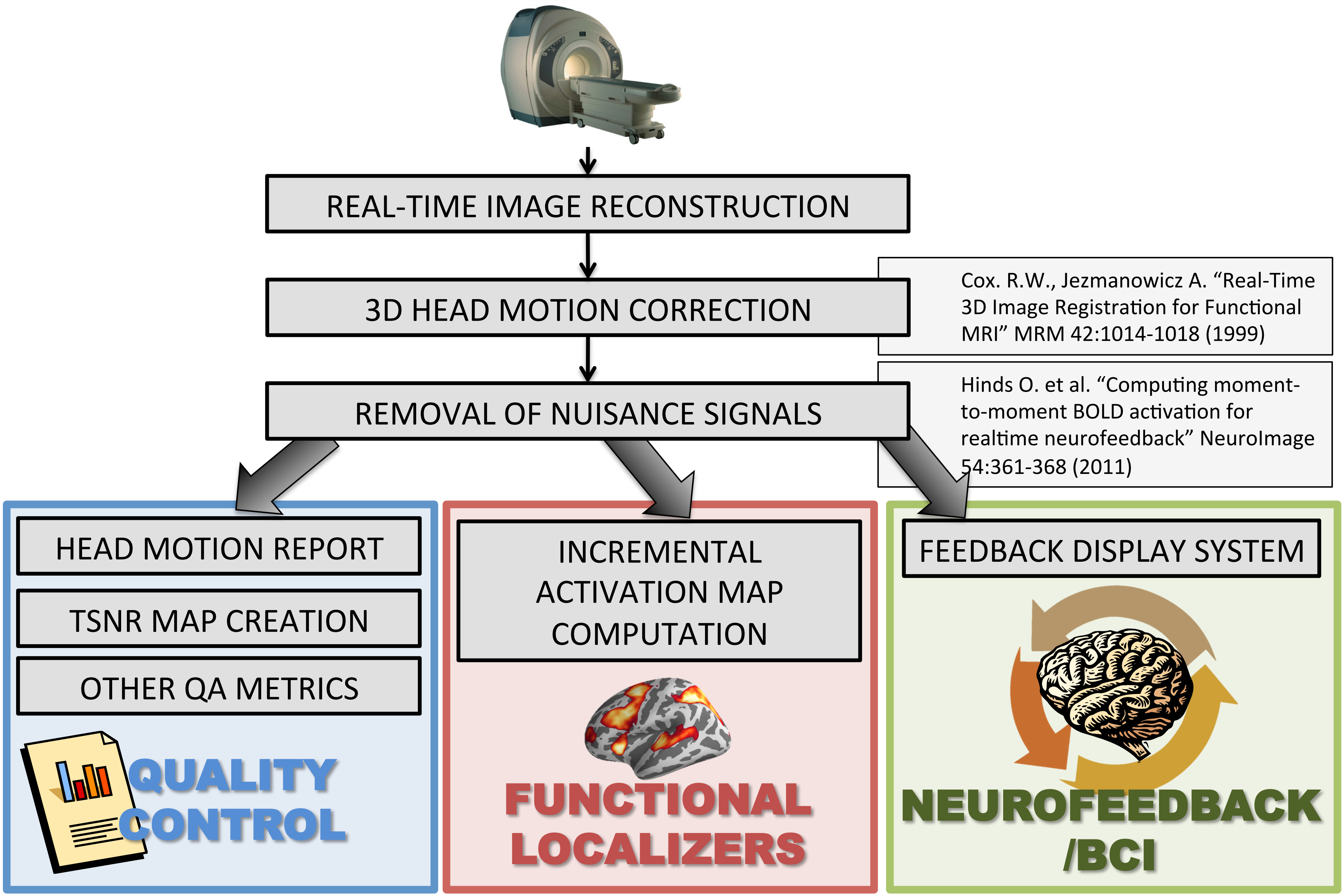
  1. Voxel-wise correlation between incoming time-series and reference vector
  2. Associated statistics and thresholded map.

- **<u>REAL-TIME fMRI WILL NOT BE A COMPLETE SUBSTITUTE FOR OFFLINE ANALYSIS</u>**

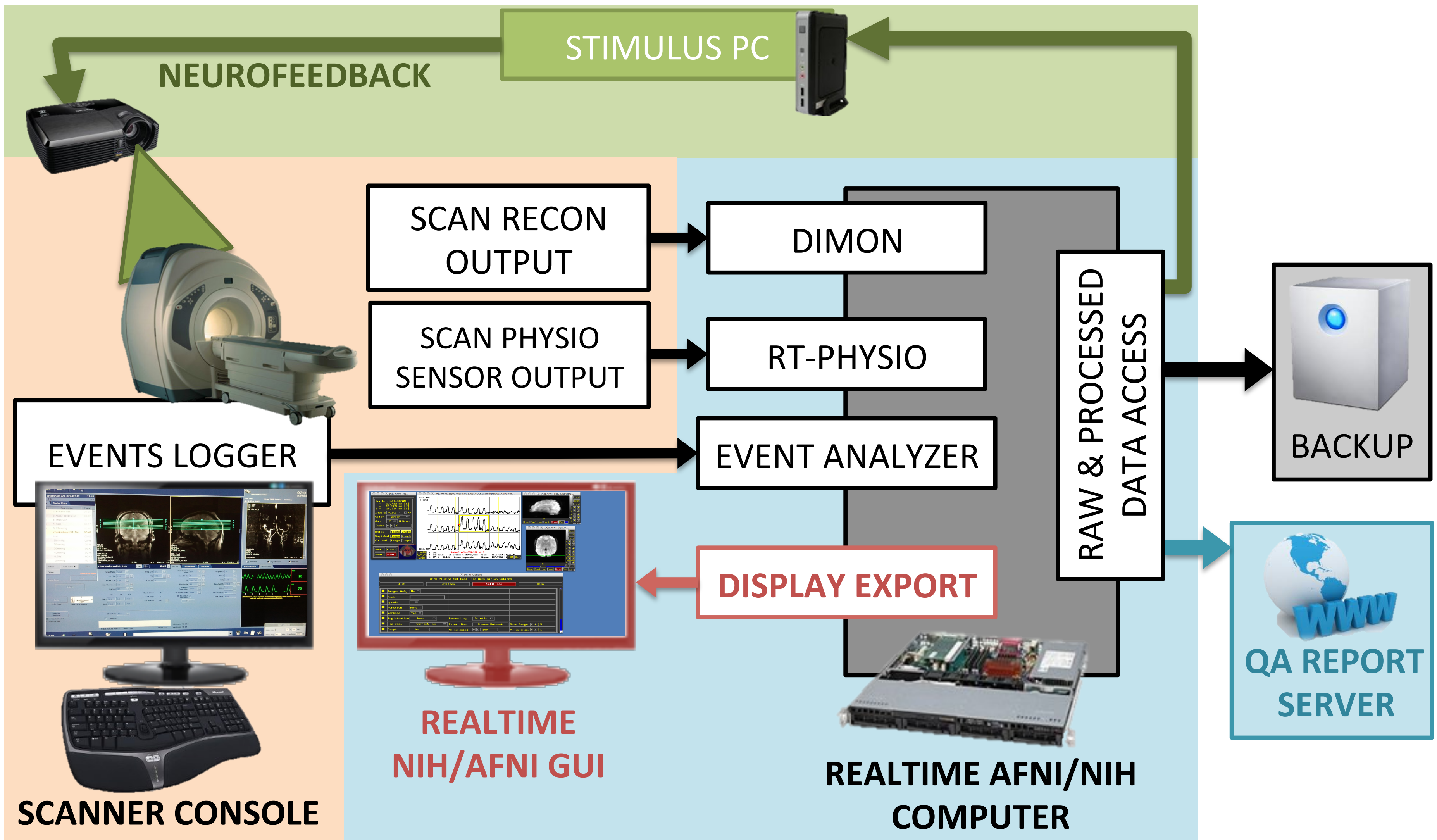
Real-time fMRI: Original Work



Real-time fMRI Today

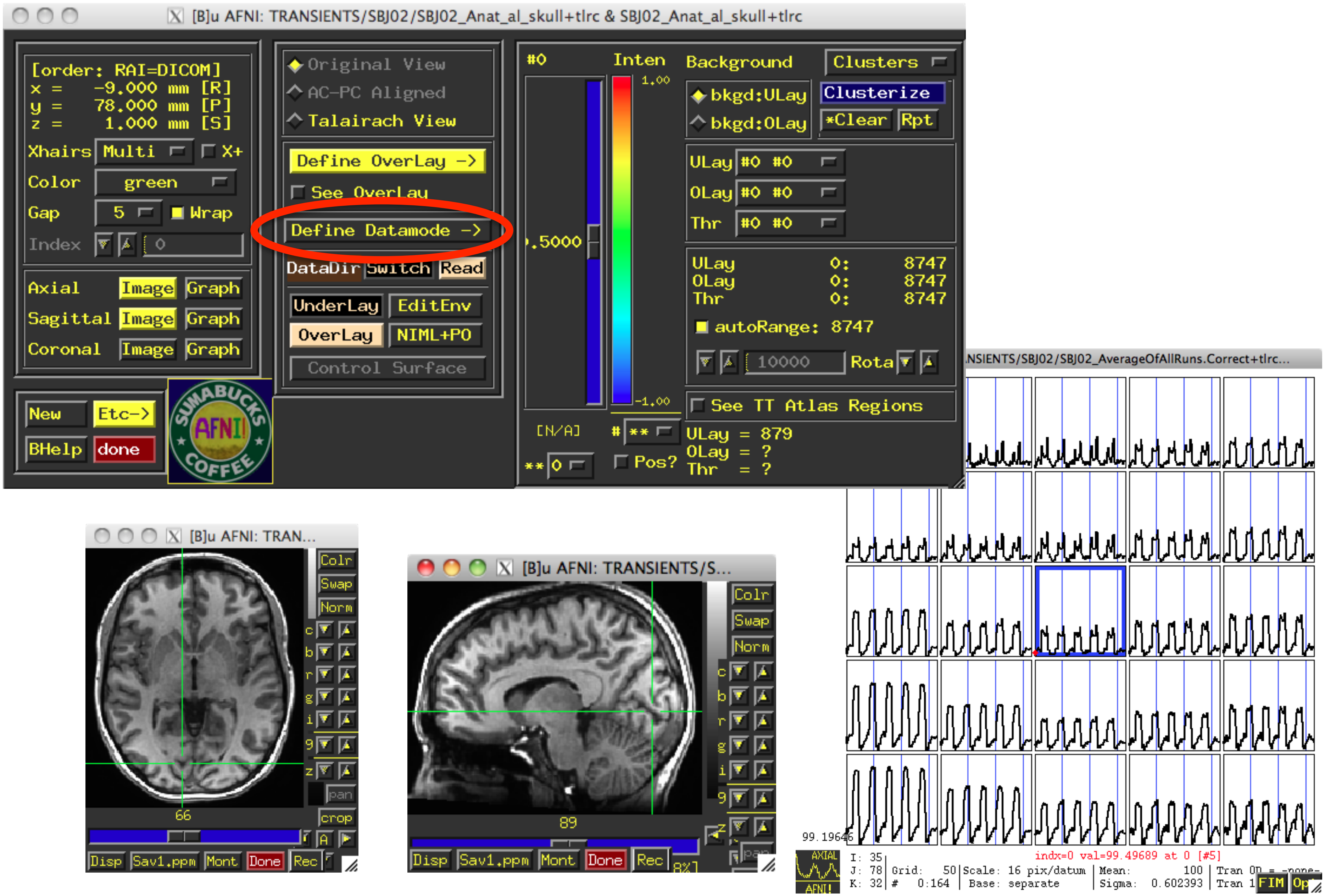


NIH/AFNI Real-time System Architecture



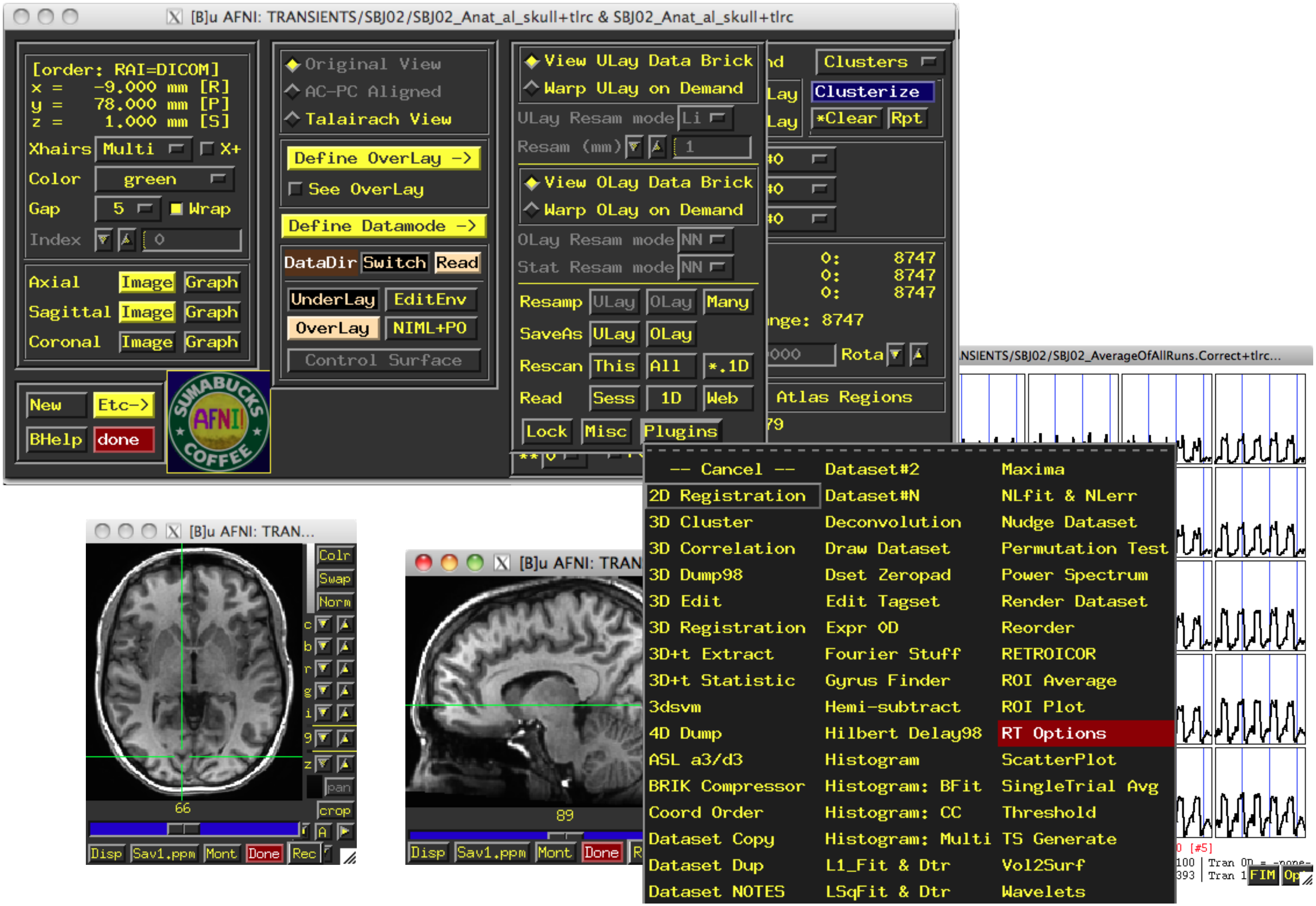
J Bodurka, V Roopchansingh, R Reynolds & Others

NIH/AFNI Real-time System: Look & Feel

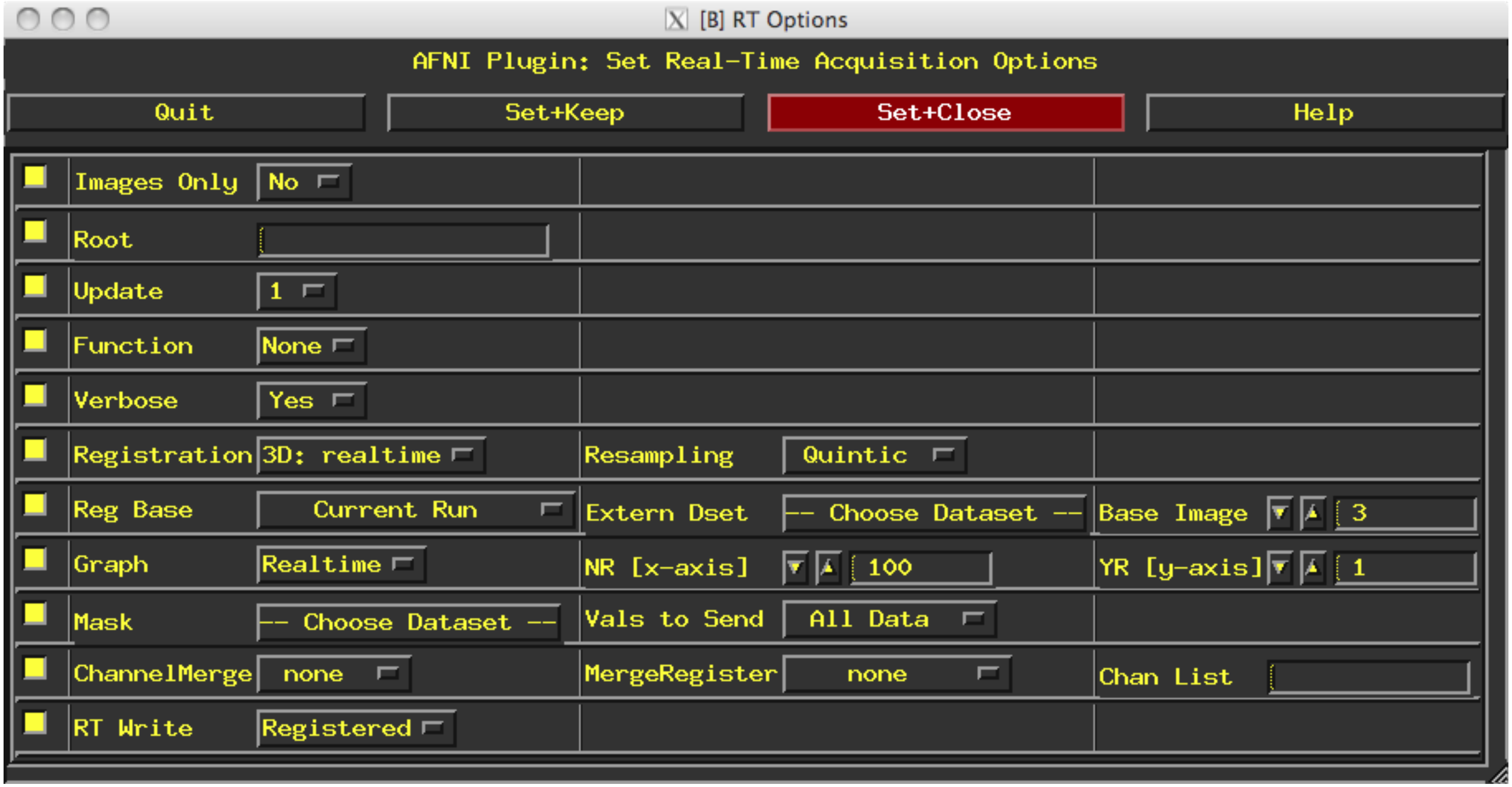


fim.nimh.nih.gov

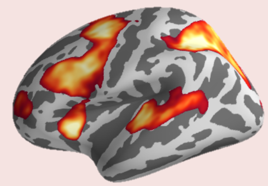
NIH/AFNI Real-time System: Look & Feel



NIH/AFNI Real-time System: Look & Feel



QUALITY CONTROL



FUNCTIONAL LOCALIZERS

NEUROFEEDBACK /BCI

Real-time fMRI Applications:

