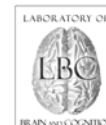


# Real-time fMRI / fMRI Neurofeedback

Javier Gonzalez-Castillo

Section on Functional Imaging Methods, NIMH, NIH

August, 2014



# Outline

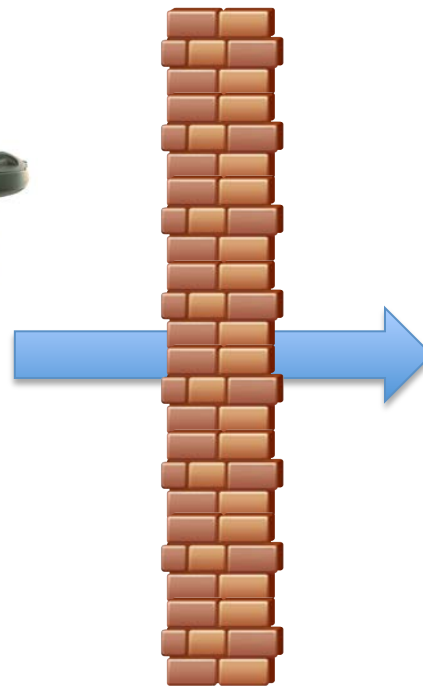


- What is “REALTIME fMRI”?
- Specific Example: NIH/AFNI Real-time fMRI System.
- Most Common Applications
  - Automatic On-line Data Quality Control
  - On-line Computation of Functional Localizations Maps
  - Neurofeedback / Brain-Computer Interfaces
- What do we know from these early experiments/prototypes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

# Traditional fMRI

1 – 2 Hours

DATA ACQUISITION



1 – 2 Days

DATA ANALYSIS



DATA ANALYSIS COMPUTER

# Real-time fMRI

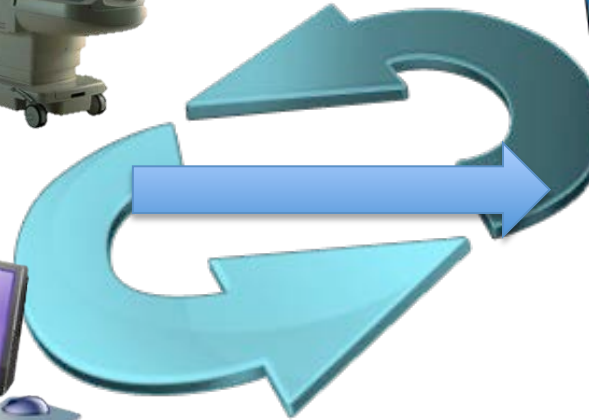
1 – 2 Hours

DATA ACQUISITION AND ANALYSIS

SCANNER



SCANNER  
CONSOLE



DATA ANALYSIS COMPUTER

# Real-time fMRI: Original Work

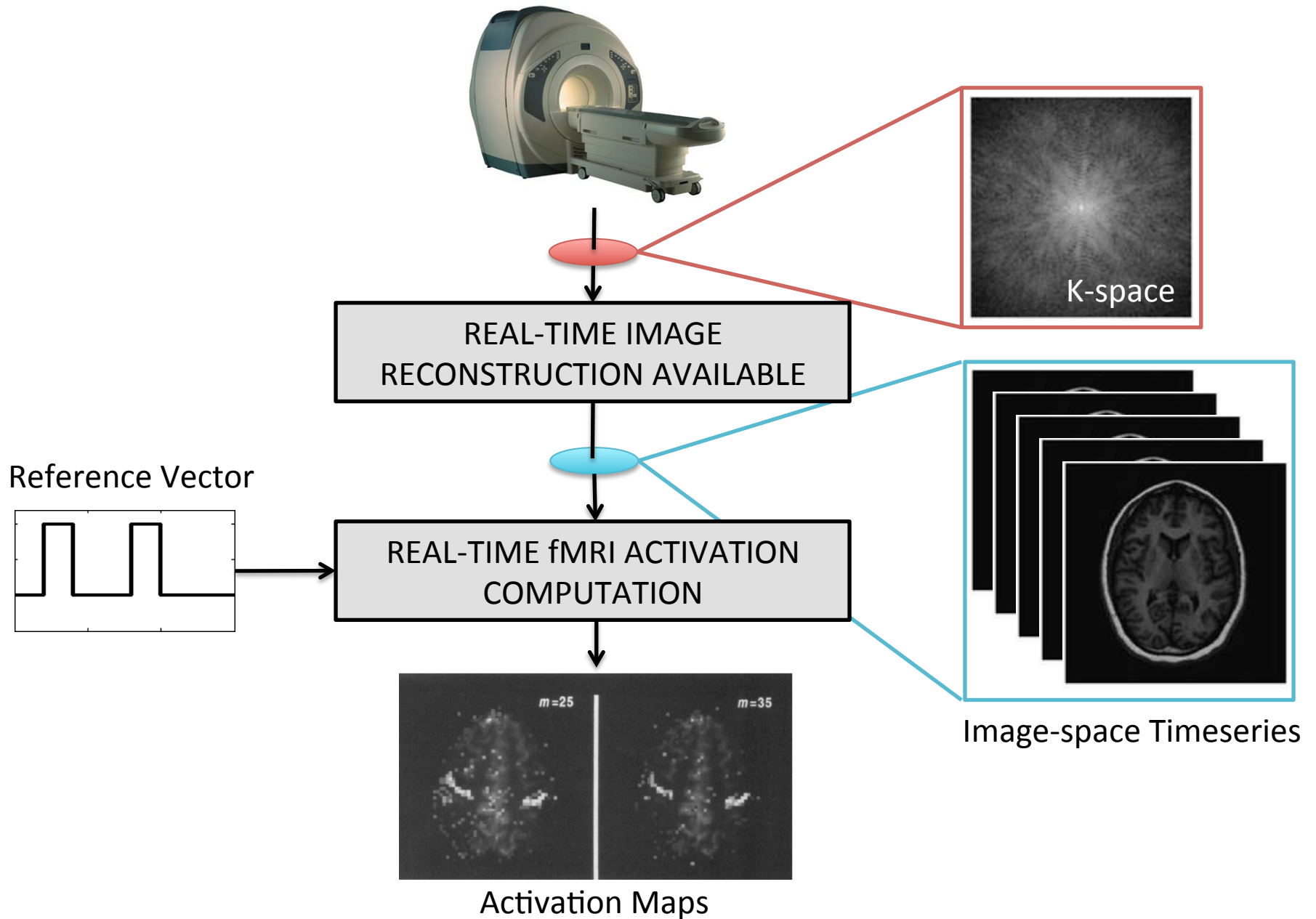


## **Real-Time Functional Magnetic Resonance Imaging**

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

- WHY NEAR-REAL-TIME VIEWING OF FMRI ACTIVATION IS DESIRABLE:
  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.
- FAST ALGORITHM TO RECURSIVELY COMPUTE:
  1. Voxel-wise correlation between incoming time-series and reference vector
  2. Associated statistics and thresholded map.
- **REAL-TIME fMRI WILL NOT BE A COMPLETE SUBSTITUTE FOR OFFLINE ANALYSIS**

# Real-time fMRI: Original Work



# Real-time fMRI Today



REAL-TIME IMAGE RECONSTRUCTION

3D HEAD MOTION CORRECTION

REMOVAL OF NUISANCE SIGNALS

Cox. R.W., Jezmanowicz A. "Real-Time 3D Image Registration for Functional MRI" MRM 42:1014-1018 (1999)

Hinds O. et al. "Computing moment-to-moment BOLD activation for realtime neurofeedback" NeuroImage 54:361-368 (2011)