(1) Automatic Data Quality Assurance

Automatic HW-QA

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- Conducted every morning before any research/clinical scans starts
- Subject: TLT Spherical Phantom
- Scans:
  - 3D Localizer
  - 2 Axial EPI Scans
  - 1 Sagittal EPI Scan
  - 1 Coronal EPI Scan

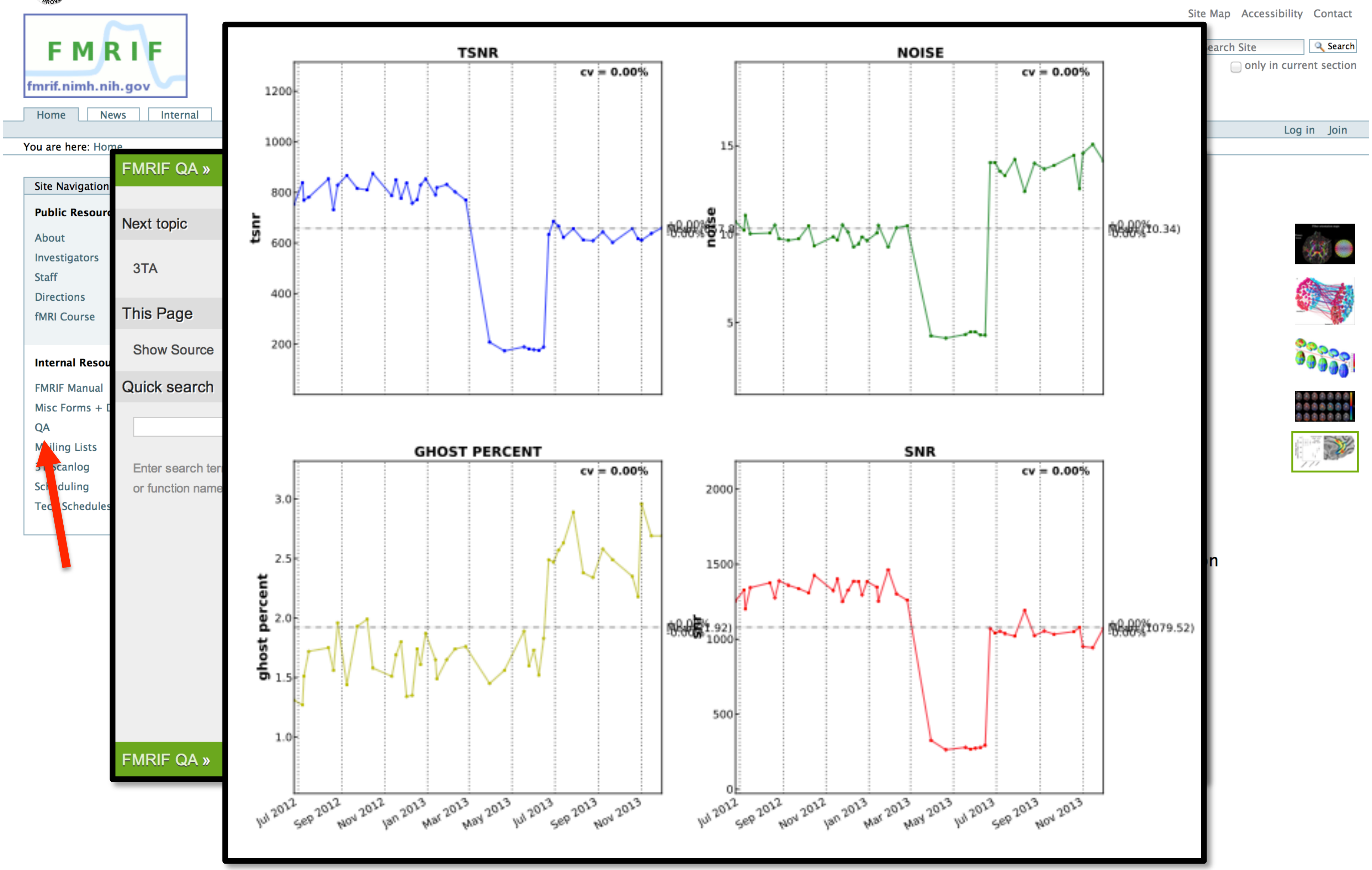
APPROX. 30 MINS OF SCAN TIME

- Real-time automatically performs QA Analysis/Publish in the Web
  - Subject = QA_<extra_text>
  - History = QA-Compute

MINIMUM HUMAN INTERACTION

- QA Metrics
  - Image Signal-to-Noise Ratio (SNR)
  - Temporal Signal-to-Noise Ratio (TSNR)
  - Ghost Intensity
  - Background Noise Levels
  - Transmit Gain | Center Frequency

Automatic HW-QA: Web Server



Vinai Roopchansingh

In-session QA

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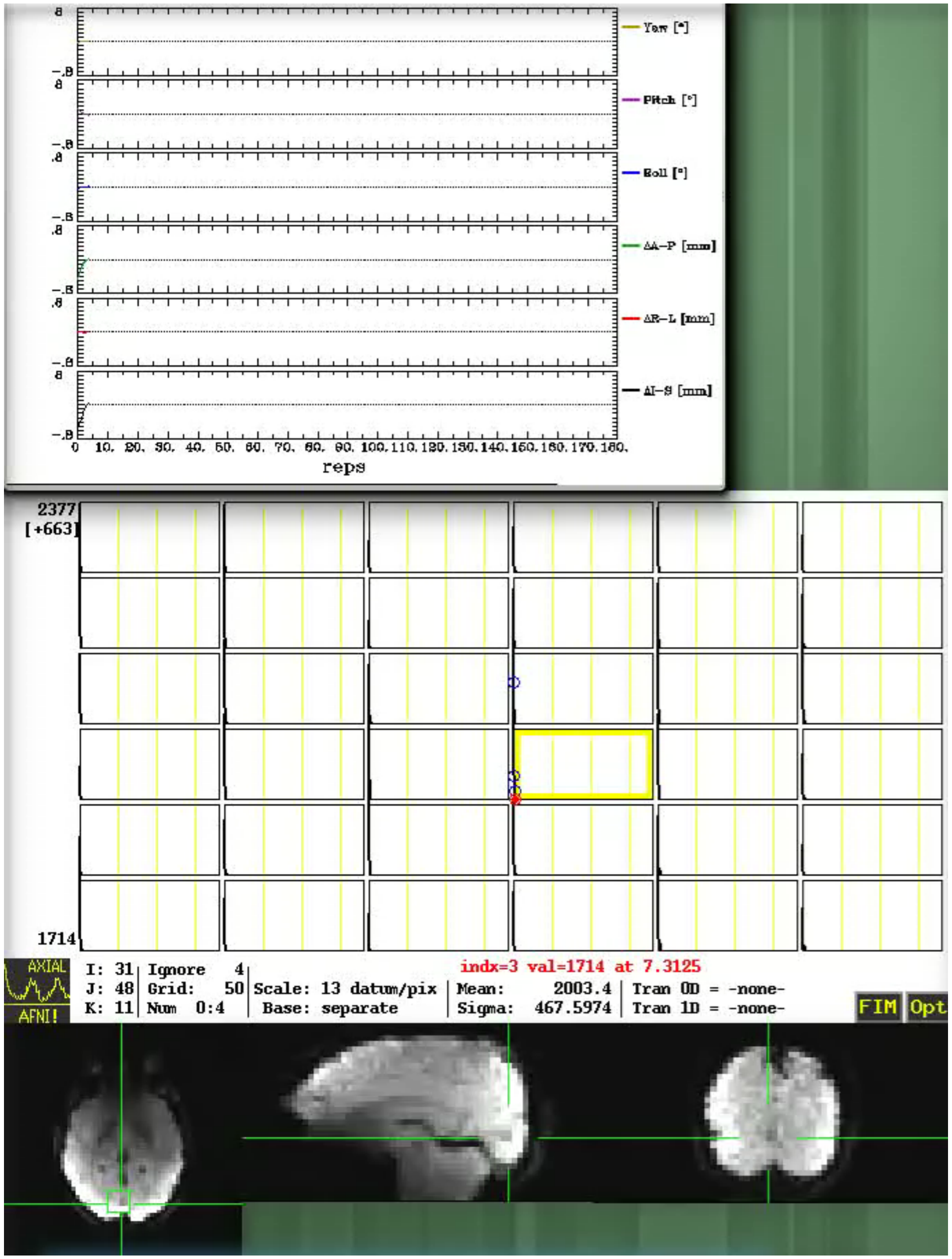
WHY DO IN-SESSION QA?

- HW is just one part of the equation
- Subjects introduce additional noise
  - Head Motion
  - Physiological Noise
- HW can break throughout the day/be incorrectly connected.

WHAT DOES IT PROVIDE?

- Check Image Quality.
- Check Time-series: spikes, drift, task fluctuations.
- Check Head Motion Estimates.
- Generate TSNR Maps at the end of each scan.



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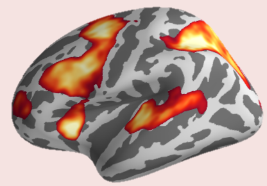


FUNCTIONAL LOCALIZERS

NEUROFEEDBACK /BCI

Real-time fMRI Applications:

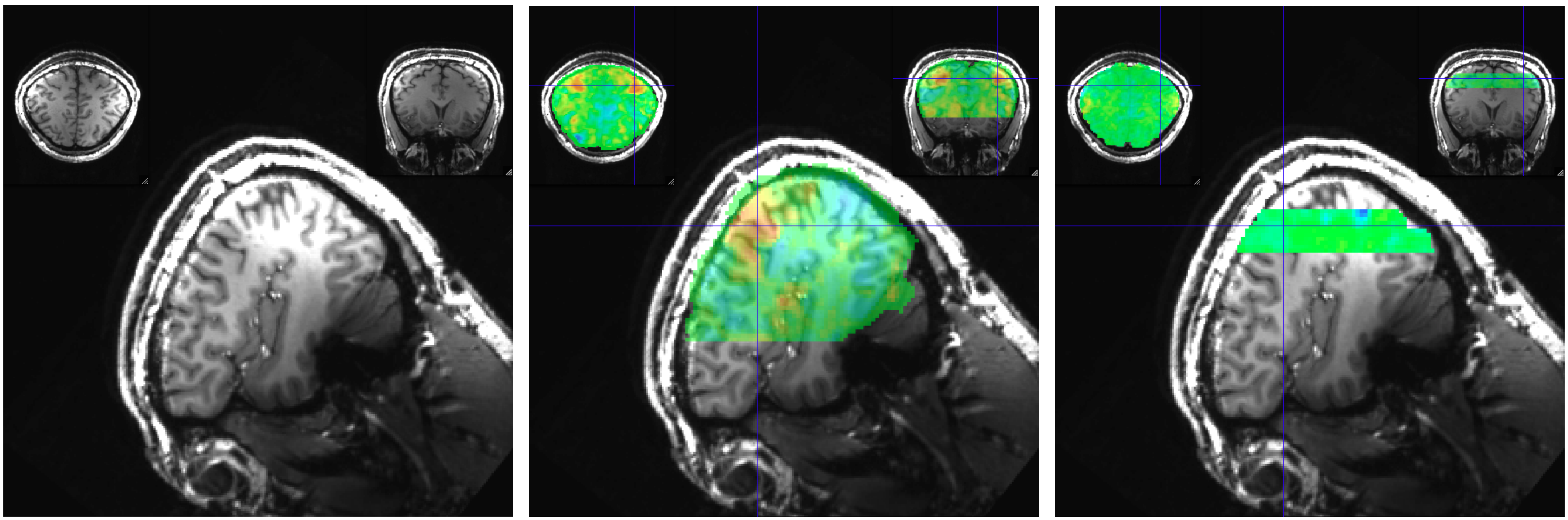
(2) Online Functional Localizers

Functional Localizers at Scan Time

GOAL: HELP REVEAL THE SPECIFIC FUNCTIONAL NEURO-ANATOMY OF THE SUBJECT

1 Define target regions for main experiment more precisely…

…so that we can scan faster and/or at higher spatial resolution

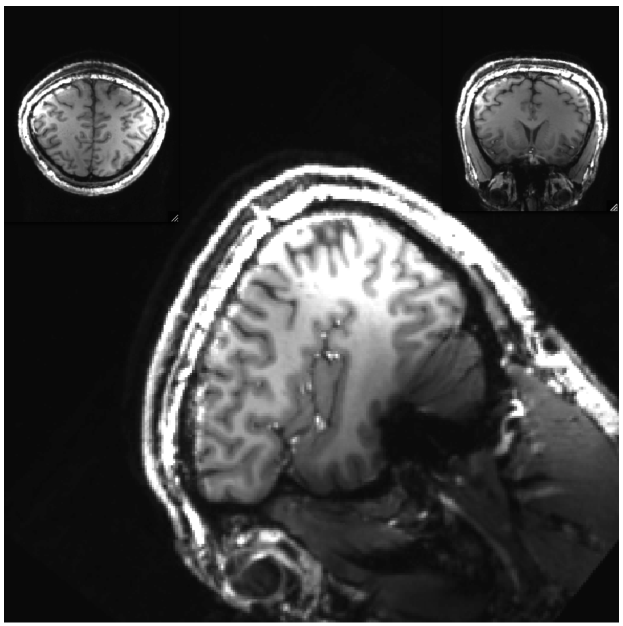


HIGH RES-ANATOMICAL	EPI FUNCTIONAL LOCALIZER	MAIN EXPERIMENT
1x1x1mm	**52 Slices** @ 2x2x2mm **TR=2000ms**	**11 Slices** @ 2x2x2mm **TR=400ms**

Functional Localizers at Scan Time (II)

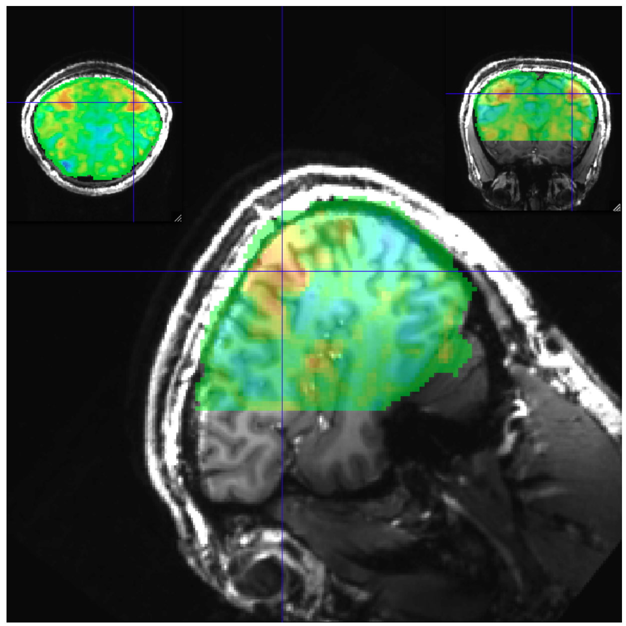
2 Define target regions for main experiment more precisely…

… to obtain a Region of Interest (ROI) for a subsequent Neurofeedback scan



HIGH RES-ANATOMICAL

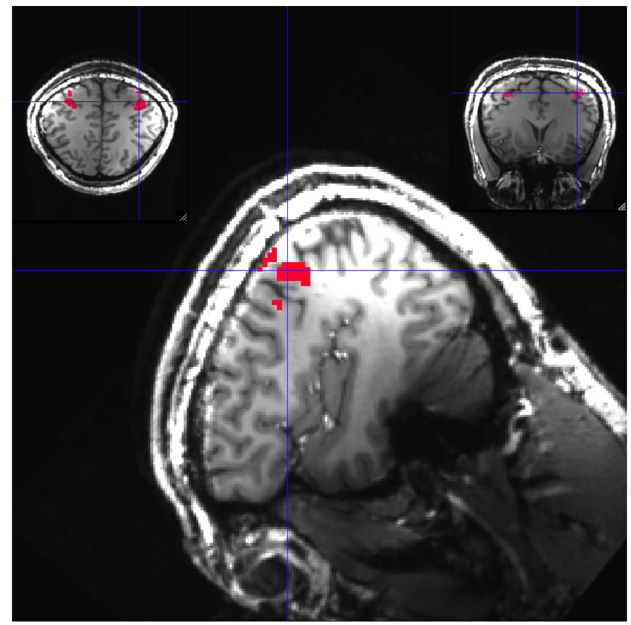
1x1x1mm



EPI FUNCTIONAL LOCALIZER

52 Slices @ 2x2x2mm

TR=2000ms

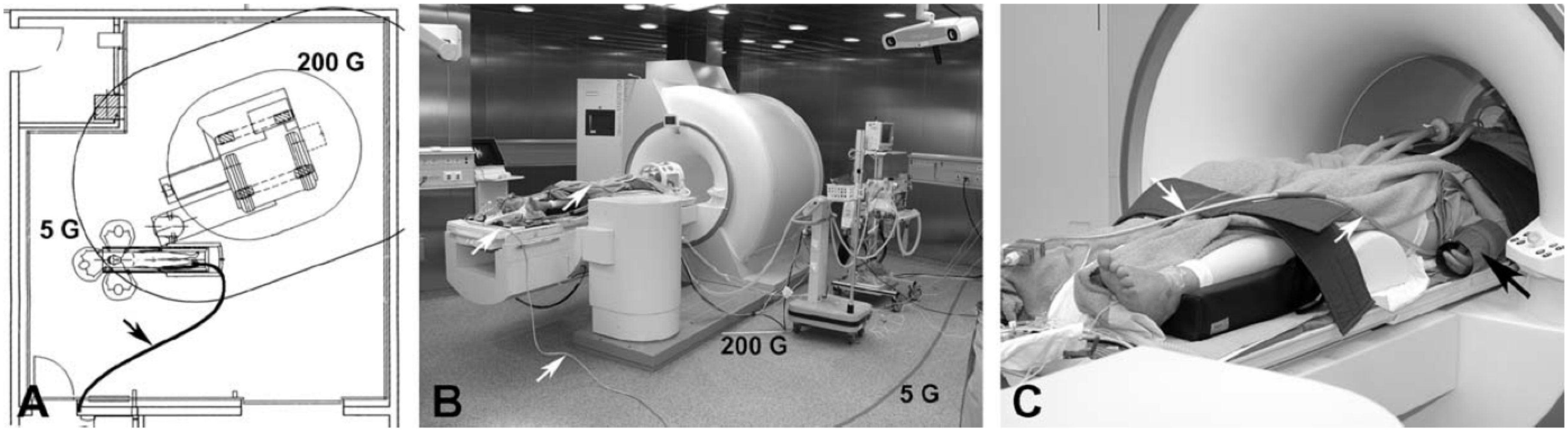


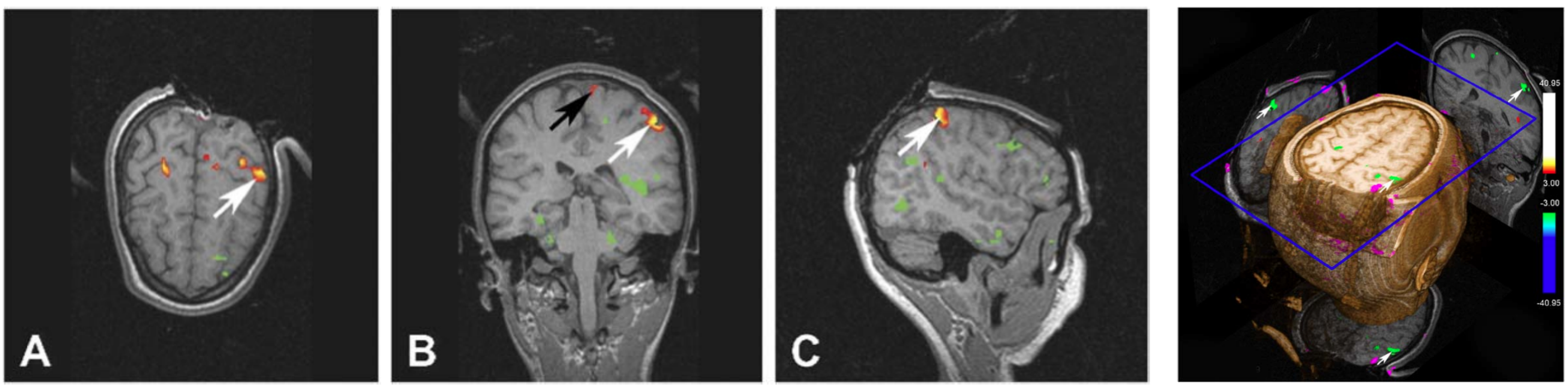
ROI FOR MAIN EXPERIMENT

NEUROFEEDBACK/BCI

Functional Localizers at Scan Time (III)