HEAD MOTION REPORT

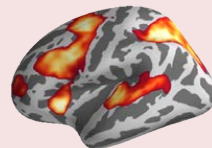
TSNR MAP CREATION

OTHER QA METRICS



**QUALITY CONTROL**

INCREMENTAL  
ACTIVATION MAP  
COMPUTATION



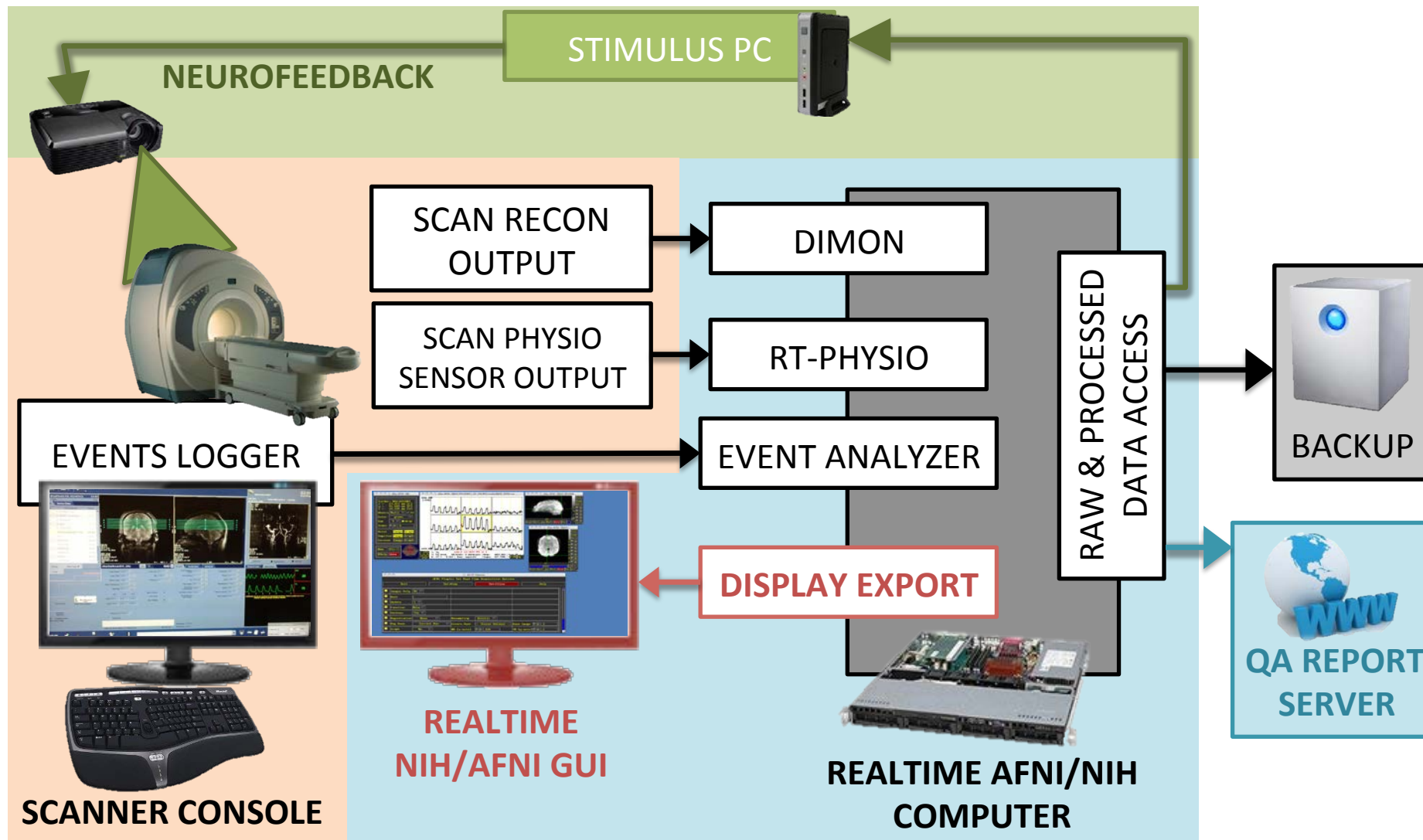
**FUNCTIONAL LOCALIZERS**

FEEDBACK DISPLAY SYSTEM



**NEUROFEEDBACK /BCI**

# NIH/AFNI Real-time System Architecture





# NIH/AFNI Real-time System: Look & Feel




[B]u AFNI: TRANSIENTS/SBJ02/SBJ02\_Anat\_al\_skull+tlrc & SBJ02\_Anat\_al\_skull+tlrc

[Order: RAI=DICOM]  
 x = -9.000 mm [R]  
 y = 78.000 mm [P]  
 z = 1.000 mm [S]

Xhairs Multi  X+  
 Color green   
 Gap 5  Wrap   
 Index

Axial Image Graph  
 Sagittal Image Graph  
 Coronal Image Graph

New Etc->  
 BHelp done



Original View  
 AC-PC Aligned  
 Talairach View

Define Overlay ->  
 See Overlay  
 Define Datamode ->

DataDir Switch Read  
 UnderLay EditEnv  
 OverLay NIIML+PO  
 Control Surface

#0 Inten Background Clusters

bkgd:ULay Clusterize  
 bkgd:OLay \*Clear Rpt

ULay #0 #0   
 OLay #0 #0   
 Thr #0 #0

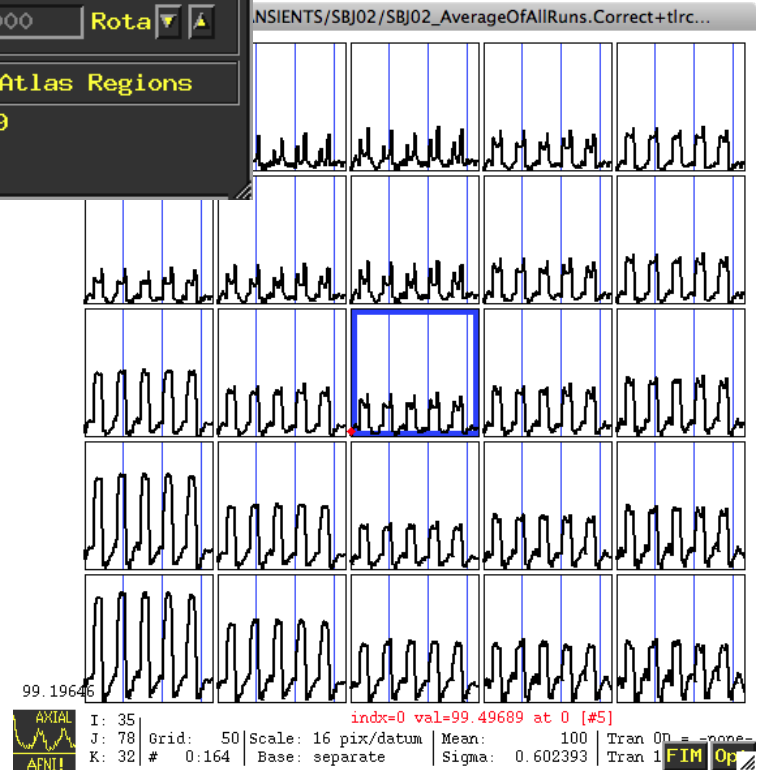
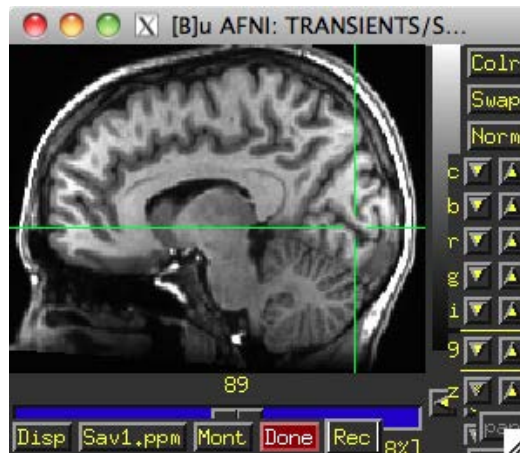
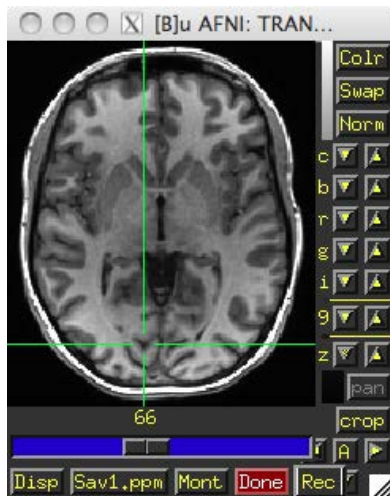
ULay 0: 8747  
 OLay 0: 8747  
 Thr 0: 8747

autoRange: 8747  
 10000 Rota

See TT Atlas Regions

ULay = 879  
 OLay = ?  
 Thr = ?

Pos?



# NIH/AFNI Real-time System: Look & Feel

The screenshot displays the AFNI software interface with several key components:

- Top Panel:** Window title "[B]u AFNI: TRANSIENTS/SBJ02/SBJ02\_Anat\_al\_skull+tlrc & SBJ02\_Anat\_al\_skull+tlrc".
- Left Panel:** Coordinate system settings (x = -9.000 mm [R], y = 78.000 mm [P], z = 1.000 mm [S]), Xhairs (Multi, X+), Color (green), Gap (5, Wrap), Index (0), and view options for Axial, Sagittal, and Coronal planes.
- Top-Right Panel:** View ULayer Data Brick and View OLayer Data Brick sections, including Warp ULayer/OLayer on Demand, Resam (mm) (1), OLayer Resam mode (NN), and Stat Resam mode (NN).
- Bottom-Right Panel:** Clusters section with a "Clusterize" button and a table of values:
 

0:	8747
0:	8747
0:	8747
- Bottom-Left Panel:** "SUMABUCKS COFFEE" logo and buttons for "New", "Etc->", "BHelp", and "done".
- Bottom-Middle Panel:** A menu listing various processing options:
  - 2D Registration
  - 3D Cluster
  - 3D Correlation
  - 3D Dump98
  - 3D Edit
  - 3D Registration
  - 3D+t Extract
  - 3D+t Statistic
  - 3dsvm
  - 4D Dump
  - ASL a3/d3
  - BRIK Compressor
  - Coord Order
  - Dataset Copy
  - Dataset Dup
  - Dataset NOTES
  - Dataset#2
  - Dataset#N
  - Deconvolution
  - Draw Dataset
  - Dset Zeropad
  - Edit Tagset
  - Expr 0D
  - Fourier Stuff
  - Gyrus Finder
  - Hemi-subtract
  - Hilbert Delay98
  - Histogram
  - Histogram: BFit
  - Histogram: CC
  - Histogram: Multi
  - L1\_Fit & Dtr
  - LSqFit & Dtr
  - Maxima
  - NLfit & NLerr
  - Nudge Dataset
  - Permutation Test
  - Power Spectrum
  - Render Dataset
  - Reorder
  - RETROICOR
  - ROI Average
  - ROI Plot
  - RT Options (highlighted in red)
  - ScatterPlot
  - SingleTrial Avg
  - Threshold
  - TS Generate
  - Vol2Surf
  - Wavelets
- Bottom-Right Panel:** A series of brain scan slices with overlaid waveforms. The top slice is labeled "TRANSIENTS/SBJ02/SBJ02\_AverageOfAllRuns.Correct+tlrc...".

# NIH/AFNI Real-time System: Look & Feel



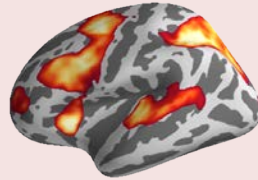
AFNI Plugin: Set Real-Time Acquisition Options

Quit      Set+Keep      **Set+Close**      Help

<input type="checkbox"/> Images Only	No		
<input type="checkbox"/> Root			
<input type="checkbox"/> Update	1		
<input type="checkbox"/> Function	None		
<input type="checkbox"/> Verbose	Yes		
<input type="checkbox"/> Registration	3D: realtime	Resampling	Quintic
<input type="checkbox"/> Reg Base	Current Run	Extern Dset	-- Choose Dataset --
<input type="checkbox"/> Graph	Realtime	NR [x-axis]	100
<input type="checkbox"/> Mask	-- Choose Dataset --	Vals to Send	All Data
<input type="checkbox"/> ChannelMerge	none	MergeRegister	none
<input type="checkbox"/> RT Write	Registered	Chan List	



**QUALITY  
CONTROL**



**FUNCTIONAL  
LOCALIZERS**



**NEUROFEEDBACK  
/BCI**

## Real-time fMRI Applications:

**(1) Automatic Data Quality Assurance**



# Automatic HW-QA



- 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



Home News Internal

You are here: Home

FMRIF QA »

Site Navigation

Public Resources

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- Investigators
- Staff
- Directions
- fMRI Course

Internal Resources

- FMRIF Manual
- Misc Forms + D
- QA
- Mailing Lists
- Scanlog
- Scheduling
- Tech Schedules

Next topic

3TA

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Enter search term or function name

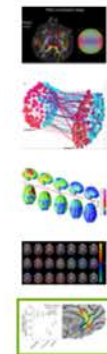
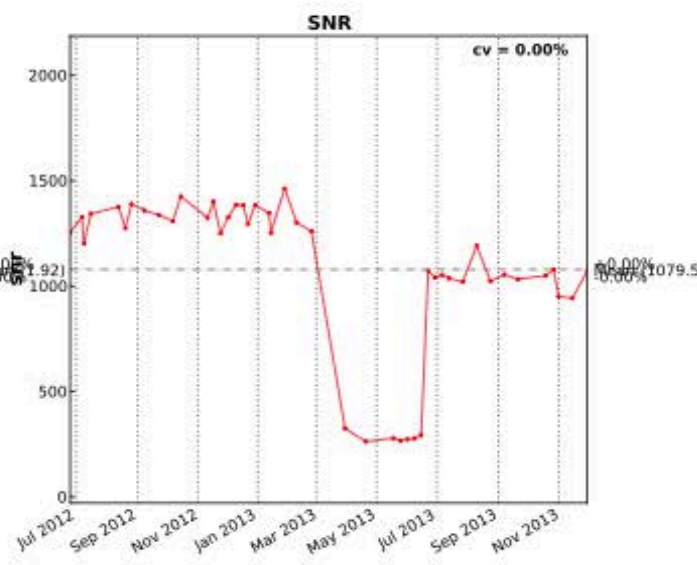
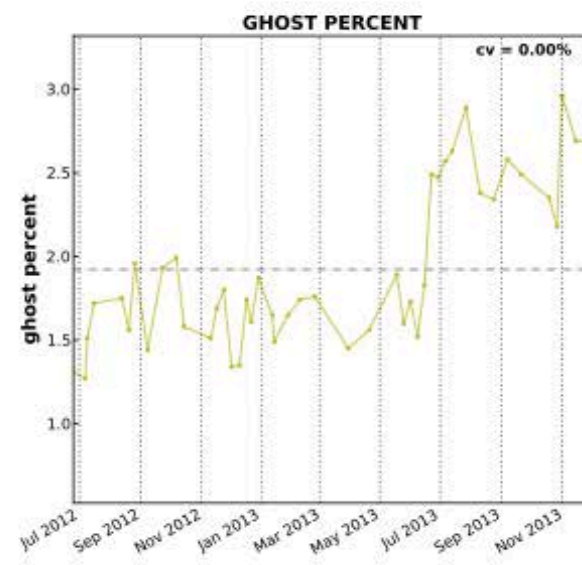
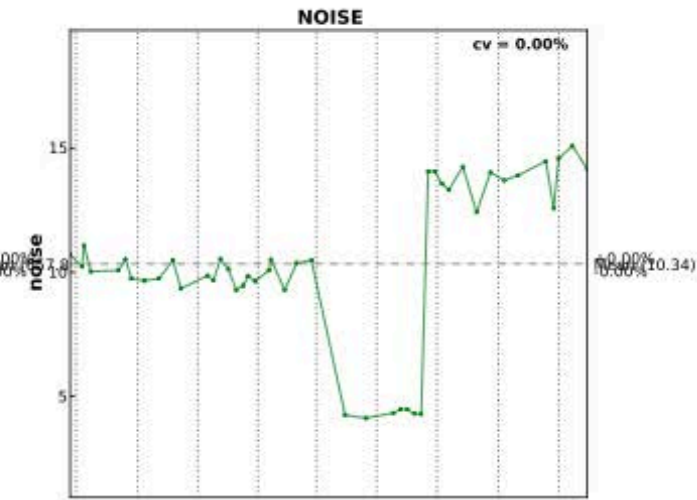
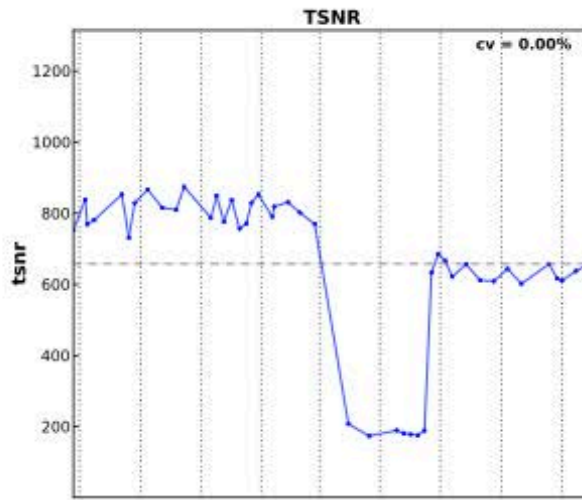
FMRIF QA »