3 Guide Surgical Interventions → Detect Tissue displacement during surgery



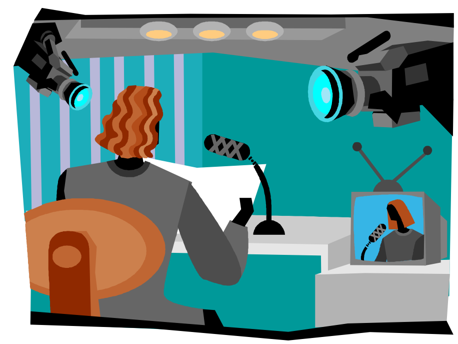


Gesser et al. “Intraoperative functional MRI: Implementation and preliminary experience”
NeuroImage 26 (2005): 685-693

Functional Localizers at Scan Time (IV)

4 Teaching / Demonstrations to journalists and interested public.

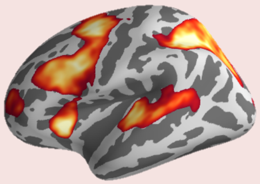
- CAN BE VERY EFFECTIVE AT EXPLAINING:
  - BOLD Effect.
  - Hemodynamic Delay/Filter.
  - Artifacts: Head motion.
  - Effect of Imaging Parameters/Tuning of Scanning Protocols



- CAN HELP GET NEW STUDENTS INTERESTED IN FMRI
- REPORTED POSITIVE PAST EXPERIENCES:
  - Wellcome Trust Center for Neuroimaging (London, UK)
  - International Max Planck Research School (Tubingen, Germany)

Weiskopf N et al. "Real-time functional magnetic resonance imaging: methods and applications"
Magnetic Resonance Imaging 25 (2007): 989-1003

QUALITY CONTROL



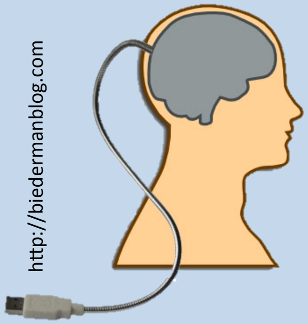
FUNCTIONAL LOCALIZERS

NEUROFEEDBACK /BCI

Real-time fMRI Applications:

(3) Brain-Computer Interfaces & Neurofeedback

Neurofeedback / Brain Computer Interfaces

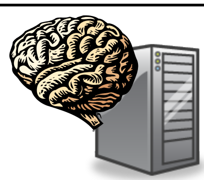


BRAIN – COMPUTER INTERFACE

"Techniques that allow translation of brain activity into direct control of mechanical or computer components without the involvement of the peripheral nervous system or muscle" Lee JH et al. (2009)

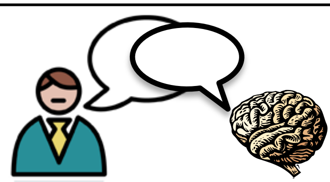
NEURO-FEEDBACK

- Specific type of Biofeedback
- Conscious control of activity within a region of one's own brain.
- Applications: Therapy and Learning



NEURO-CONTROL

- Use "thoughts" to control an electronic/motorized device
- Applications: prosthesis, gaming

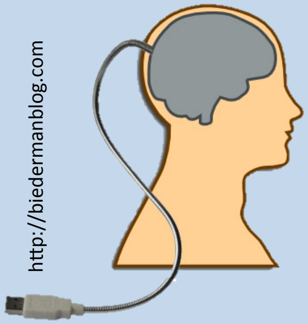


COMMUNICATION

- Use "thoughts" as a communication act.
- Applications: communicate with vegetative-state patients

Neurofeedback / Brain Computer Interfaces

fim.nimh.nih.gov



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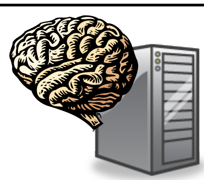

NEURO-CONTROL

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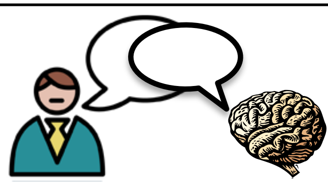
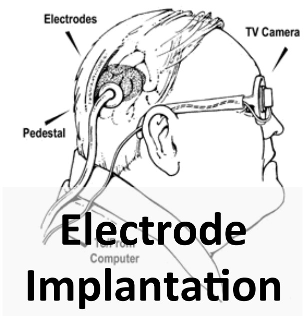


COMMUNICATION

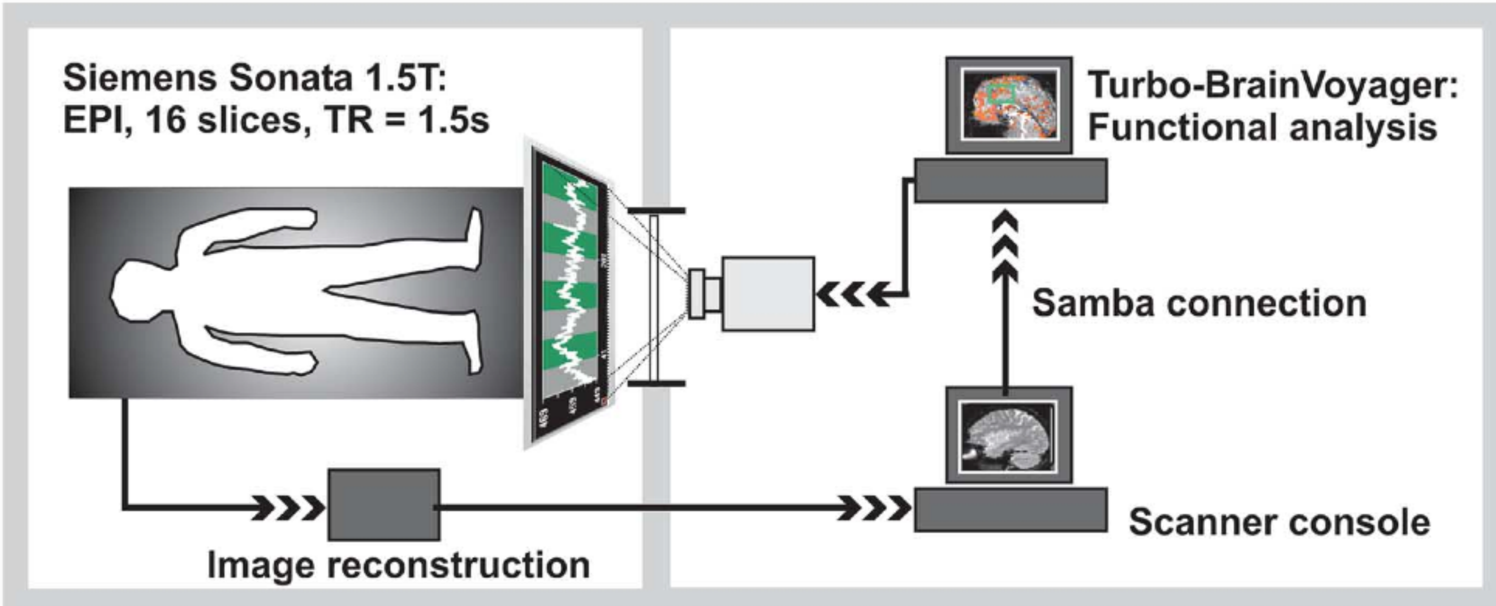
- Use "thoughts" as a communication act.
- <u>Applications:</u> communicate with vegetative-state patients

fMRI BCI/Neurofeedback in Perspective

	NON INVASIVE	PORTABLE	INTERFACE	SPECIFICITY	REACH DEEP STRUCT.
 Electrode Implantation	✗	✓	Neuronal Activity	VERY HIGH	✓
 EEG-based	✓	✓	Electric Fields	LOW	✗
 fMRI-based	✓	✗	Hemodynamic Response	HIGH	✓

Neurofeedback (1) – Original Experiments

EXPERIMENTAL SETUP



Processing Time from Acquisition to Feedback < 2 seconds

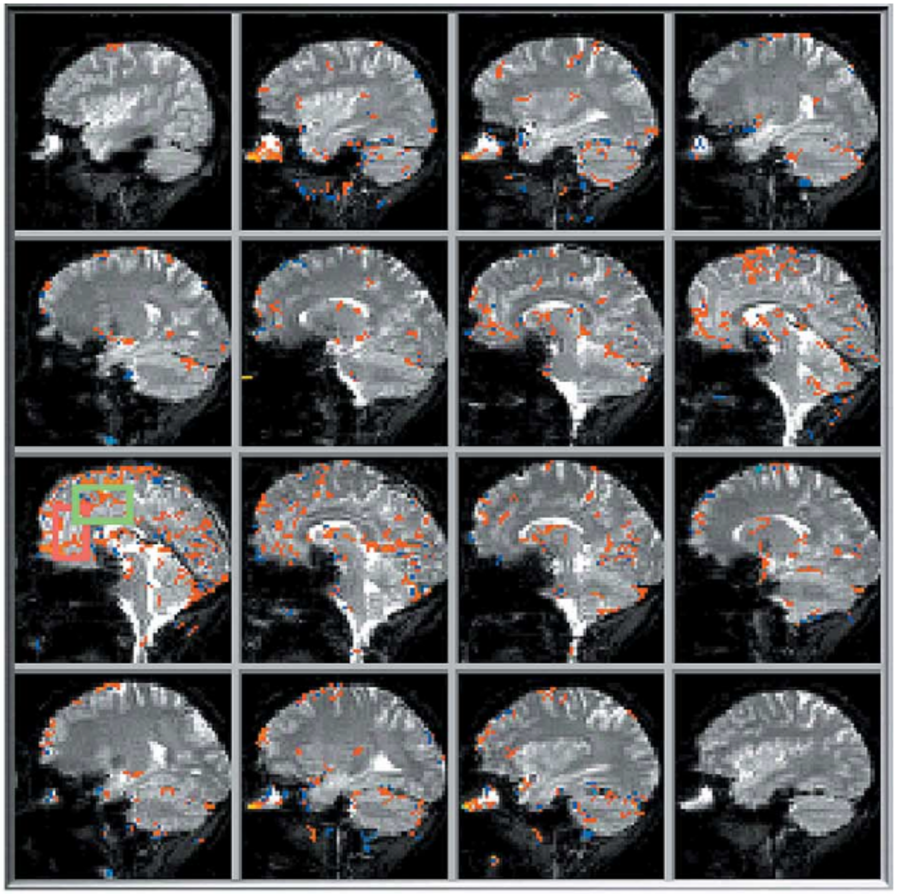
- 1 Subject.
- Consciously Increase and Decrease the BOLD signal of the Anterior Cingulate Cortex.
- Processing: (1) Linear Detrending, (2) Head Motion Correction, (3) Correlation Analysis

N. Weiskopf, R. Veit, M. Erb, et al. "Physiological self-regulation of regional brain activity using real-time functional magnetic resonance imaging (fMRI): methodology and exemplary data". NeuroImage 19 (2003): 577-586

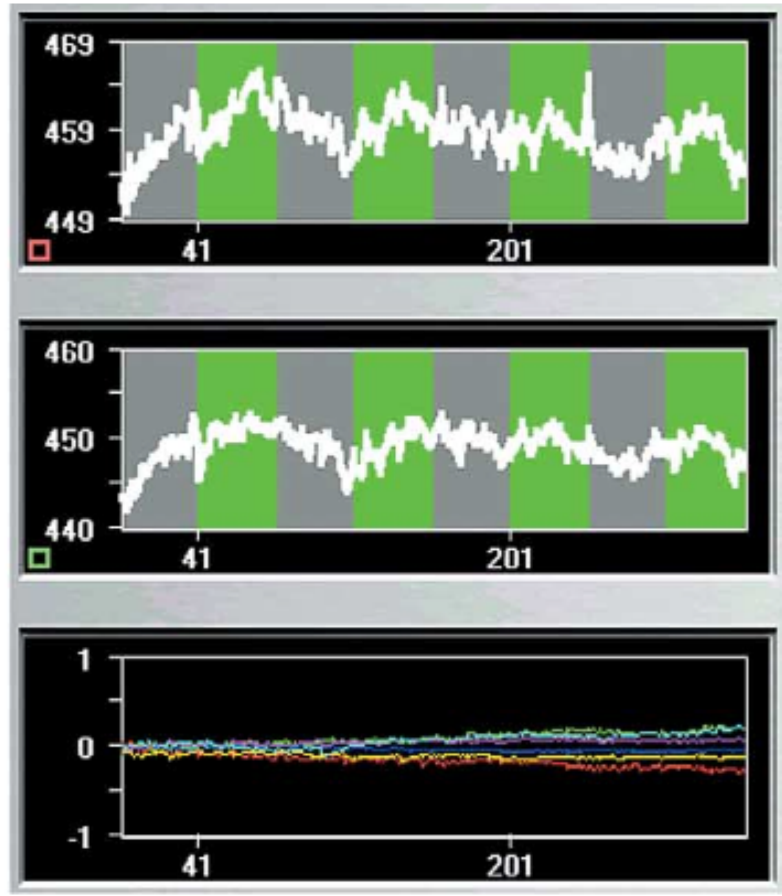
Neurofeedback (1) – Original Experiments

FEEDBACK SCREEN

TO THE EXPERIMENTER



TO THE SUBJECT



GREEN = Increase Signal | GREY = Return to Baseline

N. Weiskopf, R. Veit, M. Erb, et al. "Physiological self-regulation of regional brain activity using real-time functional magnetic resonance imaging (fMRI): methodology and exemplary data". NeuroImage 19 (2003): 577-586

Neurofeedback (1) – Original Experiments

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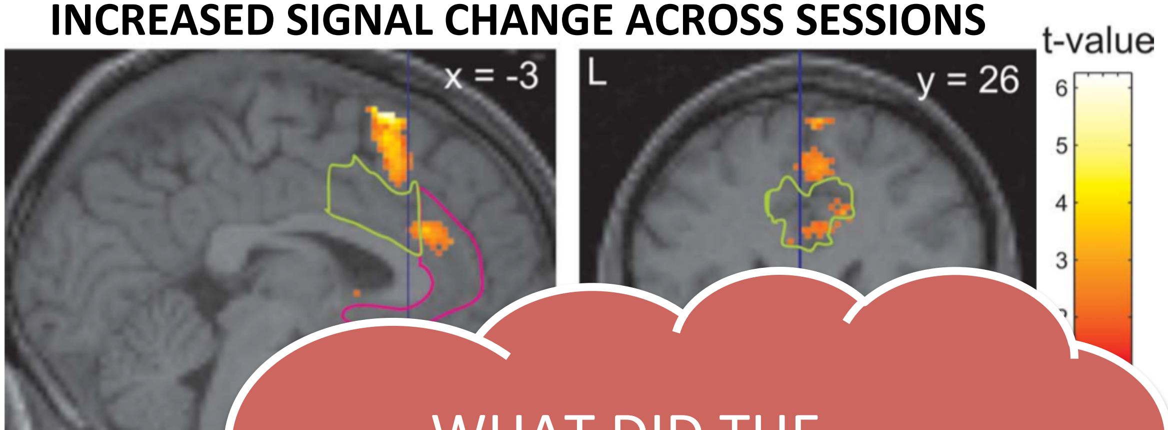
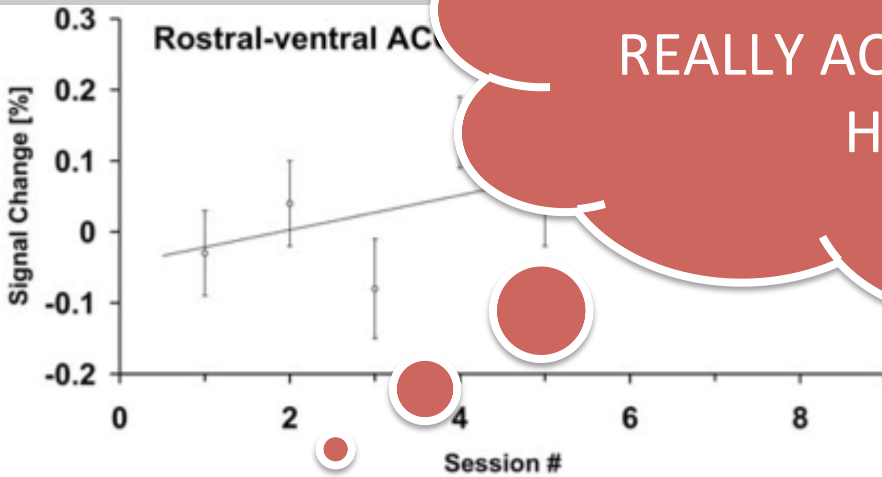
RESULTS

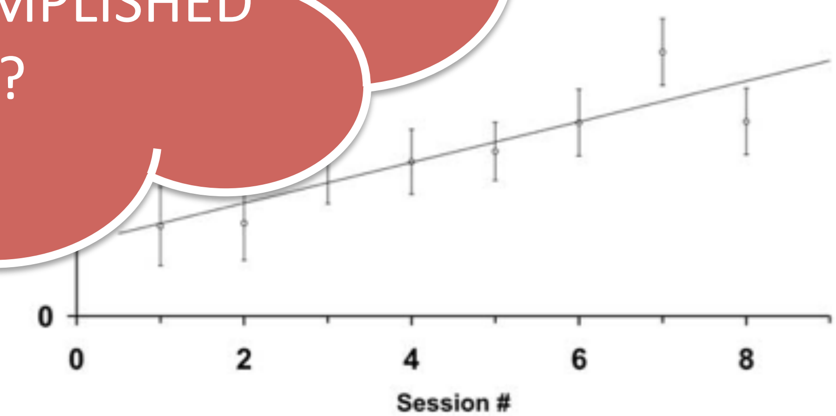
INCREASED SIGNAL CHANGE ACROSS SESSIONS



TARGET … **REGION**

WHAT DID THE NEUROFEEDBACK REALLY ACCOMPLISHED HERE?





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Neurofeedback (2) – Mitigation of Chronic Pain

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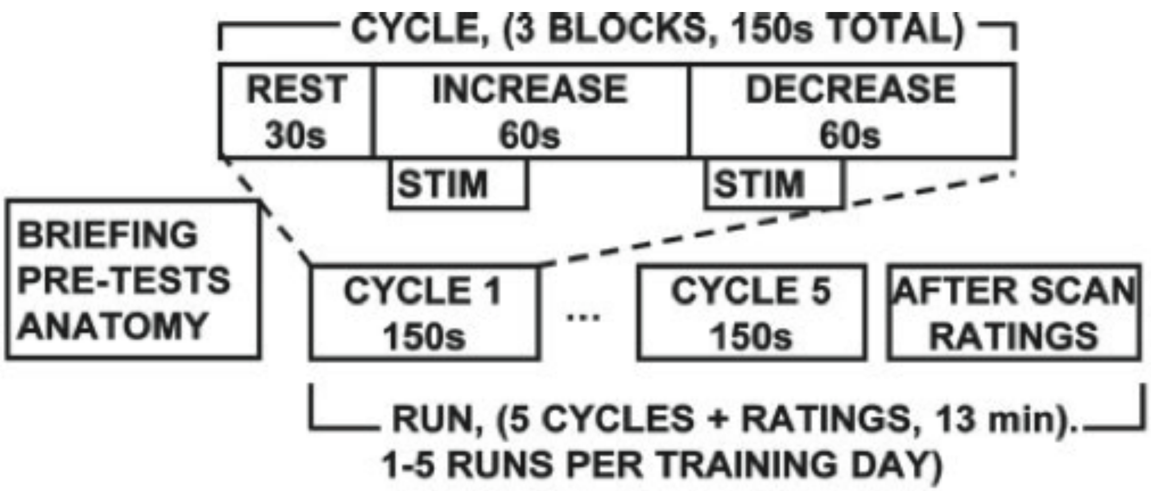
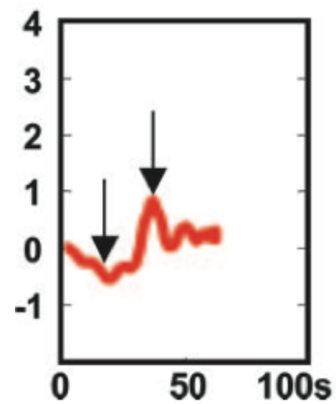
Does learned, deliberate manipulation of rostral anterior cingulate cortex (rACC) activation by subjects lead to predicted effects on pain perception?

EXPERIMENTAL DESIGN



- 36 healthy subjects & 8 Chronic Pain Patients
- Type of Scans:
  - Localizer + Anatomical Scans
  - 3 Training Runs (Rate Stimuli at end of run)
  - 1 Post-test Run (Rate Stimuli at each presentation)
- Pain Rating using a Visual Analog Scale 1 - 10

FEEDBACK SCREEN



deCharms RC, Maeda D et al. “Control over brain activation and pain learned by using real-time functional MRI” PNAS 102(2005):18626-31

Neurofeedback (2) – Mitigation of Chronic Pain

GROUP	N	POPULATION	FEEDBACK TYPE	#TRAINING RUNS (13mins)	INSTRUCTIONS
H1	8	HEALTHY	fMRI from rACC	3	Attention/Control Stim. Quality/Severity
H2	8	HEALTHY	No fMRI Feedback	3	Attention/Control Stim. Quality/Severity
H3	8	HEALTHY	No fMRI Feedback	6	Attention
H4	8	HEALTHY	fMRI other ROI	3	Attention/Control Stim. Quality/Severity
H5	4	HEALTHY	fMRI other Person	3	Attention/Control Stim. Quality/Severity
P1	4	CHRONIC PAIN	fMRI from rACC	3	Attention/Control Stim. Quality/Severity
P2	4	CHRONIC PAIN	Autonomic Biofeedback	3	Methods to induce Relaxation

deCharms RC, Maeda D et al. “Control over brain activation and pain learned by using real-time functional MRI” PNAS 102(2005):18626-31

Neurofeedback (2) – Mitigation of Chronic Pain

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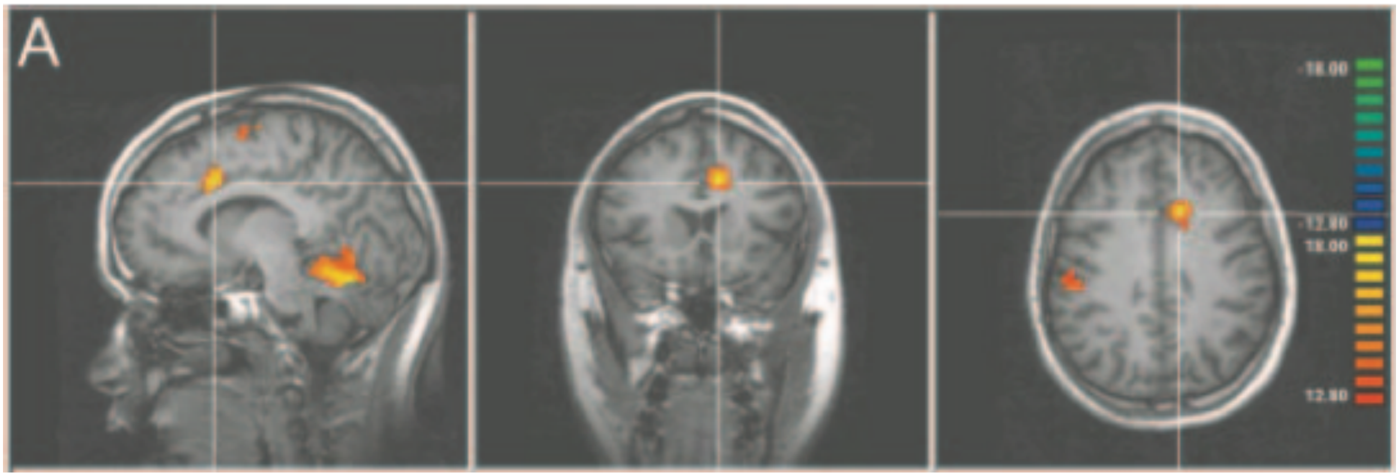
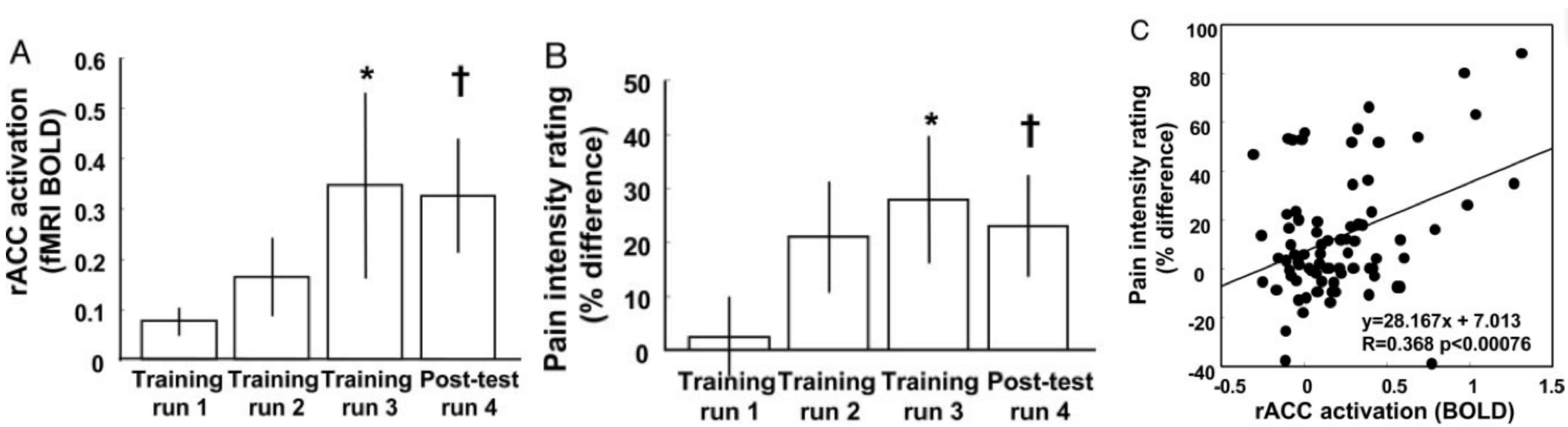
RESULTS: H1 GROUP (HEALTHY, rtFMRI rACC)





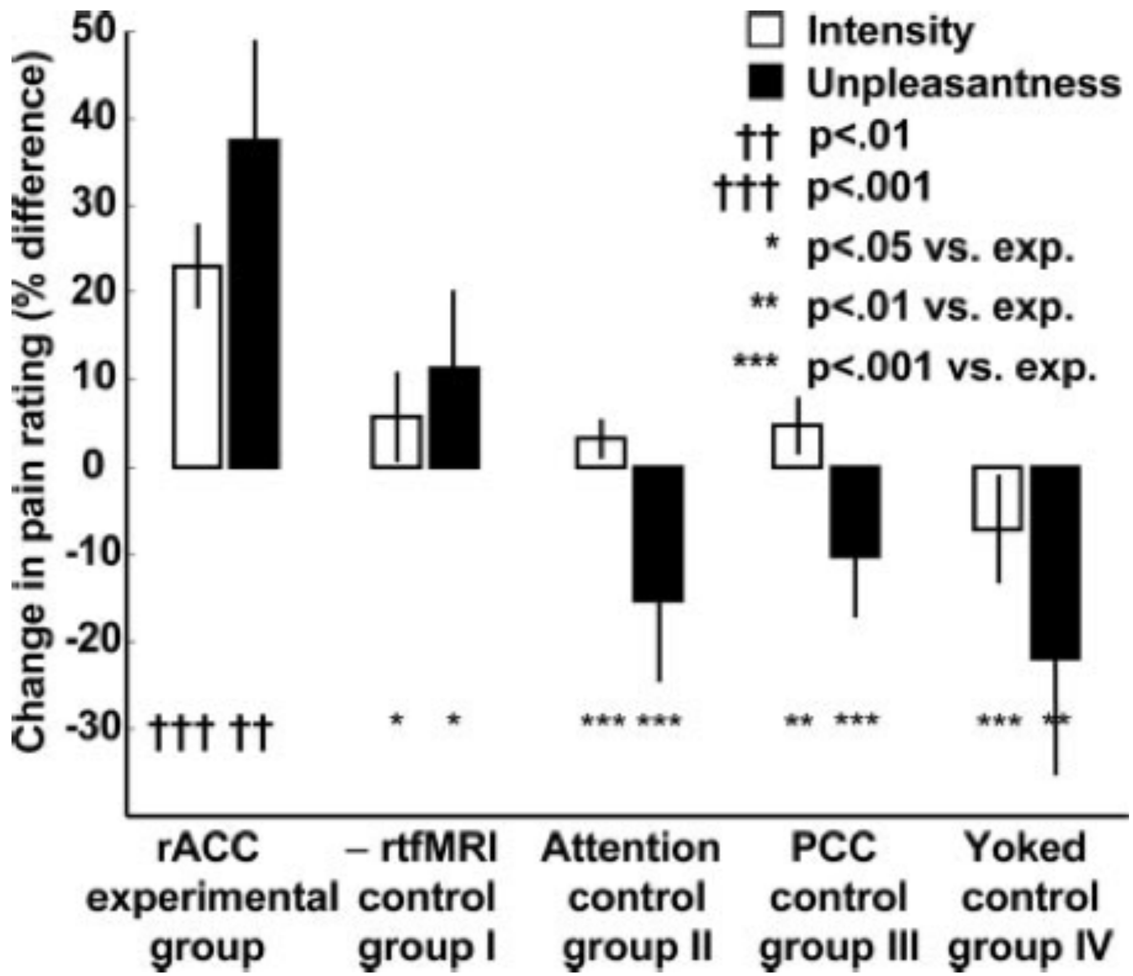
BOLD Activity Change | Behavioral Change | Correlation

deCharms RC, Maeda D et al. “Control over brain activation and pain learned by using real-time functional MRI” PNAS 102(2005):18626-31

Neurofeedback (2) – Mitigation of Chronic Pain

fim.nimh.nih.gov

RESULTS: SPECIFICITY DUE TO rtFMRI TRAINING IN HEALTHY PATIENTS



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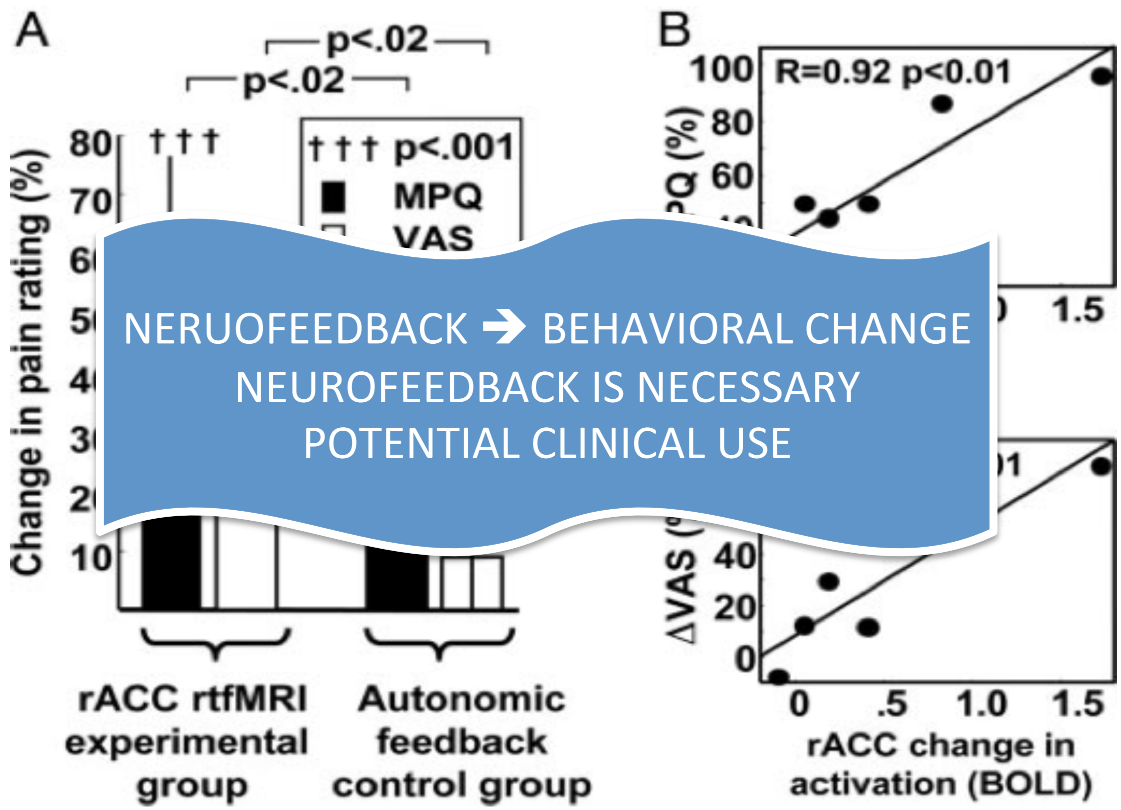
Neurofeedback (2) – Mitigation of Chronic Pain

RESULTS: CHRONIC PAIN PATIENTS



NERUOFEEDBACK → BEHAVIORAL CHANGE

NEUROFEEDBACK IS NECESSARY

POTENTIAL CLINICAL USE

“In interviews after the procedure, patients described an increased sense of control over their pain as well as an overall decrease in pain level when not overtly attempting to exercise control, but they were not able to provide clear details regarding the strategies that they used.”

deCharms RC, Maeda D et al. “Control over brain activation and pain learned by using real-time functional MRI” PNAS 102(2005):18626-31

Neurofeedback (3) – Other Studies

REGION	POPULATION	#SUBJECTS	VOLITIONAL CONTROL	BEHAVIORAL CHANGE	REFERENCE
Amygdala	Healthy	6	YES	YES	Posse et al. 2003
Anterior Insula	Schizophrenia	9	YES	YES	Ruiz et al. 2011
Insula	Healthy	15	YES	N/A	Caria et al. 2007
Suppl. Motor Area	Healthy	1	YES	N/A	Weiskopf et al. 2004
Parahippoc. Place Area	Healthy	1	YES	N/A	Weiskopf et al. 2004
Right Inferior Frontal G.	Healthy	7	YES	YES	Rota et al. 2009
Primary Auditory Ctx.	Tinnitus Patients	6	YES	2/6	Haller et al. 2009
Subgenual ACC	Healthy	18	YES	N/A	Hamilton et al. 2001
Ventral Pre-motor Ctx.	Healthy & Subcortical Stroke Patients	4/2	YES	YES	Sitaram et al. 2012
Orbito-frontal Cortex	Healthy	?	YES	N/A	Hampson et al. 2012

Good Practices for Neurofeedback Experiments

fim.nimh.nih.gov

COMMON EXPERIMENTAL SETUP

PRE-TRAINING LOCALIZER → TRAINING → TRANSFER EVALUATION → ADDITIONAL OFFLINE ANALYSIS

EXPERIMENTAL CONSIDERATIONS

- ROI Definition
- Data pre-processing prior to Feedback
- Baseline Calculation
- Feedback Display Configuration
- Provide Strategy: Yes/No
- Control for Motion, Physiology, etc.
- Do I really need a multi-million machine to do this?