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# In-session QA

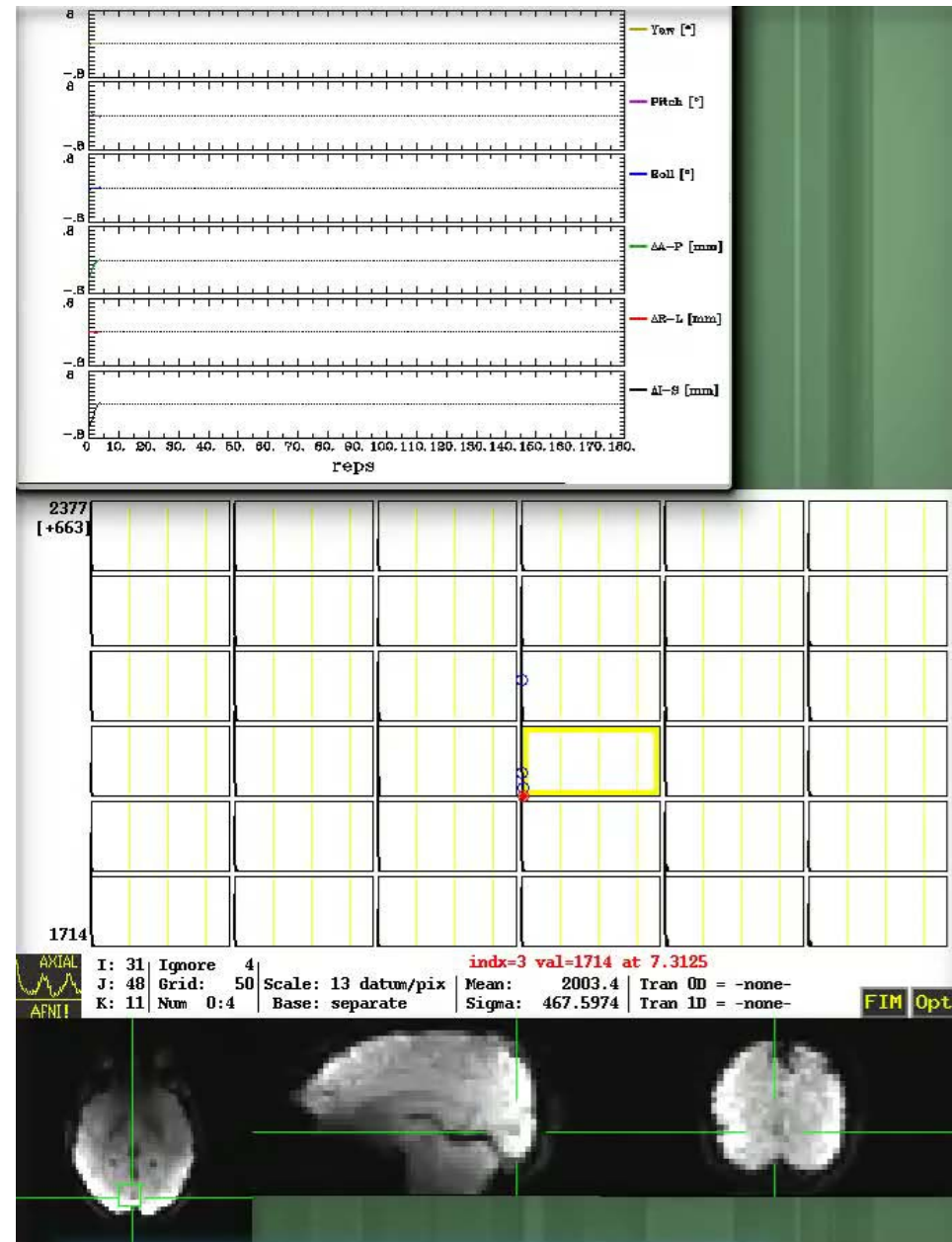


## WHY DO IN-SESSION QA?

- 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.

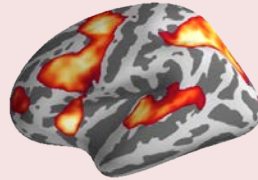
## WHAT DOES IT PROVIDE?

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





**QUALITY  
CONTROL**



**FUNCTIONAL  
LOCALIZERS**

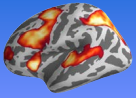


**NEUROFEEDBACK  
/BCI**

**Real-time fMRI Applications:**

**(2) Online Functional Localizers**





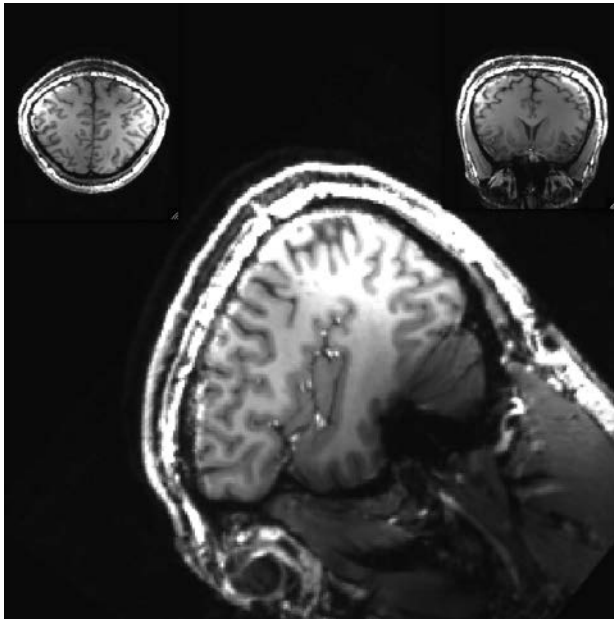
# Functional Localizers at Scan Time



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

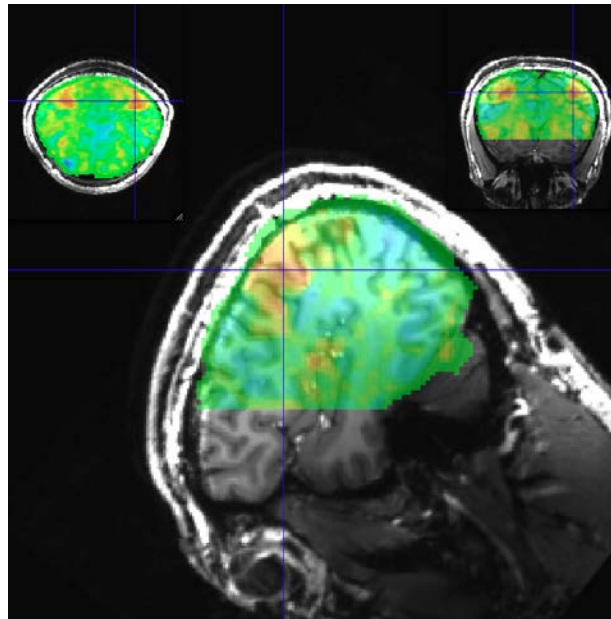
**1** Define target regions for main experiment more precisely...