DESIRED OUTCOMES

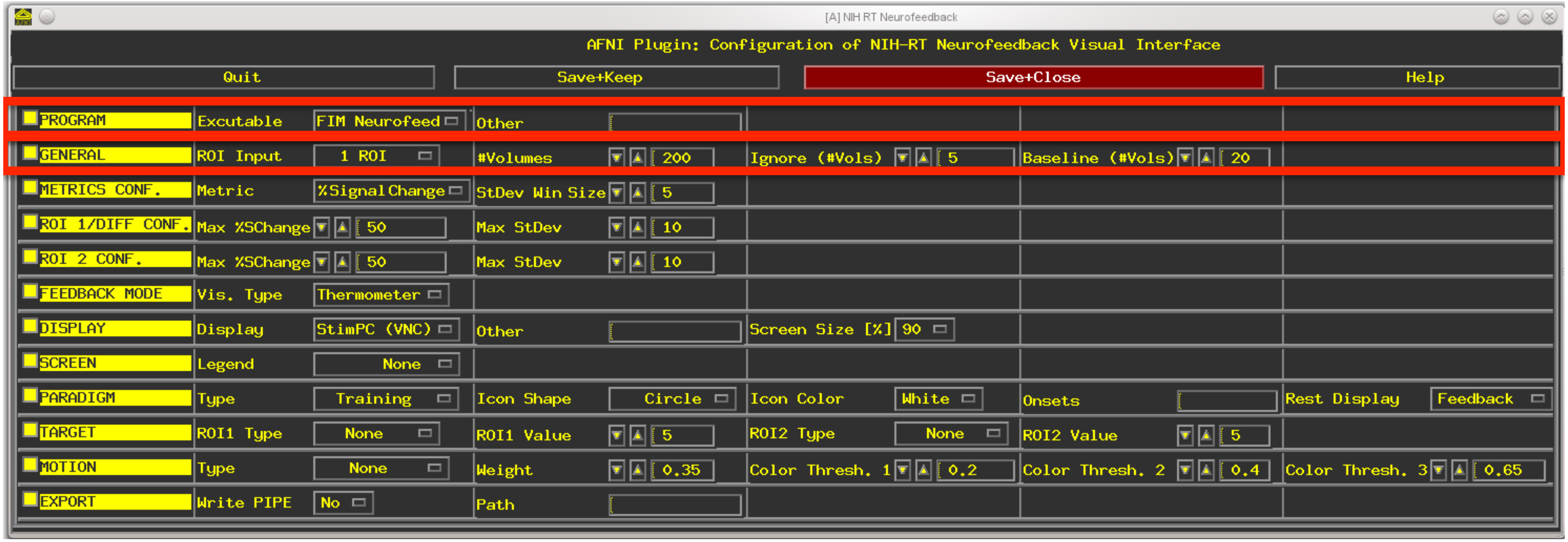
	Volitional Control	Behavioral Change
Real Feedback	YES	YES
Sham Feedback	NO	NO

+

Transfer of Behavioral Change beyond Scanning Sessions

NIH/AFNI Neurofeedback System

NIH/AFNI Neurofeedback System



(1) External Presentation Software to Use → Default is our in-house development.

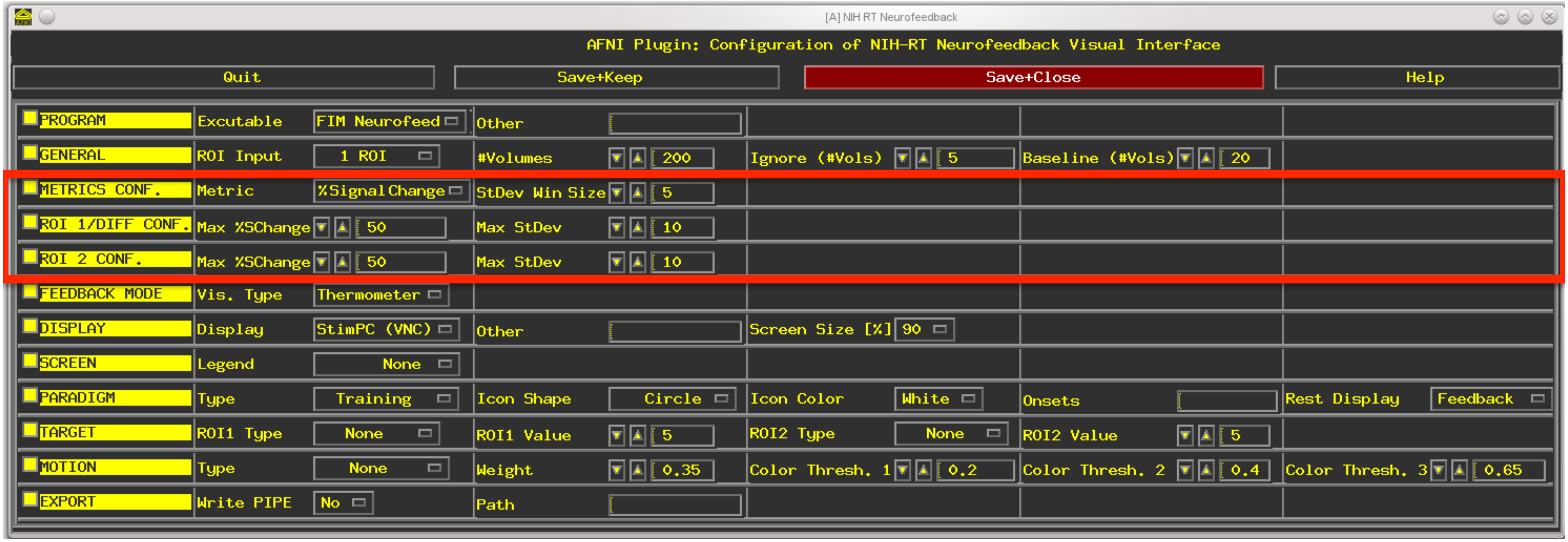
(2) Number of ROIs: 1 ROI, 2 ROIs, (A – B)

(3) Number of Acquisitions

(4) How many volumes to ignore

(5) How many volumes to use for baseline computation

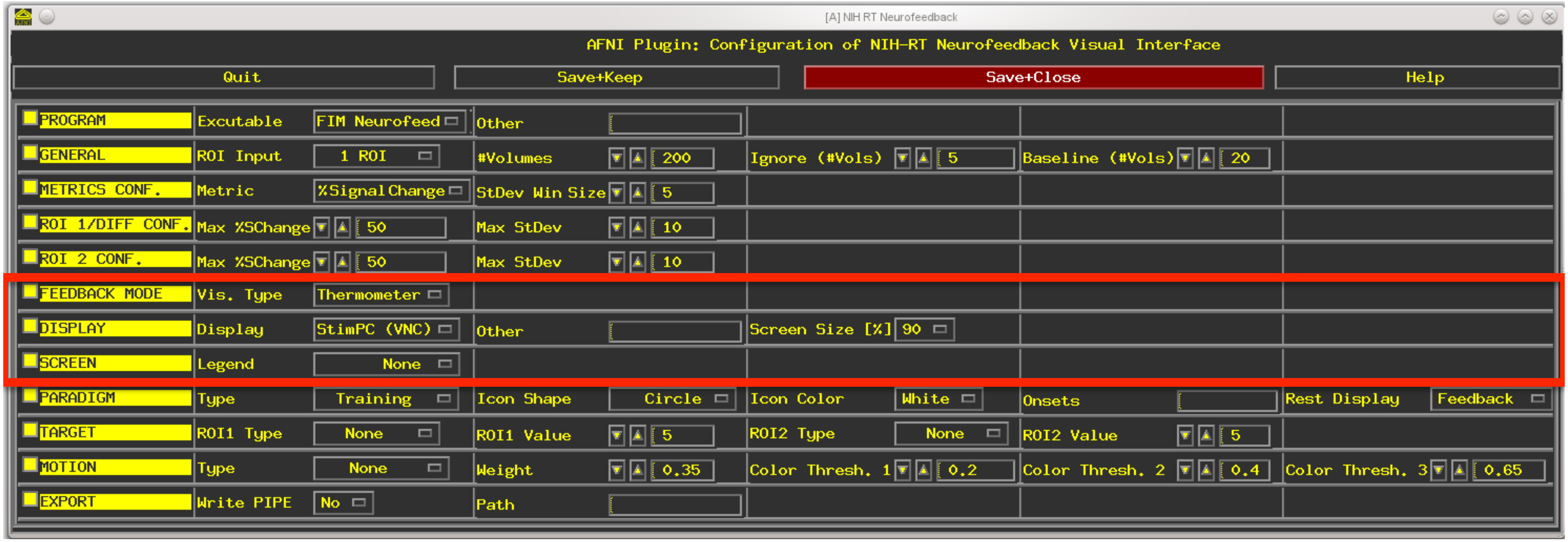
NIH/AFNI Neurofeedback System



(6) DISPLAY METRIC

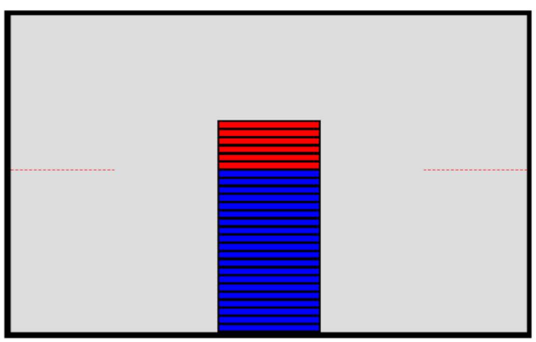
- Percent Signal Change from Baseline: [Min, Max]
- Standard Deviation from Baseline over time: [Min, Max, Window]

NIH/AFNI Neurofeedback System

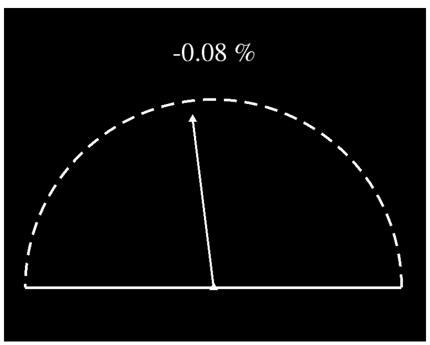


(7) FEEDBACK DISPLAY CONFIGURATION

SINGLE ROI

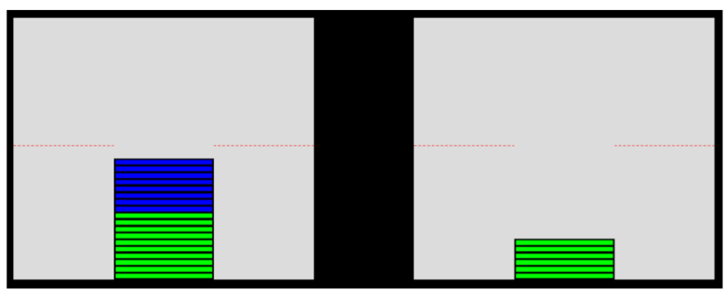


THERMOMETER | LEGEND OFF



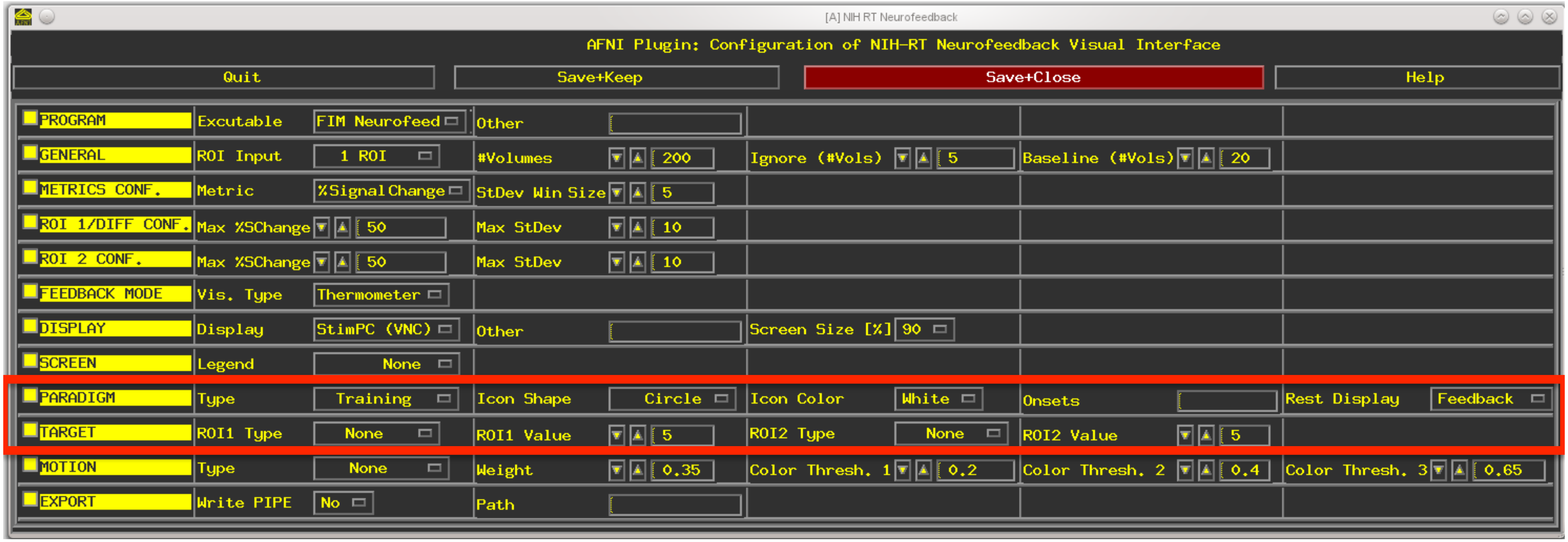
GAUGE | LEGEND ON

TWO ROIS

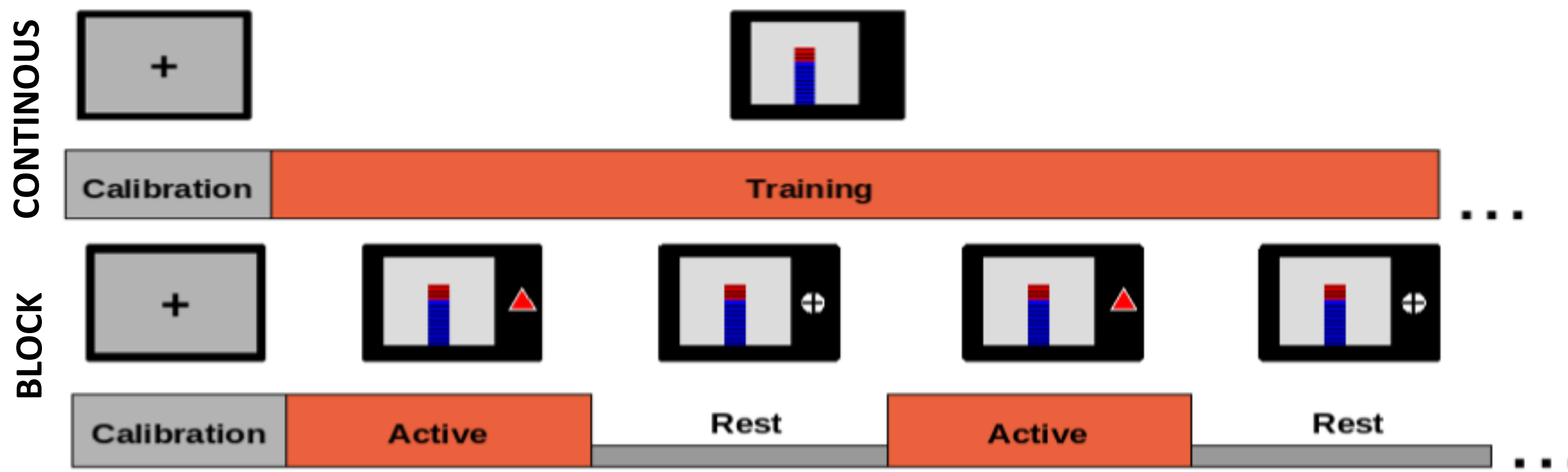


THERMOMETER | LEGEND OFF

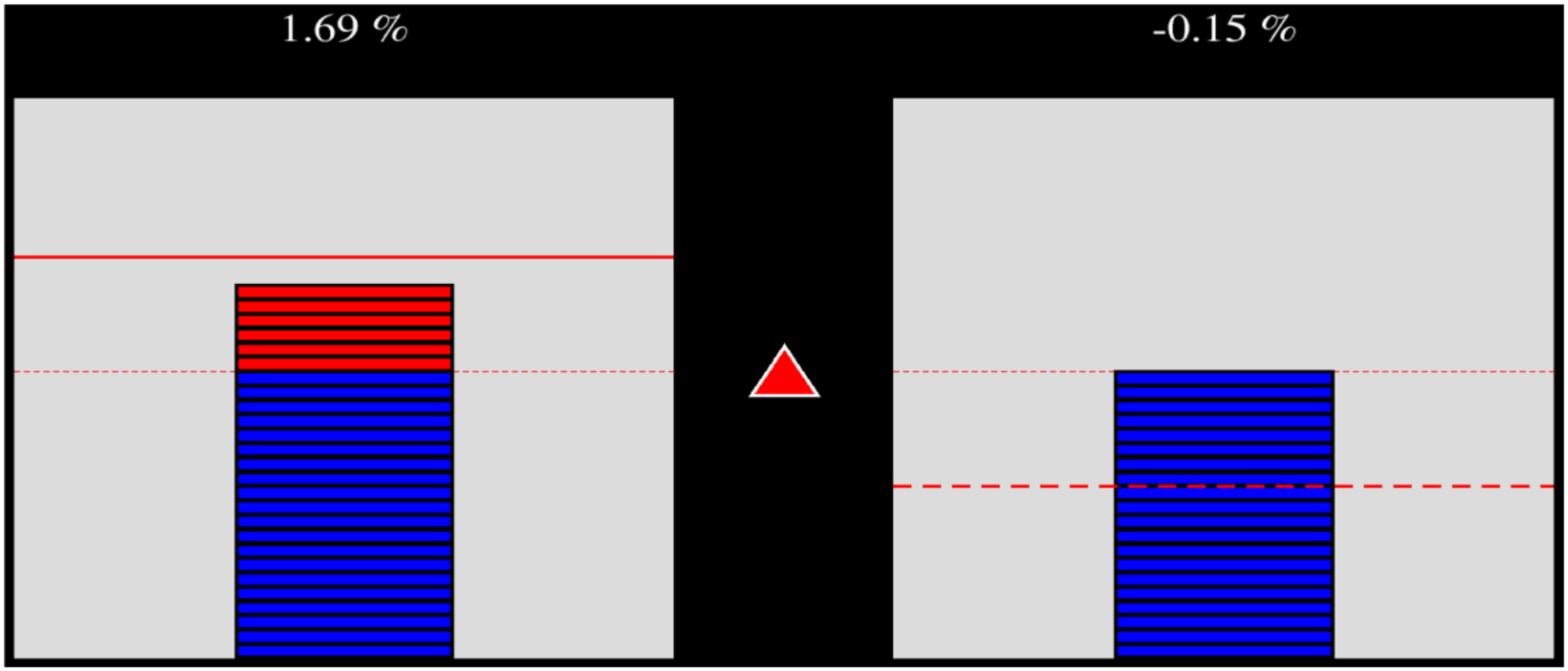
NIH/AFNI Neurofeedback System



(8) MODE OF OPERATION



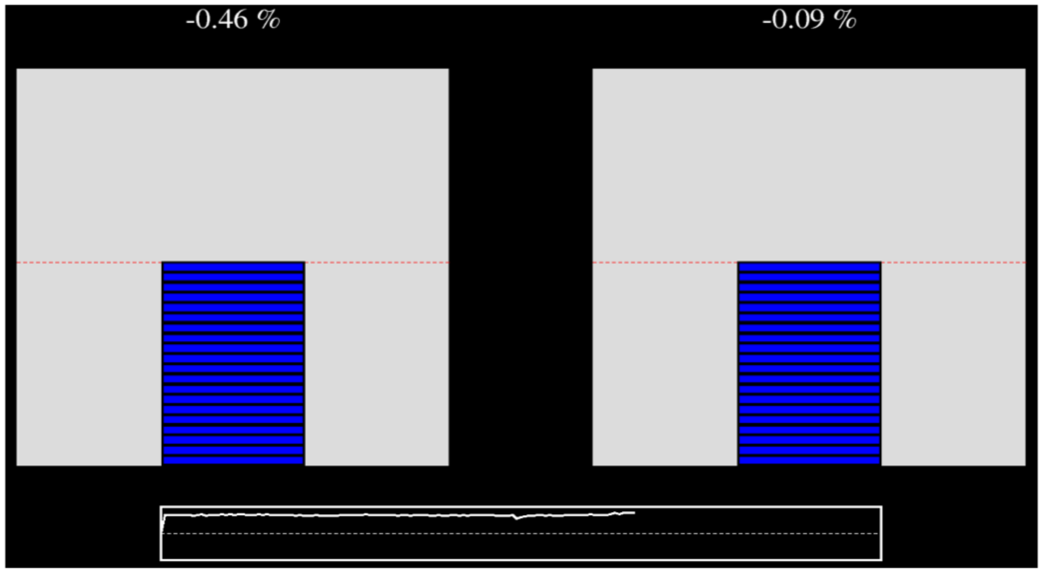
TARGET VALUES



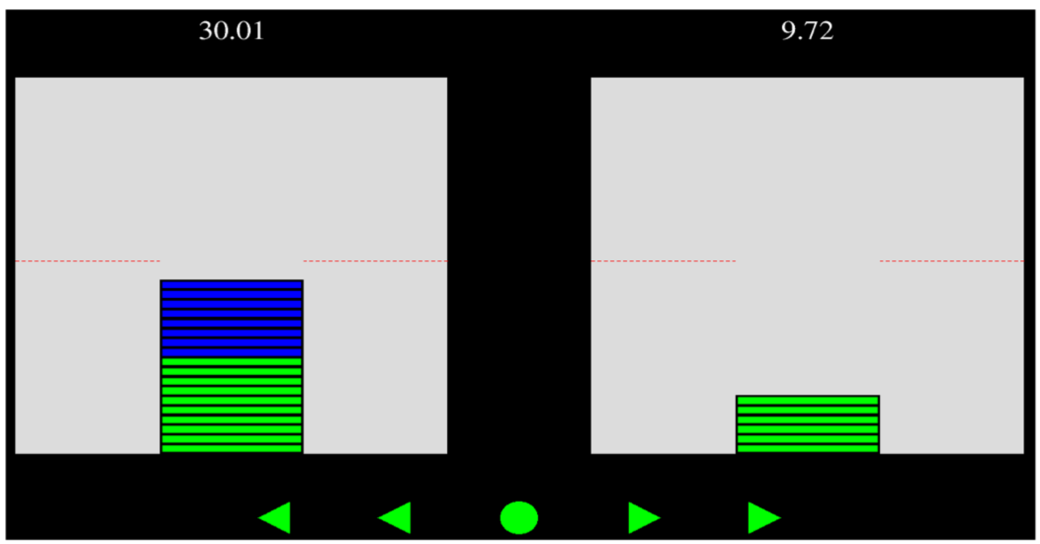
NIH/AFNI Neurofeedback System

MOTION FEEDBACK

AS TIMESRIES



AS COLORED DOTS



Neurofeedback / Brain Computer Interfaces

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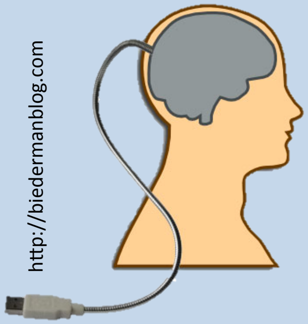
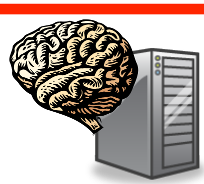


BRAIN – COMPUTER INTERFACE

“Techniques that allow translation of brain activity into direct control of mechanical or computer components without the involvement of the peripheral nervous system or muscle” Lee JH et al. (2009)

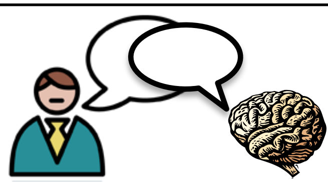
NEURO-FEEDBACK

- Specific kind of Biofeedback
- Conscious control of activity within a region of one’s own brain.
- <u>Applications:</u> Therapy and Learning



NEURO-CONTROL

- Use “thoughts” to control an electronic/motorized device
- <u>Applications:</u> prosthesis, gaming



COMMUNICATION

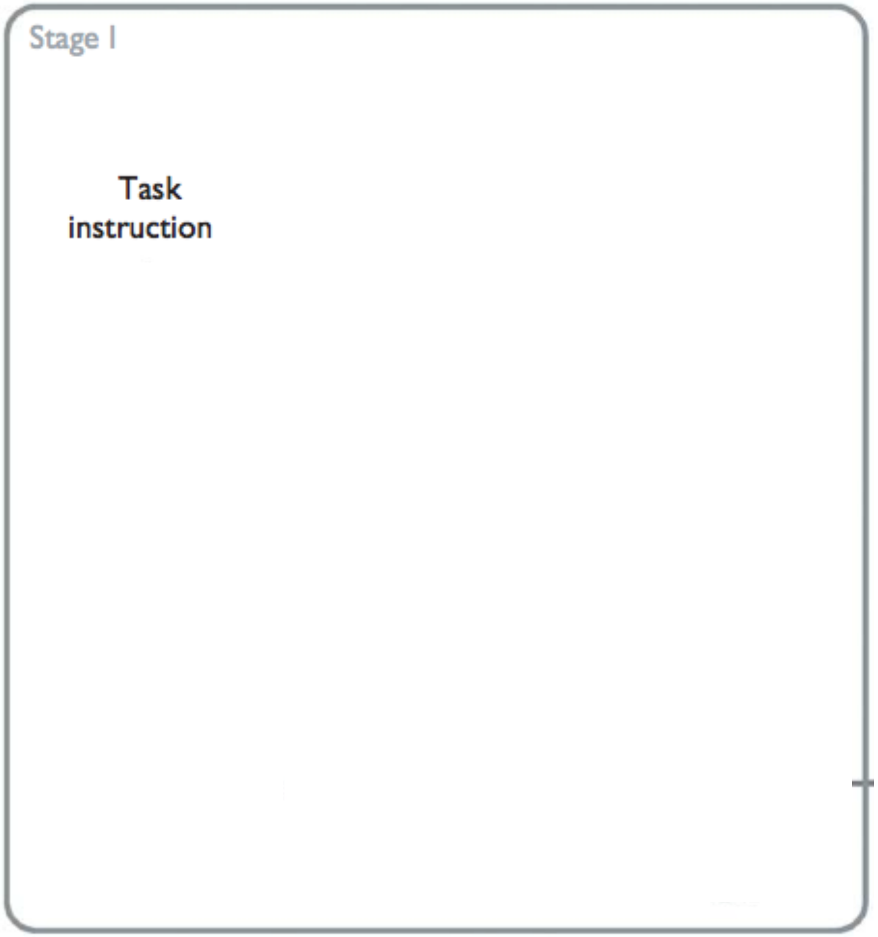
- Use “thoughts” as a communication act.
- <u>Applications:</u> communicate with vegetative-state patients

Neuro-control (1) – Cursor Control

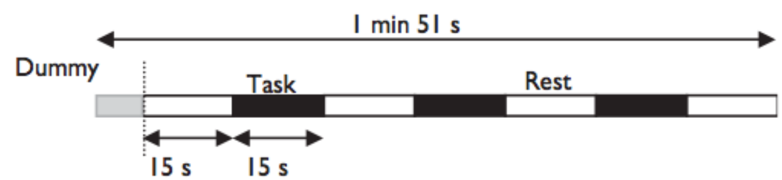
BOLD activity patterns from 4 different tasks were measured and translated into four directional cursor commands for navigation through a 2D maze presented to the subjects.

PHASE I

SUBJECT TRAININ & ROI DEFINITION



Training Paradigm

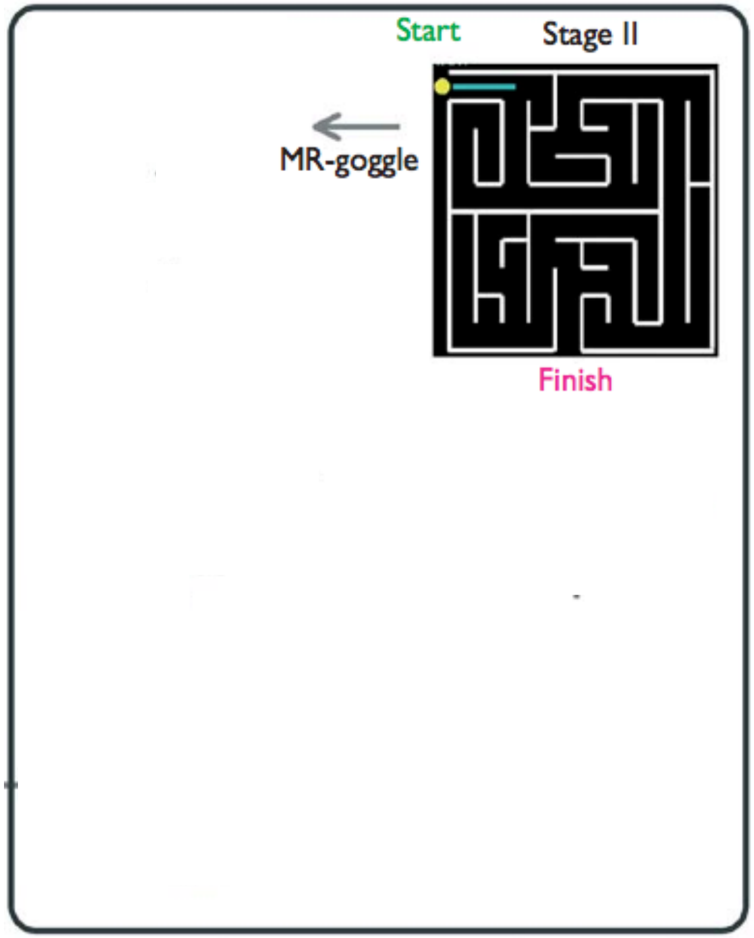


S.S. Yoo, T. Fairneny, N.K. Chen, S.E. Choo, L.P. Panych, H. Park, S.Y. Lee, F.A. Jolesz, Brain–computer interface using fMRI: spatial navigation by thoughts, Neuroreport 15 (2004) 1591–1595.

Neuro-control (1) – Cursor Control

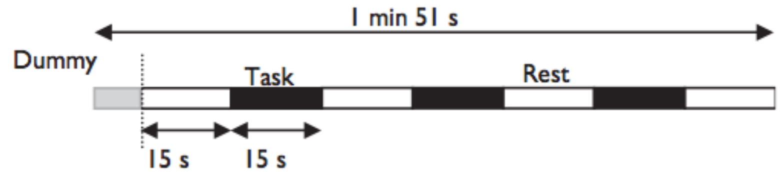
BOLD activity patterns from 4 different tasks were measured and translated into four directional cursor commands for navigation through a 2D maze presented to the subjects.

PHASE II
ATTEMPT TO NAVIGATE THE MAZE

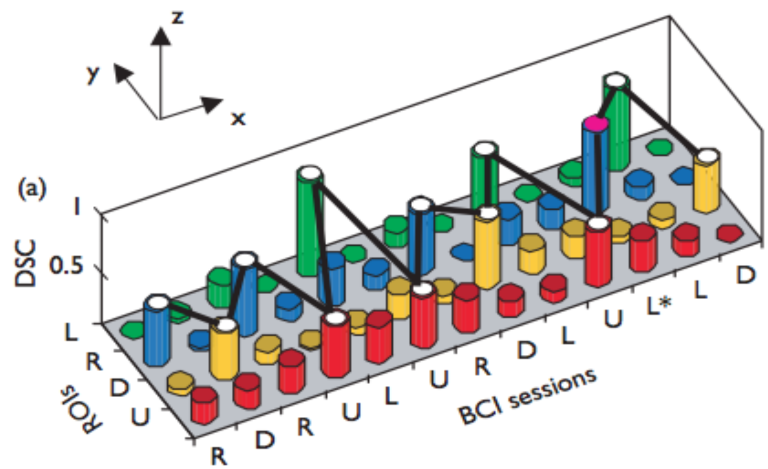


TR=1.5s | 3.75x3.75x5mm

- Data processed in near real-time (2min 15s).



- Cursor moved according to the pattern with the best match (Max Overlap).

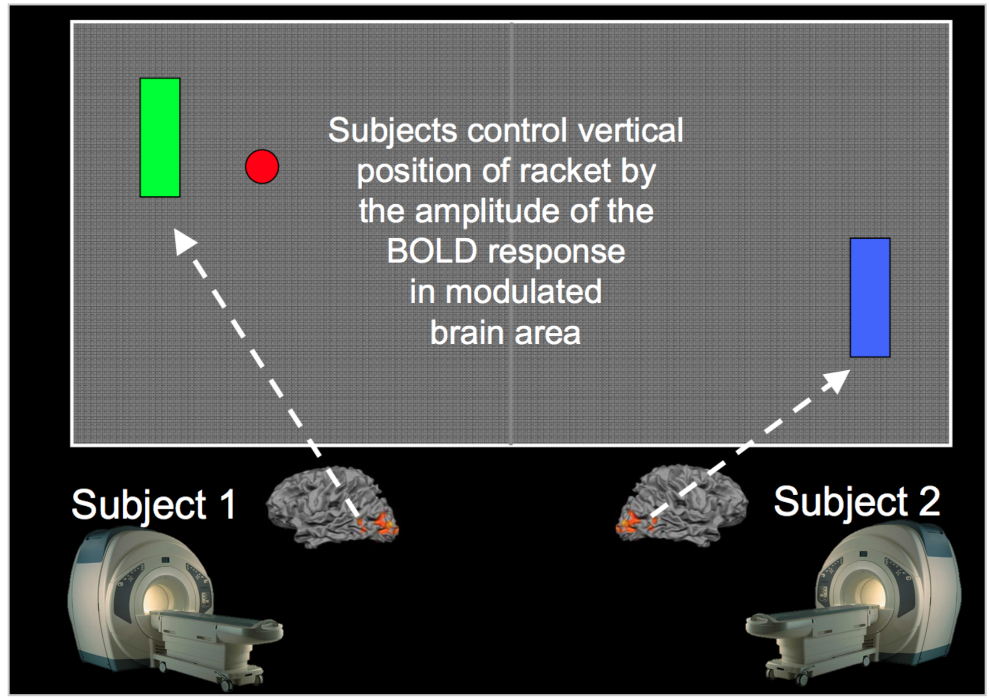


No errors for 2 subjects | 1 error for 1 subject

S.S. Yoo, T. Fairneny, N.K. Chen, S.E. Choo, L.P. Panych, H. Park, S.Y. Lee, F.A. Jolesz, "Brain–computer interface using fMRI: spatial navigation by thoughts", Neuroreport 15 (2004) 1591–1595.

Neuro-control (2) - BOLD Brain-Pong

Play the traditional Ping-Pong videogame controlling the racket with the level of BOLD activity within a given brain ROI.

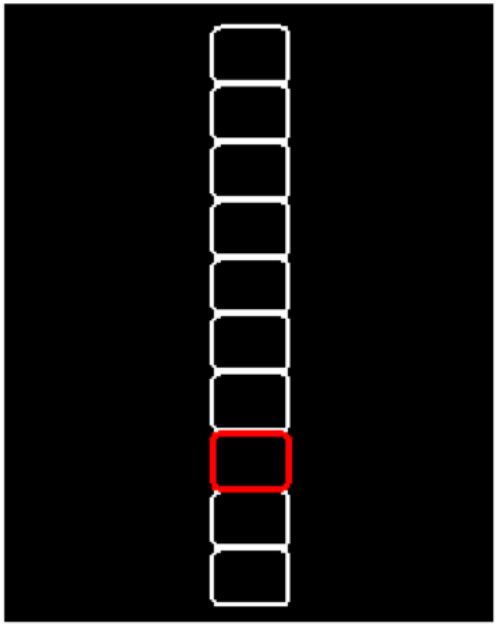


- How difficult is adaptation to the hemodynamic delay?
- Can two subjects exchange information based on ongoing fMRI measurements?
- Can we finely control activation levels within an ROI?

Goebel R, Sorger B, Kaiser J, Birbaumer N, Weiskopf N. BOLD Brain Pong: self-regulation of local brain activity during synchronously scanned, interacting subjects" Washington (DC) Society for Neuroscience; 2004.

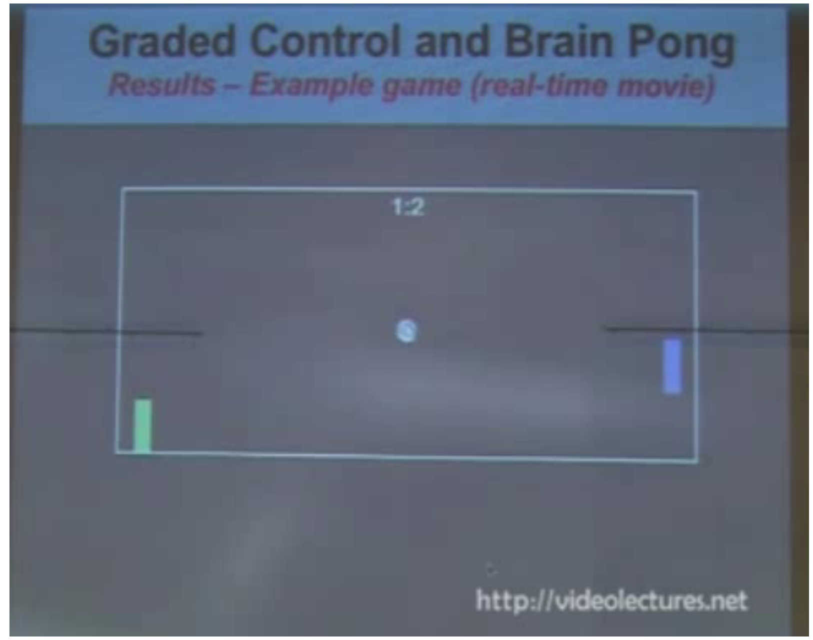
Neuro-control (2) - BOLD Brain-Pong

TRAINING SESSION



(1) Adapt to Hemodynamic Delay
(2) Learn Fine control of activity level
(3) Select optimal ROI per subject

VIDEO-GAME SESSION



- Hit Rate: 60 – 80%
- The game was highly motivating to practice the otherwise effortful brain modulation process.
- With extensive practice subjects could reach & maintain levels of brain activity with high accuracy.
- Potential use to explore the neural substrate of social cognitive processes.

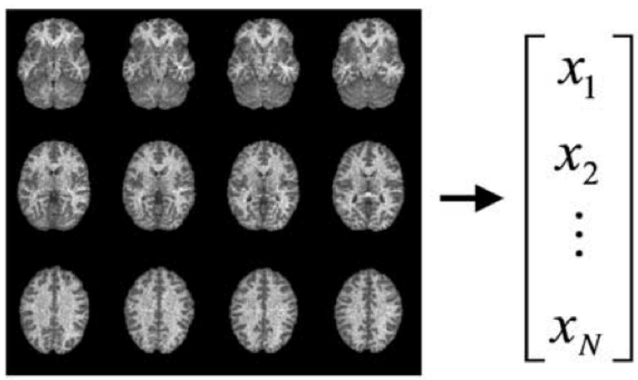
Goebel R, Sorger B, Kaiser J, Birbaumer N, Weiskopf N. BOLD Brain Pong: self-regulation of local brain activity during synchronously scanned, interacting subjects" Washington (DC) Society for Neuroscience; 2004.