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



HIGH RES-ANATOMICAL

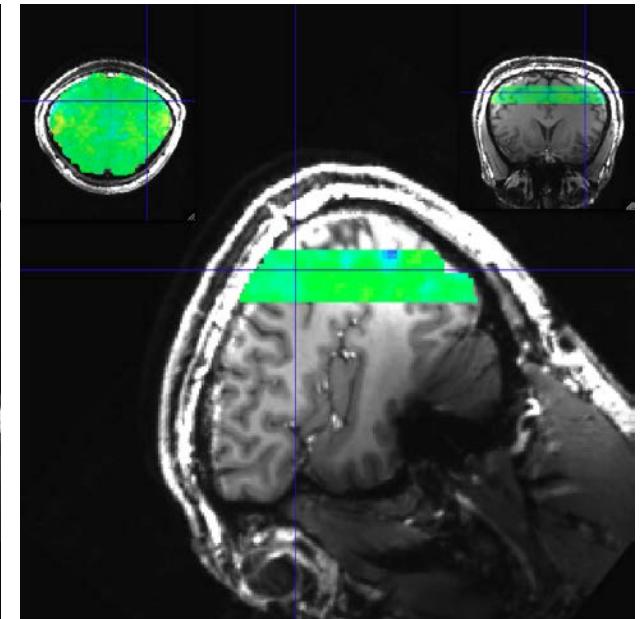
1x1x1mm



EPI FUNCTIONAL LOCALIZER

52 Slices @ 2x2x2mm

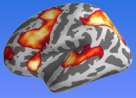
TR=2000ms



MAIN EXPERIMENT

11 Slices @ 2x2x2mm

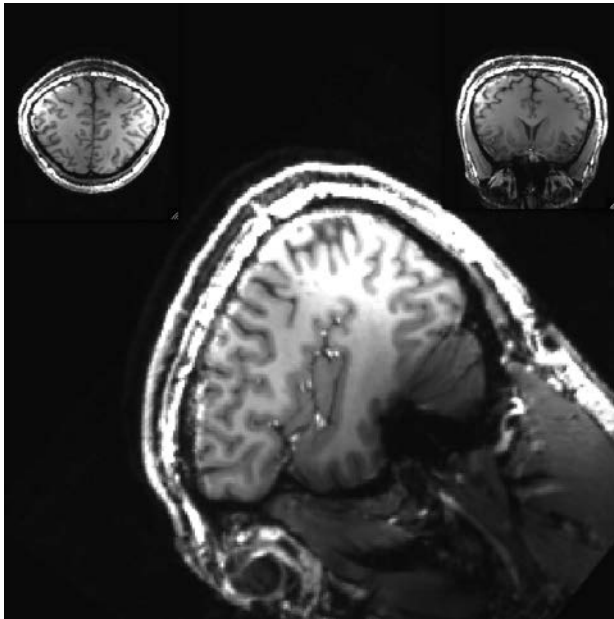
TR=400ms



# Functional Localizers at Scan Time (II)

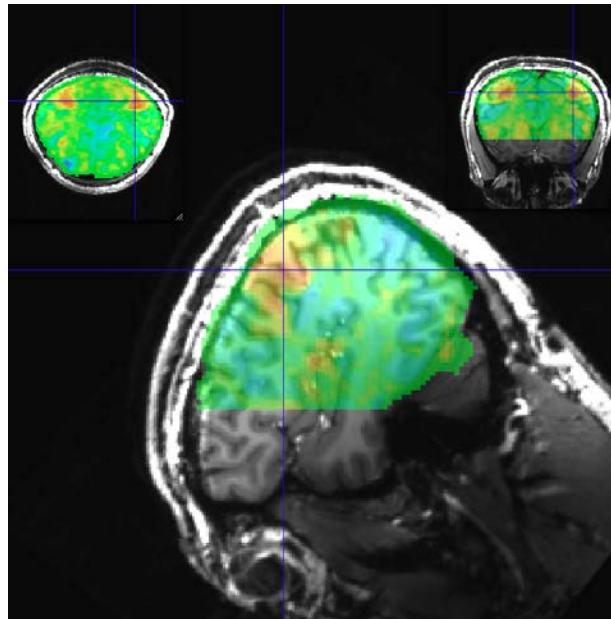
**2** Define target regions for main experiment more precisely...

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



HIGH RES-ANATOMICAL

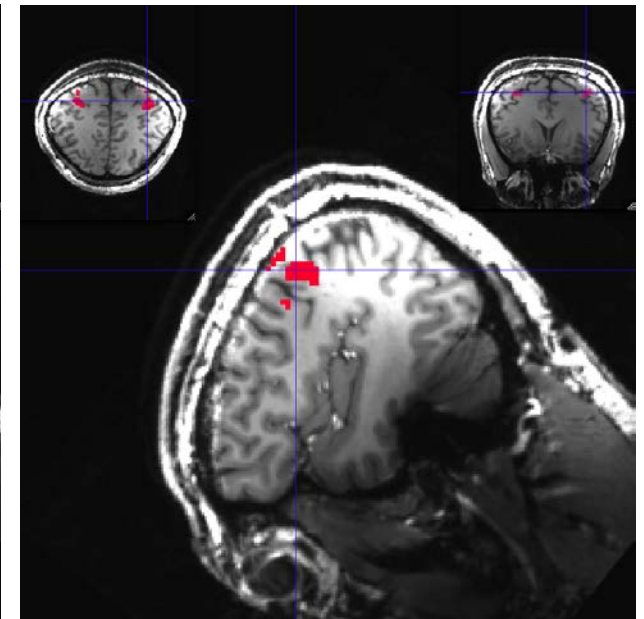
1x1x1mm



EPI FUNCTIONAL LOCALIZER

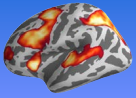
52 Slices @ 2x2x2mm

TR=2000ms



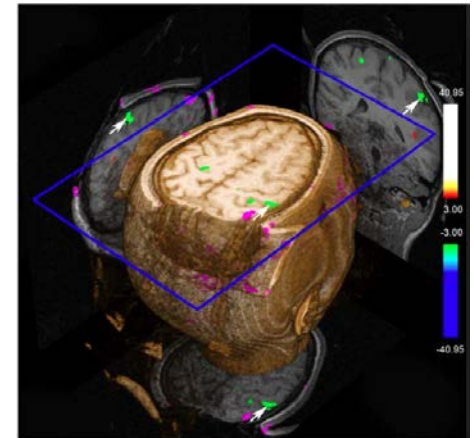
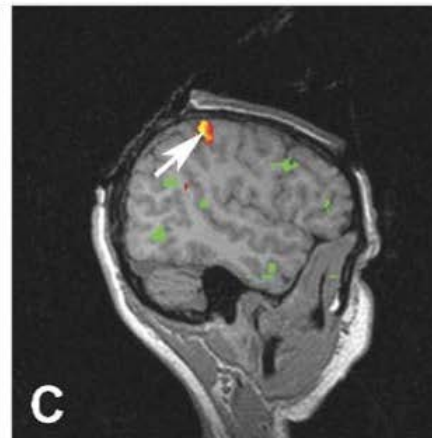
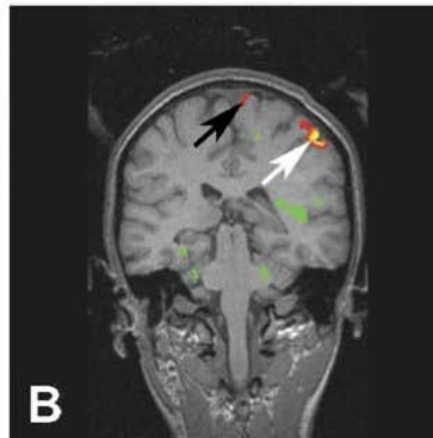
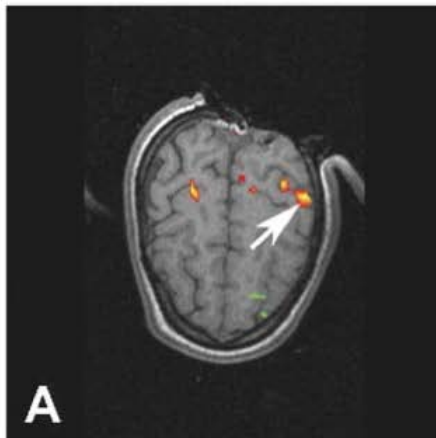
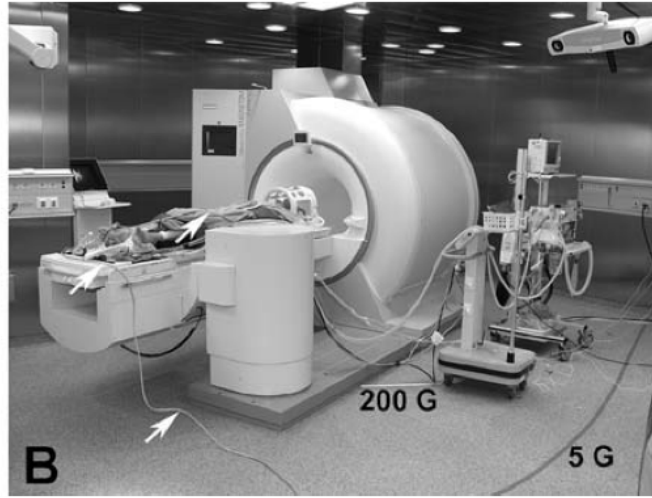
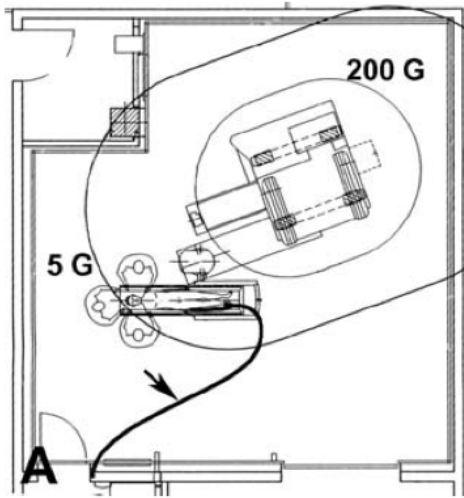
ROI FOR MAIN EXPERIMENT

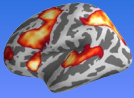
NEUROFEEDBACK/BCI



# Functional Localizers at Scan Time (III)

## 3 Guide Surgical Interventions → Detect Tissue displacement during surgery





# Functional Localizers at Scan Time (IV)



## 4 Teaching / Demonstrations to journalists and interested public.

- CAN BE VERY EFFECTIVE AT EXPLAINING:

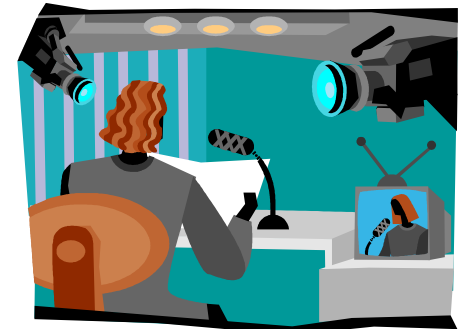
- BOLD Effect.
- Hemodynamic Delay/Filter.
- Artifacts: Head motion.
- Effect of Imaging Parameters/Tuning of Scanning Protocols



- CAN HELP GET NEW STUDENTS INTERESTED IN FMRI

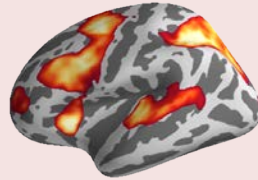
- REPORTED POSITIVE PAST EXPERIENCES:

- Wellcome Trust Center for Neuroimaging (London, UK)
- International Max Planck Research School (Tubingen, Germany)





**QUALITY  
CONTROL**



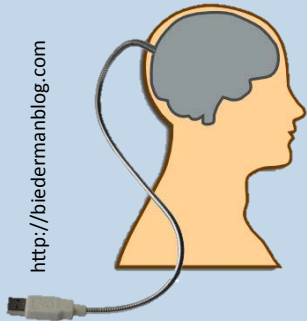
**FUNCTIONAL  
LOCALIZERS**



**NEUROFEEDBACK  
/BCI**

**Real-time fMRI Applications:**

**(3) Brain-Computer Interfaces &  
Neurofeedback**



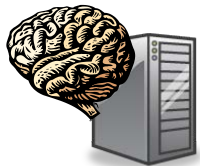
## BRAIN – COMPUTER INTERFACE

“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



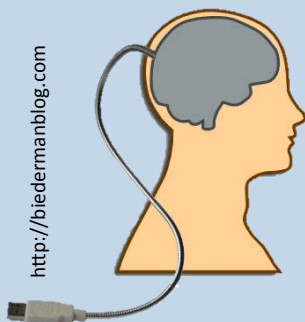
### NEURO-CONTROL

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



### COMMUNICATION

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



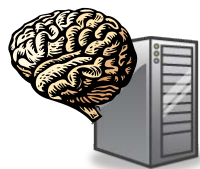
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### NEURO-CONTROL

- Use “thoughts” to control an electronic/motorized device
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### COMMUNICATION

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



# fMRI BCI/Neurofeedback in Perspective



	NON INVASIVE	PORTABLE	INTERFACE	SPECIFICITY	REACH DEEP STRUCT.
<p><b>Electrode Implantation</b></p>			<i>Neuronal Activity</i>	<b>VERY HIGH</b>	
<p><b>EEG-based</b></p>			<i>Electric Fields</i>	<b>LOW</b>	
<p><b>fMRI-based</b></p>			<i>Hemodynamic Response</i>	<b>HIGH</b>	

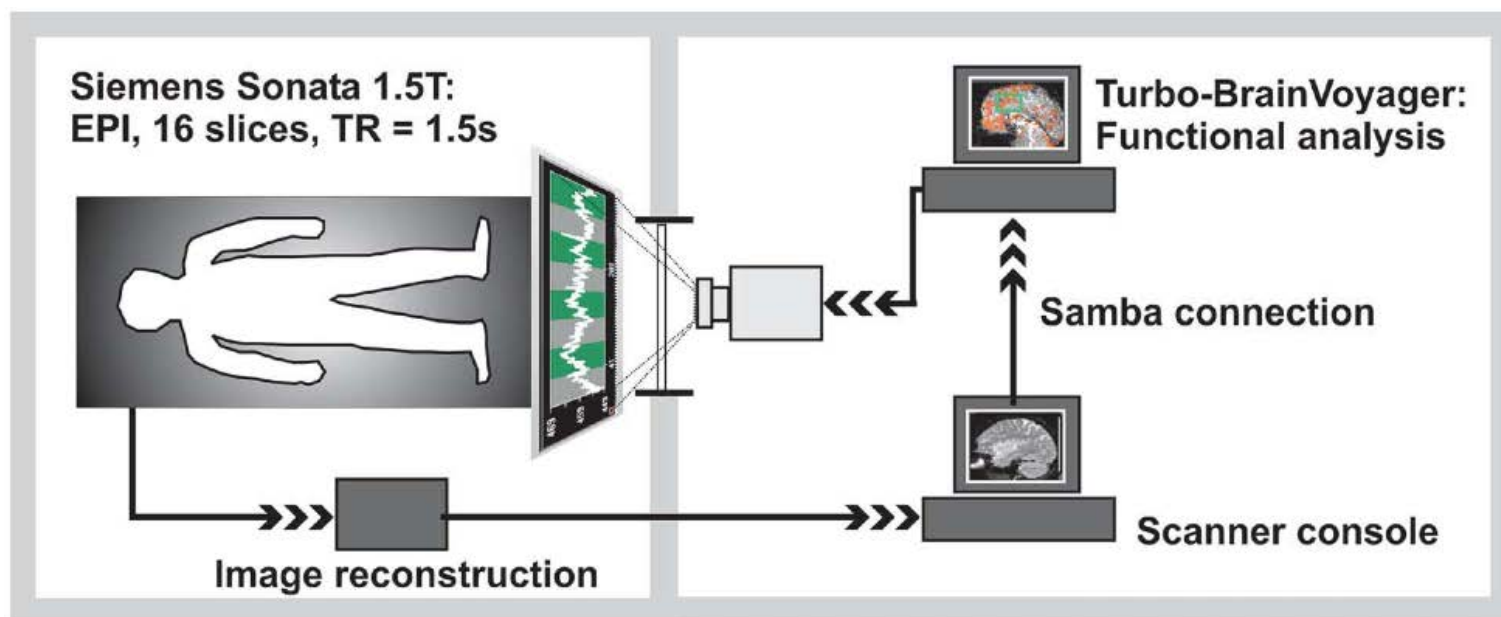




# Neurofeedback (1) – Original Experiments



## 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

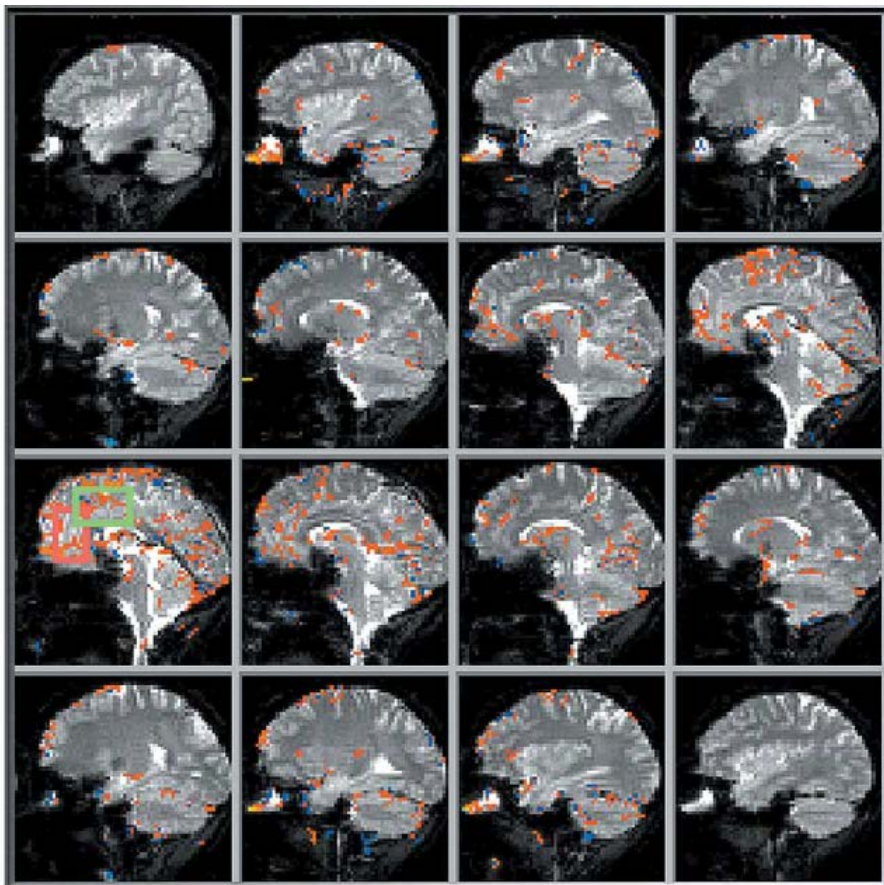


# Neurofeedback (1) – Original Experiments

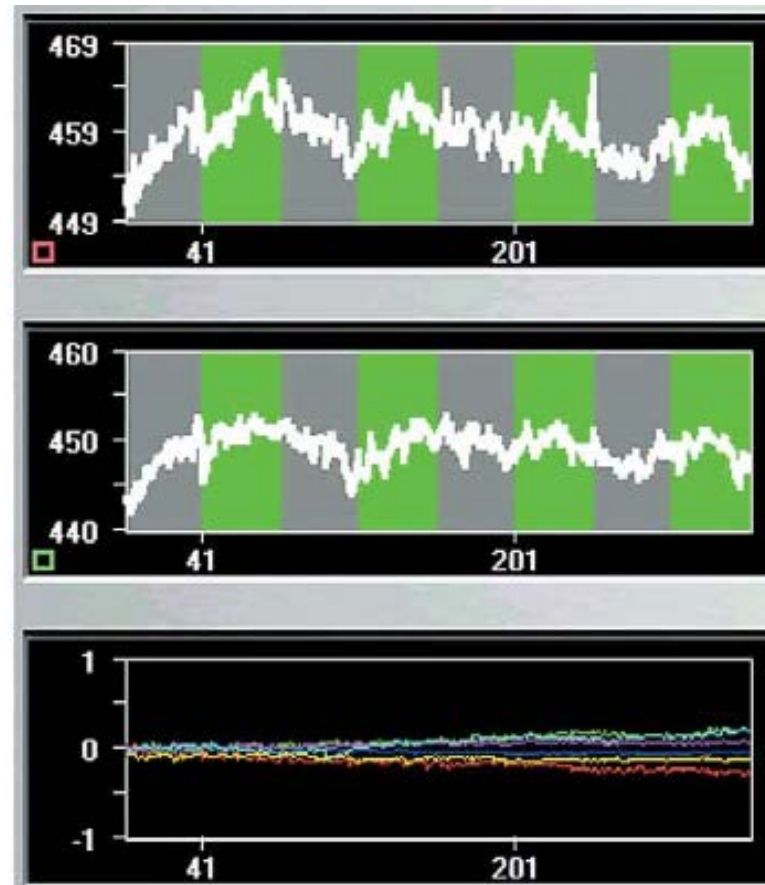


## FEEDBACK SCREEN

### 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

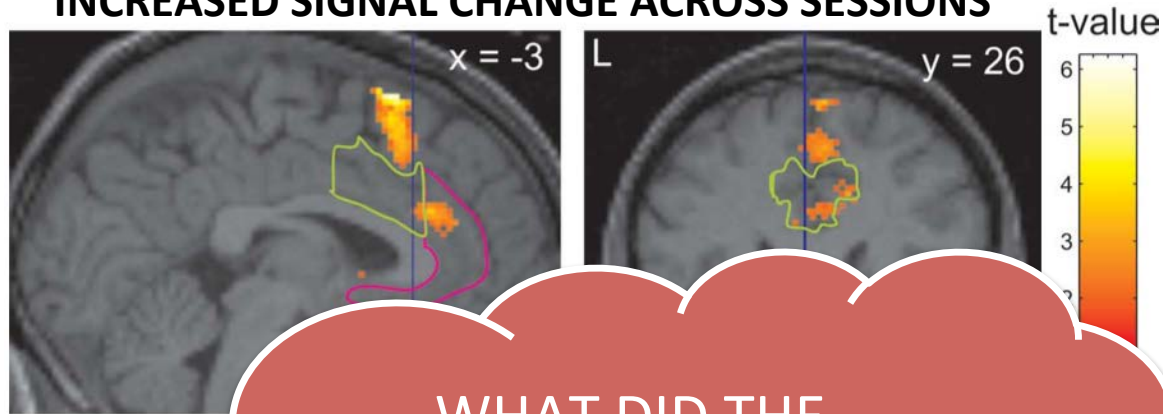


# Neurofeedback (1) – Original Experiments

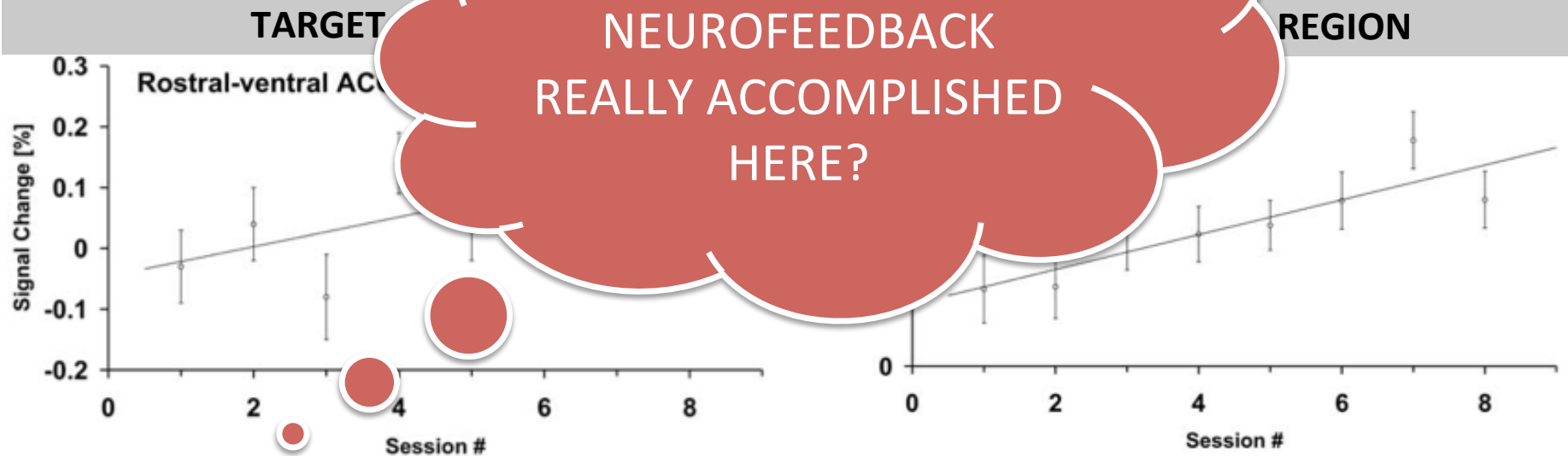


## RESULTS

### INCREASED SIGNAL CHANGE ACROSS SESSIONS



WHAT DID THE  
NEUROFEEDBACK  
REALLY ACCOMPLISHED  
HERE?



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

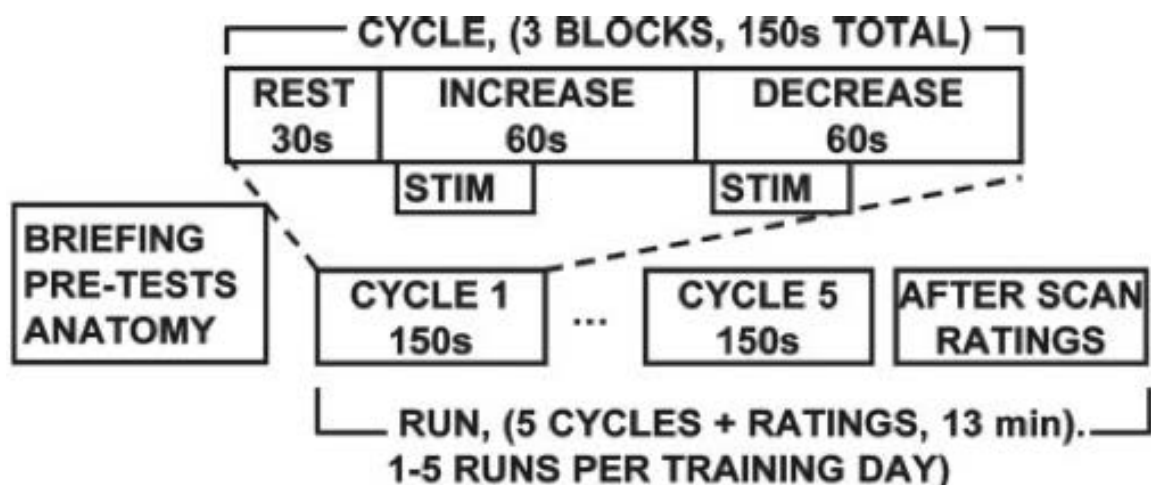


# Neurofeedback (2) – Mitigation of Chronic Pain

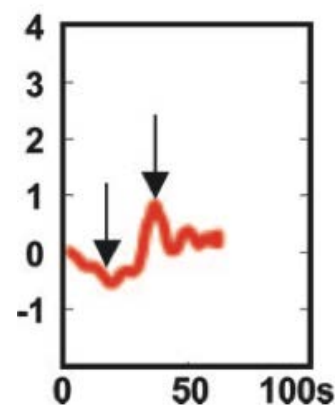


Does learned, deliberate manipulation of rostral anterior cingulate cortex (rACC) activation by subjects lead to predicted effects on pain perception?