Neuro-control (3) – **SVM**

SVM = Support Vector Machine | Supervised Learning & Classification Technique

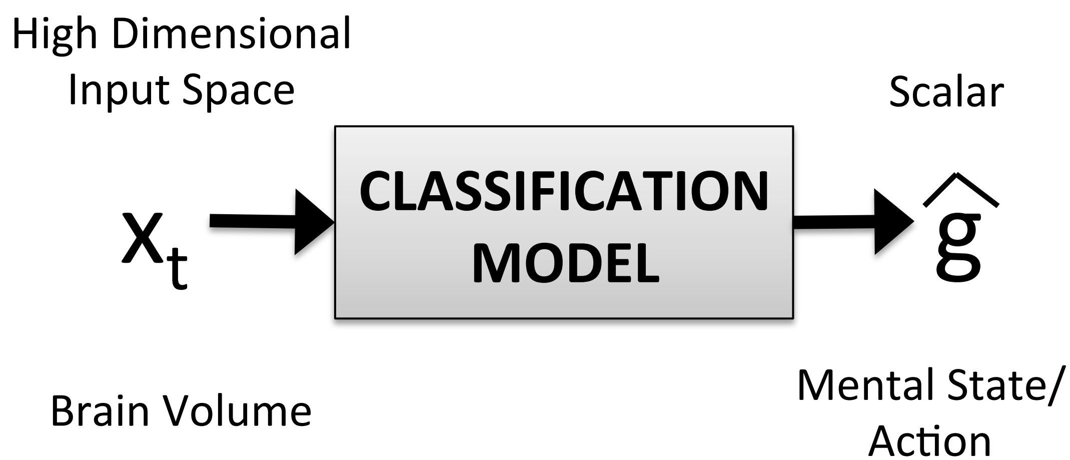
Every BOLD volume is regarded as a high dimensional vector

A Vector representation of a brain image time point



N = number of brain voxels

CLASSIFICATION PROBLEM



- Does not require feature selection.
- Classifies every incoming volume

LaConte S, Strother S et al. "Support vector machines for temporal classification of block design data" NeuroImage (2005) 26: 317-29

Neuro-control (3) – SVM

CLASSIFIER TRAINING

fMRI Training Data

$$\begin{bmatrix} X_{11} & X_{12} & X_{13} & \dots & X_{1T} \\ X_{21} & X_{22} & X_{23} & \dots & X_{2T} \\ \dots \\ \dots \\ X_{N1} & X_{N2} & X_{N3} & \dots & X_{NT} \end{bmatrix}$$

N = # of Voxels
T = # of Volumes

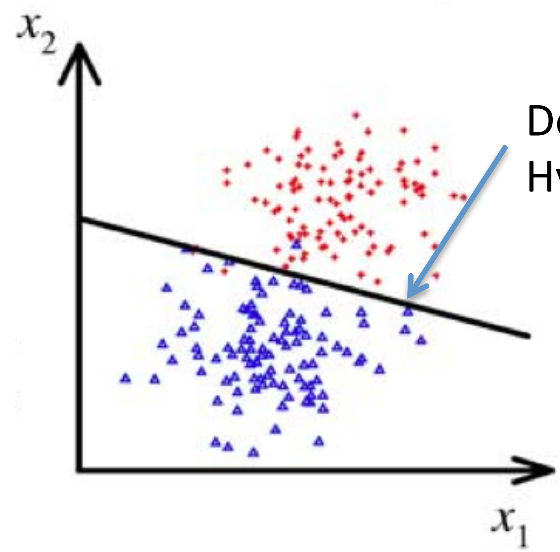
Training Labels

$[\ y_1 \quad y_2 \quad y_3 \quad \dots \quad y_T\ ]$

Mask

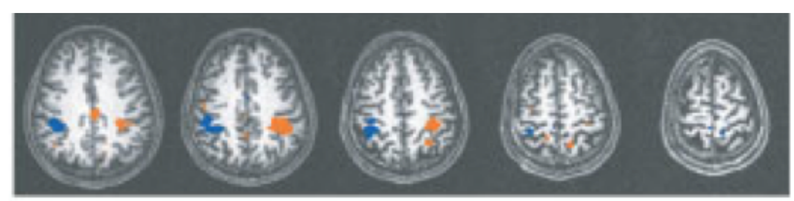
SUPPORT VECTOR MACHINE

OUPUT: CLASSIFICATION MODEL



Decision Function: $D(X_t) \rightarrow$ { > 0 : Label A (Left); < 0 : Label B (Right) }

SVM Map:



LaConte S, Strother S et al. “Support vector machines for temporal classification of block design data” NeuroImage (2005) 26: 317-29

Neuro-control (3) – SVM for Cursor Control

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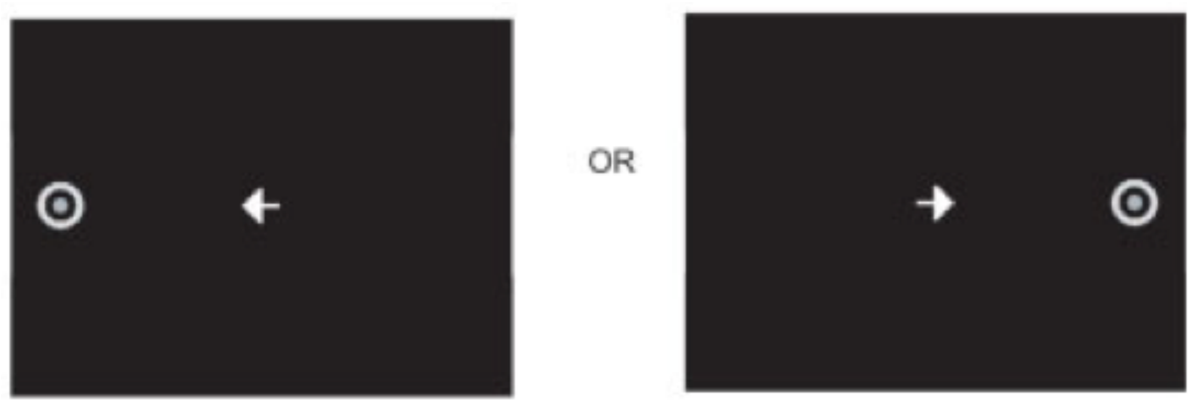
TRAINING RUN

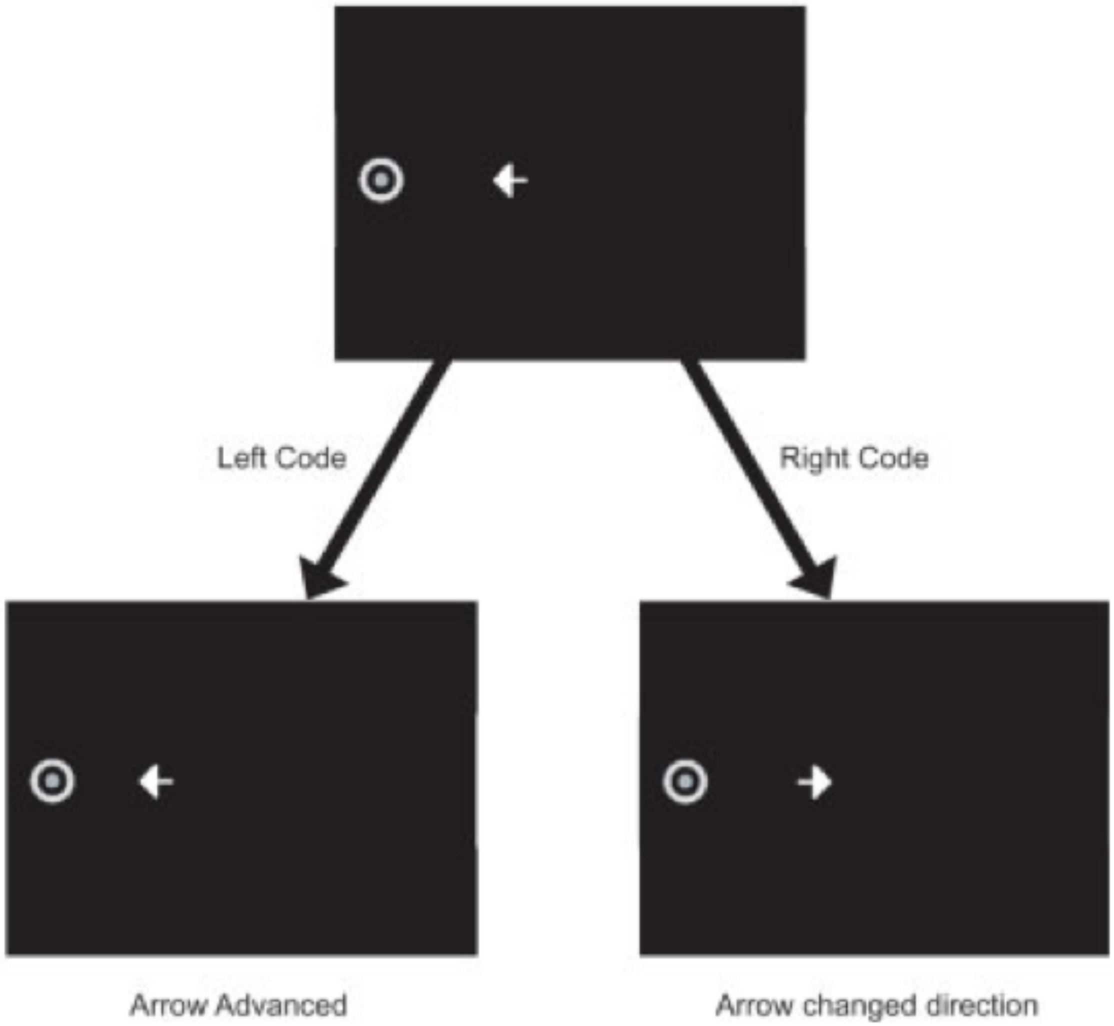


Left Button Press	Right Button Press
OR	OR
Sad Thoughts	Happy Thoughts
OR	OR
English Inner Speech	Chinese Inner Speech
OR	OR
Left Motor Imagery	Right Motor Imagery

LaConte S, Peltier SJ, Hu XP. “Real-time fMRI using brain-state classification.” Human Brain Mapping (2007) 28:1033-1044

Neuro-control (3) – SVM for Cursor Control

TEST RUN



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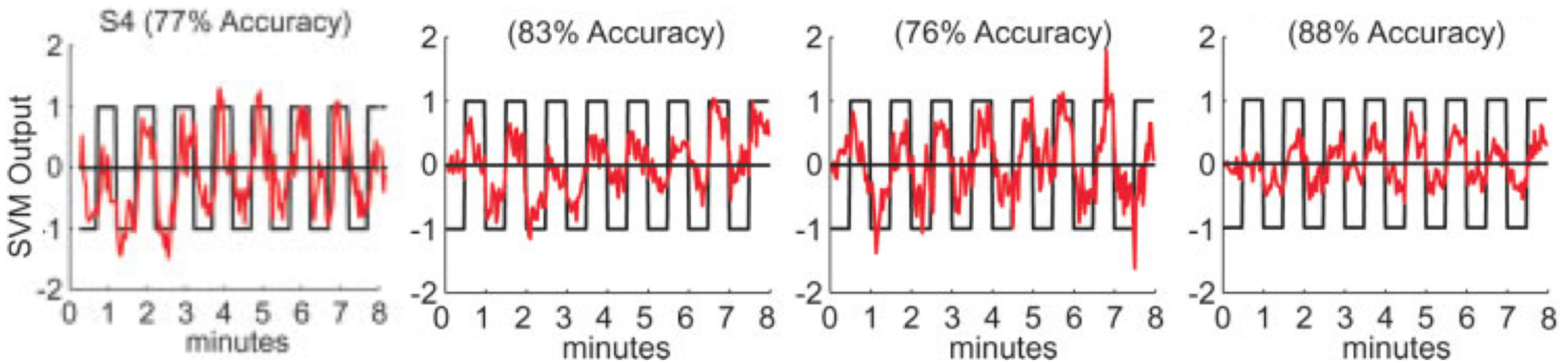
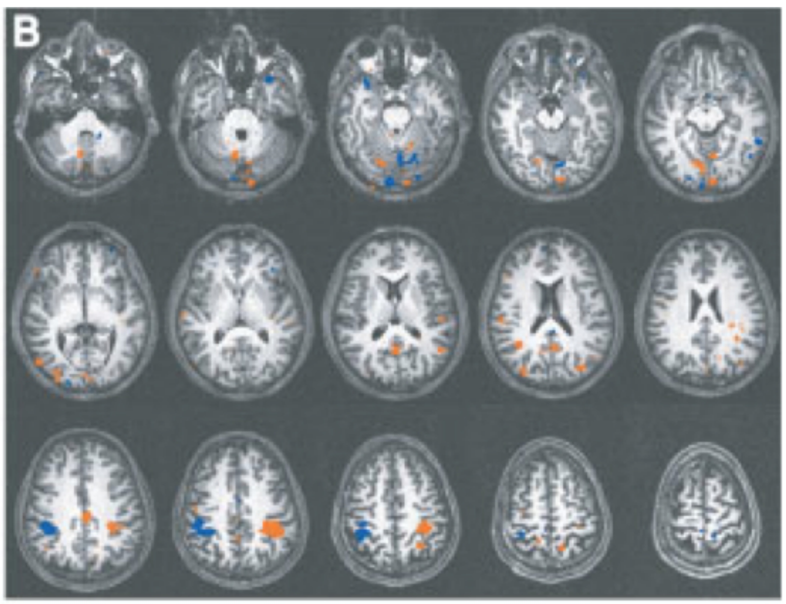
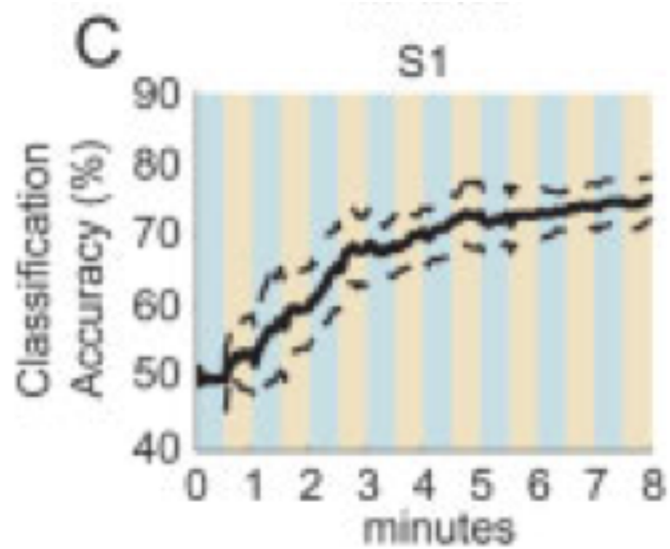
Neuro-control (3) – SVM for Cursor Control



Right/Left Motor Task | Sad/Happy | English/Chinese | Right/Left Imagery

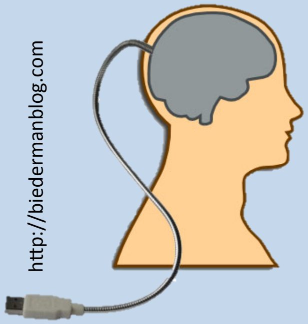




LaConte S, Peltier SJ, Hu XP. "Real-time fMRI using brain-state classification." Human Brain Mapping (2007) 28:1033-1044

AFNI Realtime SVM Support

Neurofeedback / Brain Computer Interfaces



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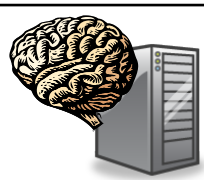


NEURO-CONTROL

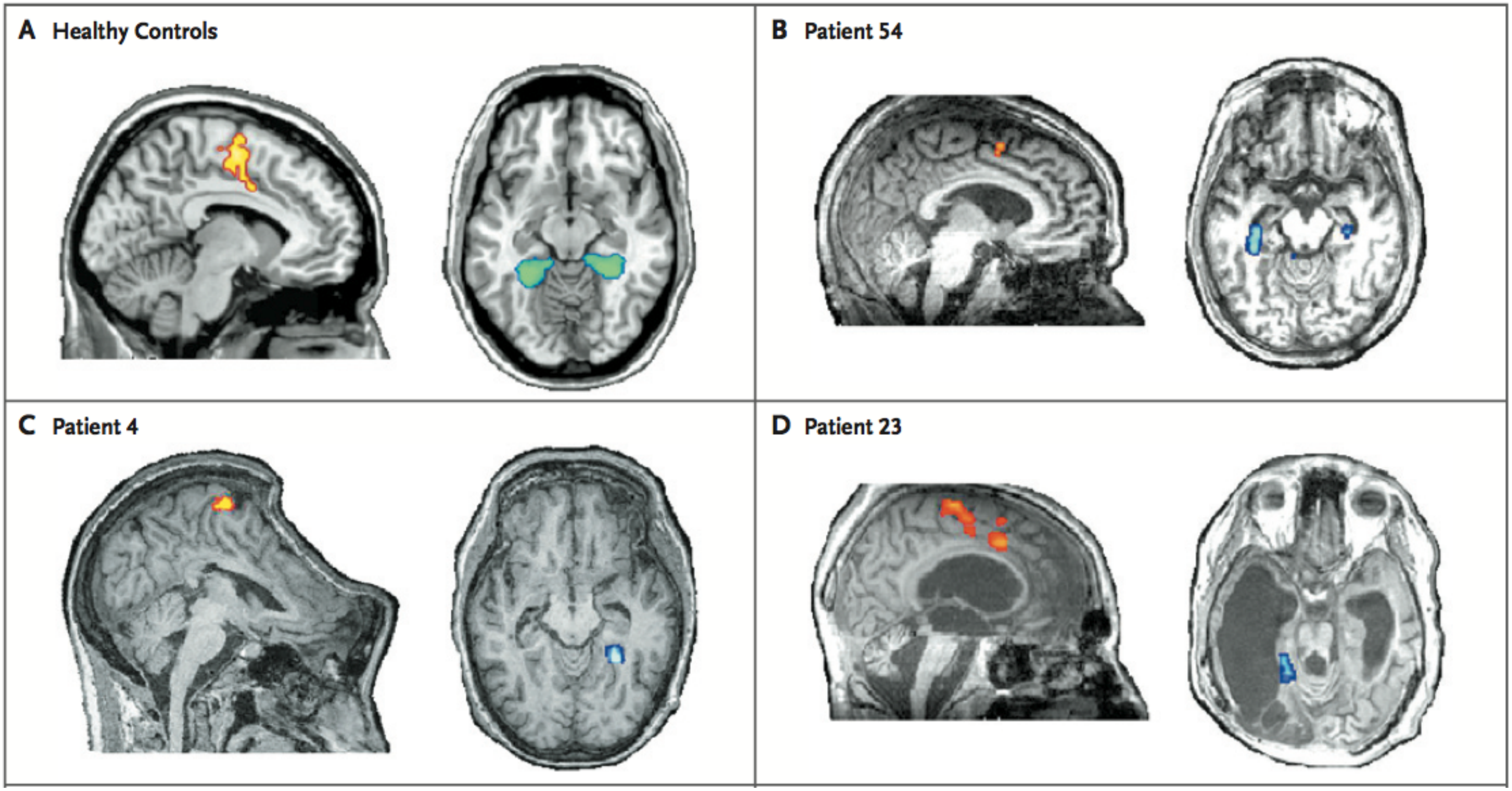
- Use “thoughts” to control an electronic/motorized device
- <u>Applications:</u> prosthesis, gaming

COMMUNICATION

- Use “thoughts” as a communication act.
- <u>Applications:</u> communicate with vegetative-state patients

IN SUBJECT WITH ZERO MOTOR CONTROL/RESPONSIVENESS

(1) Detect potential ability to generate willful, neuroanatomical specific BOLD responses.



Mental Imagery (Yellow & Red) | Motor Imagery (Blue & Green)

Monti M, Vanhaudenhuyse A, Coleman M, Boly M, Pickard J, Tshibanda L, Owen A, Laureys S. "Willful modulation of brain activity in disorders of consciousness" The New England Journal of Medicine. 2010: 579-589

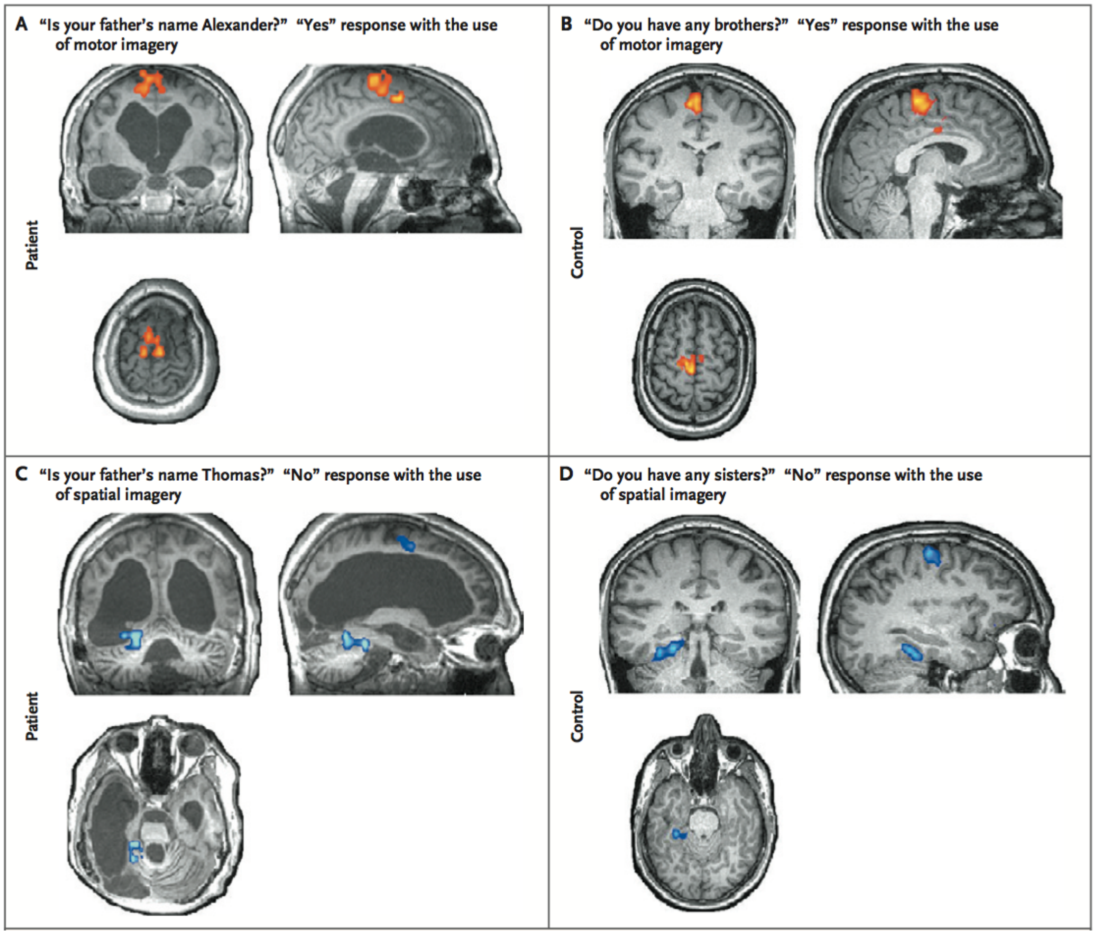
Neuro-Communication

IN SUBJECT WITH ZERO MOTOR CONTROL/RESPONSIVENESS

(2) Determine whether such responses could be used to answer simple yes-no questions.

MOTOR IMAGERY = YES

SPATIAL IMAGERY = NO



PATIENTS = 54

5 Willfully modulated brain activity

1 Was able to answer questions correctly

Identify incorrect diagnosis

Establish basic communication with patients

Monti M, Vanhaudenhuyse A, Coleman M, Boly M, Pickard J, Tshibanda L, Owen A, Laureys S. “Willful modulation of brain activity in disorders of consciousness” The New England Journal of Medicine. 2010: 579-589

Neuro-Communication – BOLD Spelling

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System to allow subjects spell any word based on their pattern of BOLD activity

MULTI-DIMENSIONAL CODING TECHIQUE

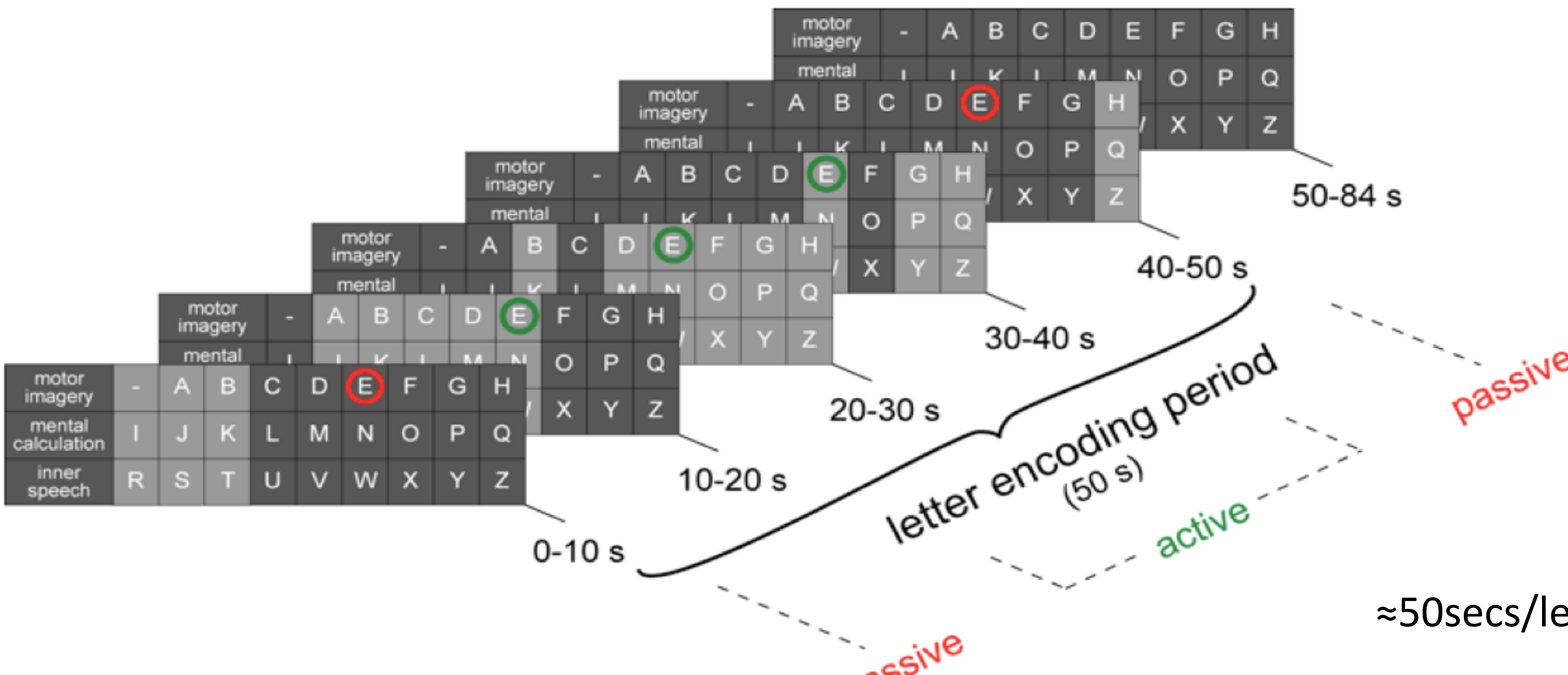
	TIMING								
Onset delay	0 s			10 s			20 s		
Duration	10 s	20 s	30 s	10 s	20 s	30 s	10 s	20 s	30 s
MENTAL TASK: motor imagery (ROIs)	-	A	B	C	D	E	F	G	H
MENTAL TASK: mental calculation (ROIs)	I	J	K	L	M	N	O	P	Q
MENTAL TASK: inner speech (ROIs)	R	S	T	U	V	W	X	Y	Z

Letter = f(task, when you start, for how long you do it)

Sorger, B., Reithler, J., Dahmen B. & Goebel, R. (2007). "A Realtime-based spelling device immediately enabling robust motor-independent communication". Current Biology (22):14, 1333-1338 (2012)

Neuro-Communication – BOLD Spelling

motor imagery	-	A	B	C	D	E	F	G	H
mental calculation	I	J	K	L	M	N	O	P	Q
inner speech	R	S	T	U	V	W	X	Y	Z



≈50secs/letter

Sorger, B., Reithler, J., Dahmen B. & Goebel, R. (2007). "A Realtime-based spelling device immediately enabling robust motor-independent communication". Current Biology (22):14, 1333-1338 (2012)

Neuro-Communication – BOLD Spelling

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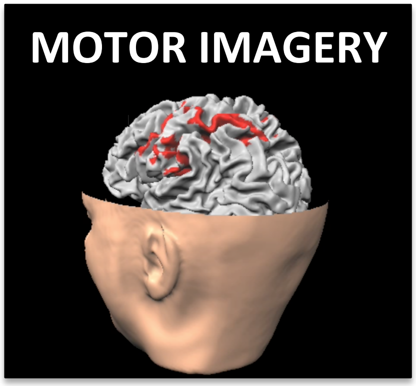

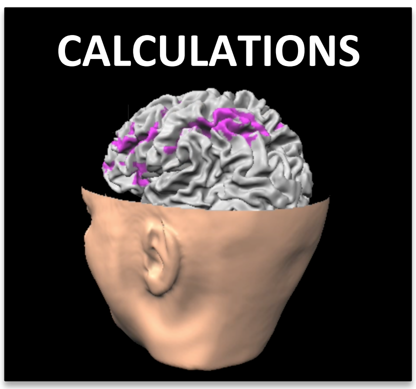

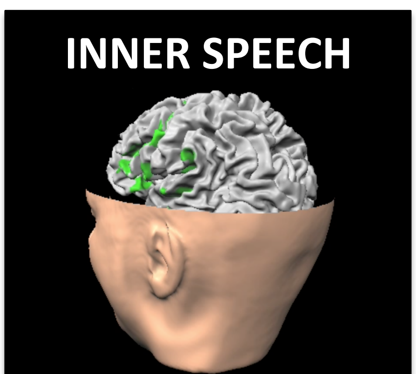

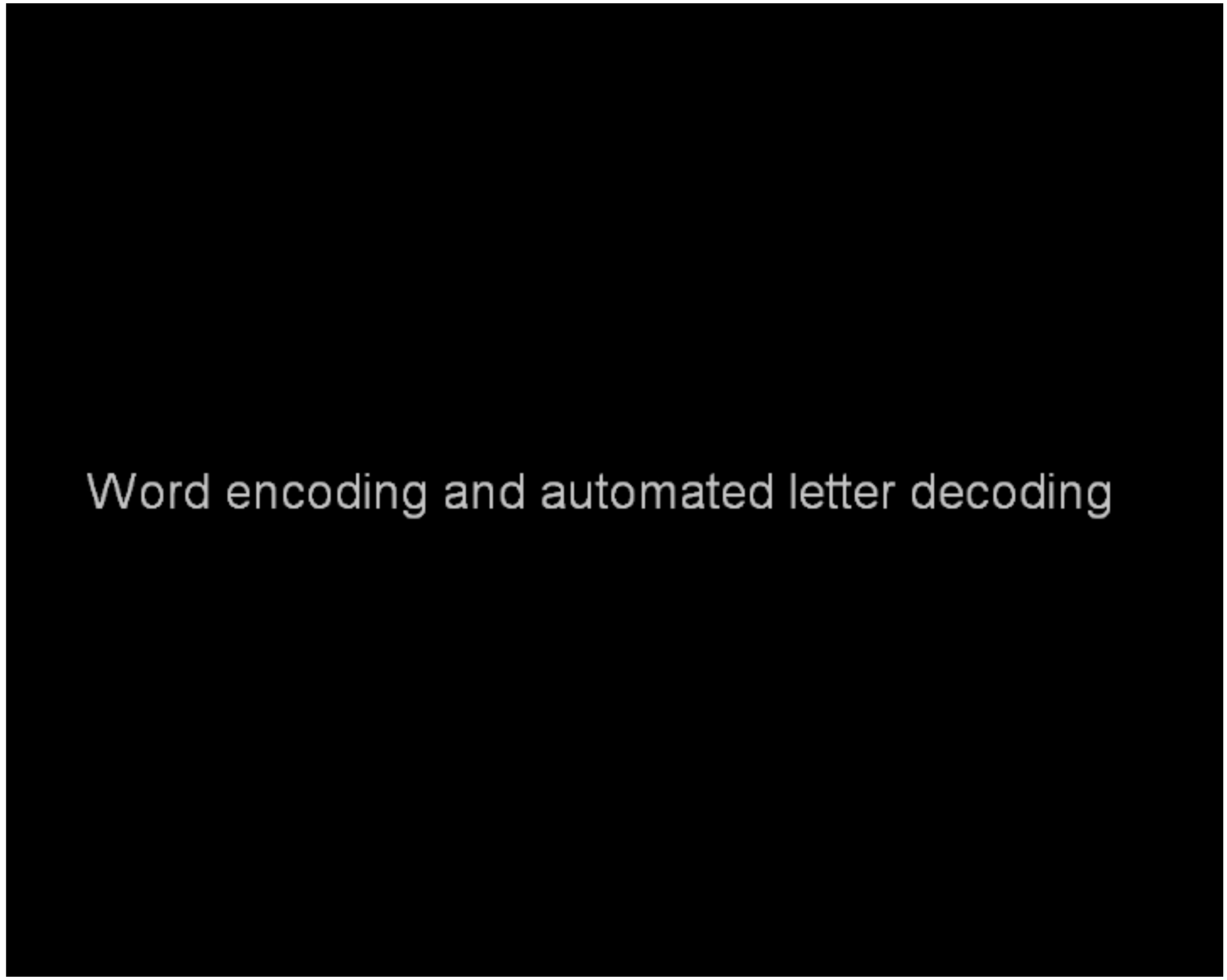

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Neuro-Communication – BOLD Spelling

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participant	initial question: stated question	initial question: decoder output/ human interpreter's decision	follow-up question: stated question	follow-up question: decoder output/ human interpreter's decision
1	"What is your hobby?"	P H O T O G R A P H Y - - O G M X X E I C N G W R R N E P S V H S - Y Z X I I P H O T O G R A P H Y - -	"What did you PHOTOGRAPH last?"	- O Y - H O M E - R M W R Z M O G R A T Z S G V T W A - M Y - H O M E -
2	"Where did you spend your most recent vacation?"	- I N D C N E R C A - A F O F M M G S I - A I R O B O O F J O C B - I N D O N E S I A -	"What did you like most in INDONESIA?"	- T E K P L E S - I R G M X U D J I A S D L Q M G R A - T E M P L E S -
3	"Where did you spend your most recent vacation?"	- I N D I A - S - E B - C A U A M E A B B - I N D I A -	"What do you consider most typical for INDIA?"	- C L O S H I N G - A A J X T G R M E A R O U P R E A V D R - C L O T H I N G -
4	"What is your hobby?"	- D R S C U S R R N G - R C I T U S U S I P E R A B - R S T R U F M F I - D I S C U S S I N G -	"What is your favorite DISCUSSION topic?"	- A W Y T H I N G - A - N Z S G R P E I B K P W V Z J W H A - A N Y T H I N G -
5	"What are you interested in?"	- X O V I D R A V M U R E S I M X W - N J - M O V I E S	"Which MOVIE did you watch last?"	T O P F U N - V X N N L M I U Y O G J P A T O P G U N -
6	"Where did you spend your most recent vacation?"	- - U D - D E S T - I A V C A P C U U I A B C F B Y D R V A - B U D A P E S T -	"What did you like most in BUDAPEST?"	- S W N - E D F U E - A U X L A G X E V D A J T Y M O F M G S C R - S Y N A G O G U E -

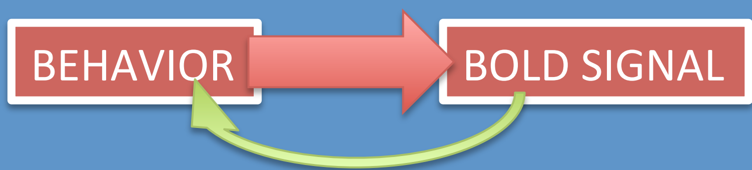
Sorger, B., Reithler, J., Dahmen B. & Goebel, R. (2007). "A Realtime-based spelling device immediately enabling robust motor-independent communication". Current Biology (22):14, 1333-1338 (2012)

Conclusions

1

REALTIME FMRI CAN

- Help increase the quality and productivity of your fMRI center.
- Allow novel/more interactive scanning protocols.



- Incorporate More and More Offline Processing Tools / Get Faster.
- Gone a long way….

2

fMRI NEUROFEEDBACK/BCI HAS TEACH US THAT:

- Healthy and Clinical subjects can gain volitional control of regional brain activity.
    - How fine is that control?
- Volitional control can translate into behavioral changes.
- Results are quite variable across subjects / not very strong.
- Neurofeedback has no adverse effects (safe therapy) [Hawkinson et al. 2011]

Conclusions

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3

WHEN DESIGNING NEUROFEEDBACK EXPERIMENTS WE NEED TO

- Make sure subjects understand hemodynamic delay & variability of signal.
- Make sure we account for signal drift & motion artifacts.
- Make sure our baseline calculation is not contaminated.
- Use simple interfaces the subject can understand (Fire Metaphor)
- As scanning progresses, make sure our ROIs are still in the correct place.
- Too small ROI (Motion problems) | Too big ROI (wash out effect of interest)
- Providing strategy seems to accelerate learning.
- We need to show that the Neurofeedback is essential to the result (Sham group).
- Do we want to show consolidation effects beyond scanning sessions?
- Use more subjects / Show more convincing results

Bibliography / Questions

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[2] Cox RW, Jermanowicz."Real-time 3D Image registration for functional MRI". Magn Reson Med. 1999 Dec;42(6):1014-8.

[3] Schwindack et al. "Real-time functional magnetic resonance imaging (rt-fMRI) in patients with brain tumors: preliminary findings using motor and language paradigms". British Journal of Neurosurgery 19 (2005): 25-32

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[6] S.S. Yoo et al. "Brain–computer interface using fMRI: spatial navigation by thoughts" Neuroreport 15 (2004): 1591–1595.

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