## EXPERIMENTAL DESIGN



## FEEDBACK SCREEN



- 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



# Neurofeedback (2) – Mitigation of Chronic Pain



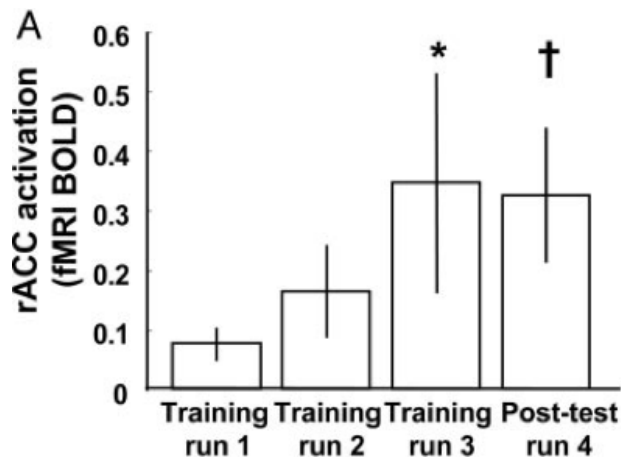
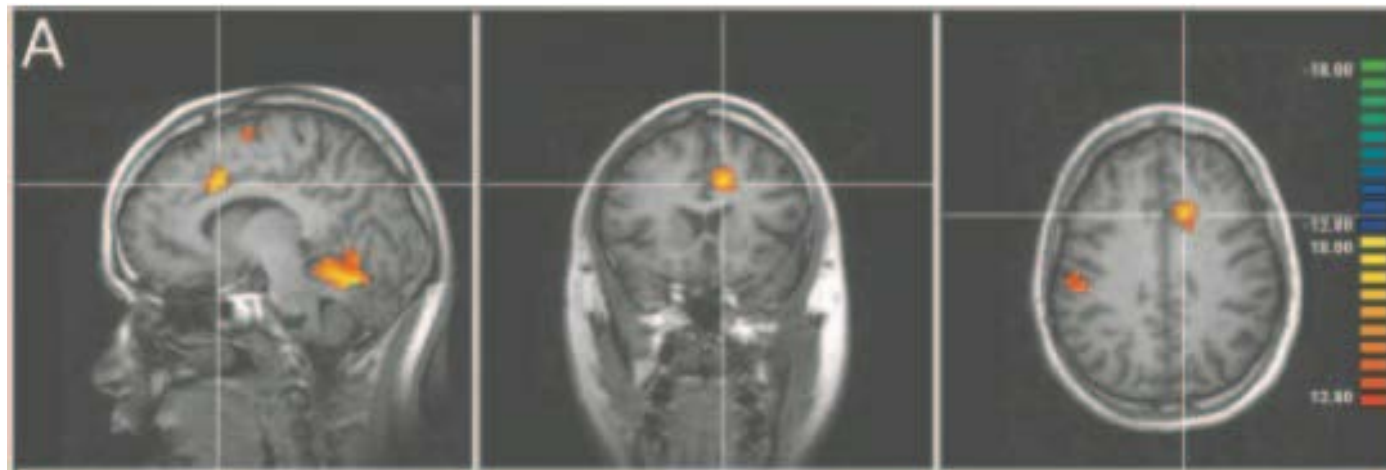
GROUP	N	POPULATION	FEEDBACK TYPE	#TRAINING RUNS (13mins)	INSTRUCTIONS
H1	8	HEALTHY	fMRI from rACC	3	Attention/Control Stim. Quality/Severity
H2	8		No fMRI Feedback	3	Attention/Control Stim. Quality/Severity
H3	8		No fMRI Feedback	6	Attention
H4	8		fMRI other ROI	3	Attention/Control Stim. Quality/Severity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



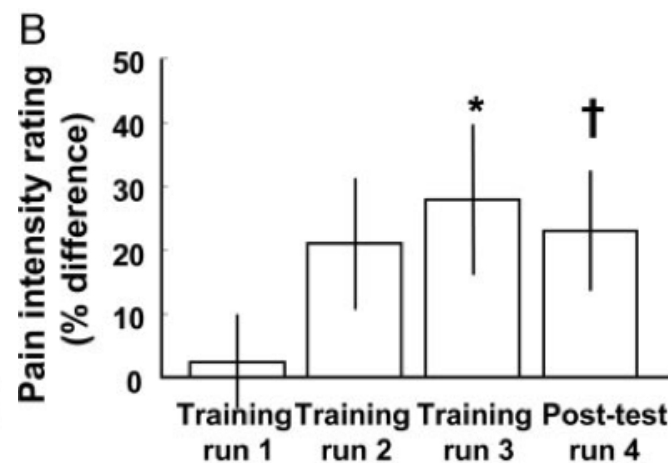
# Neurofeedback (2) – Mitigation of Chronic Pain



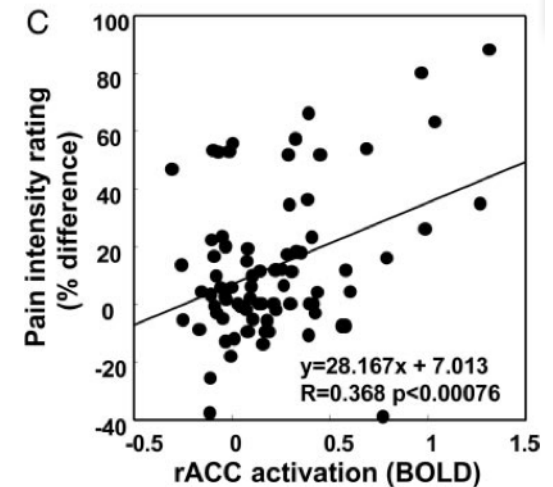
## RESULTS: H1 GROUP (HEALTHY, rtfMRI rACC)



BOLD Activity Change



Behavioral Change



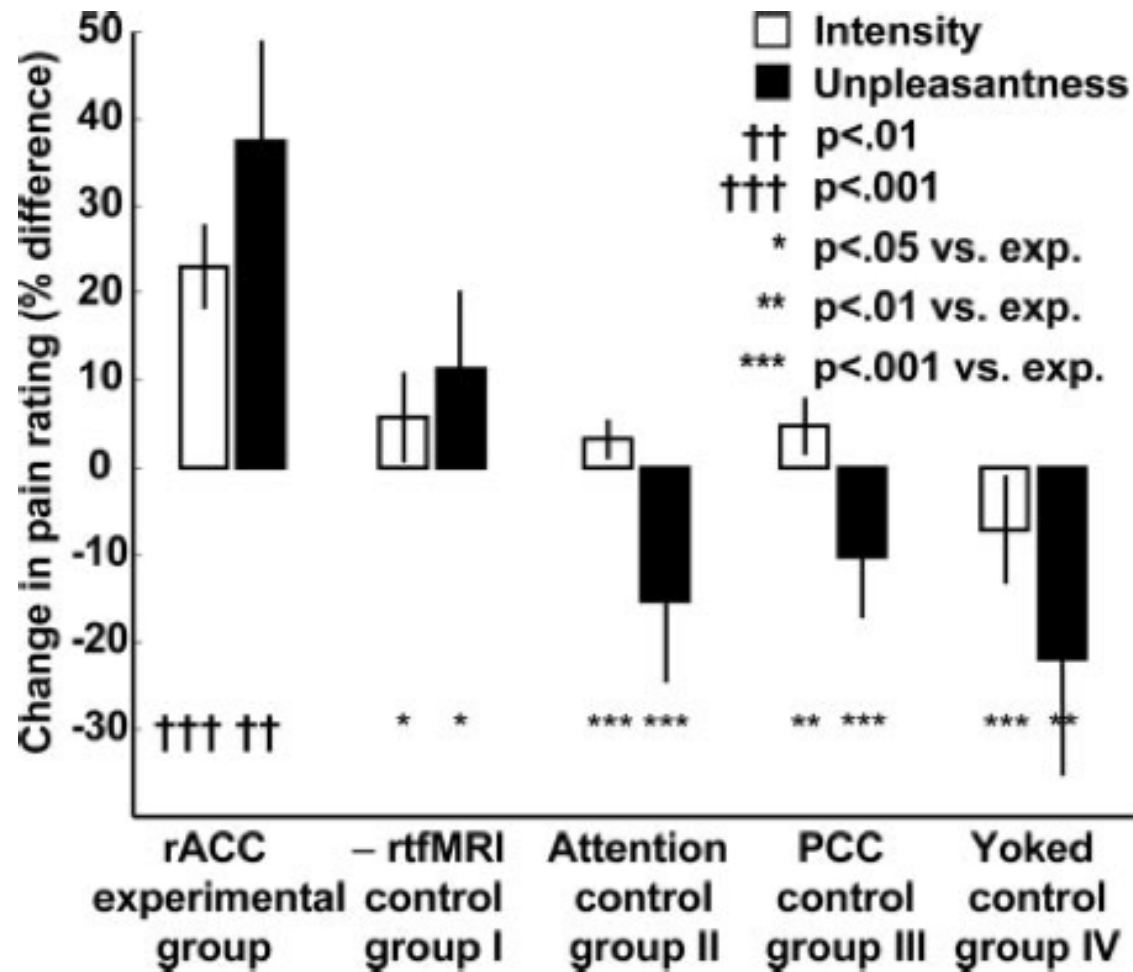
Correlation



# Neurofeedback (2) – Mitigation of Chronic Pain



## RESULTS: SPECIFICITY DUE TO rtfMRI TRAINING IN HEALTHY PATIENTS

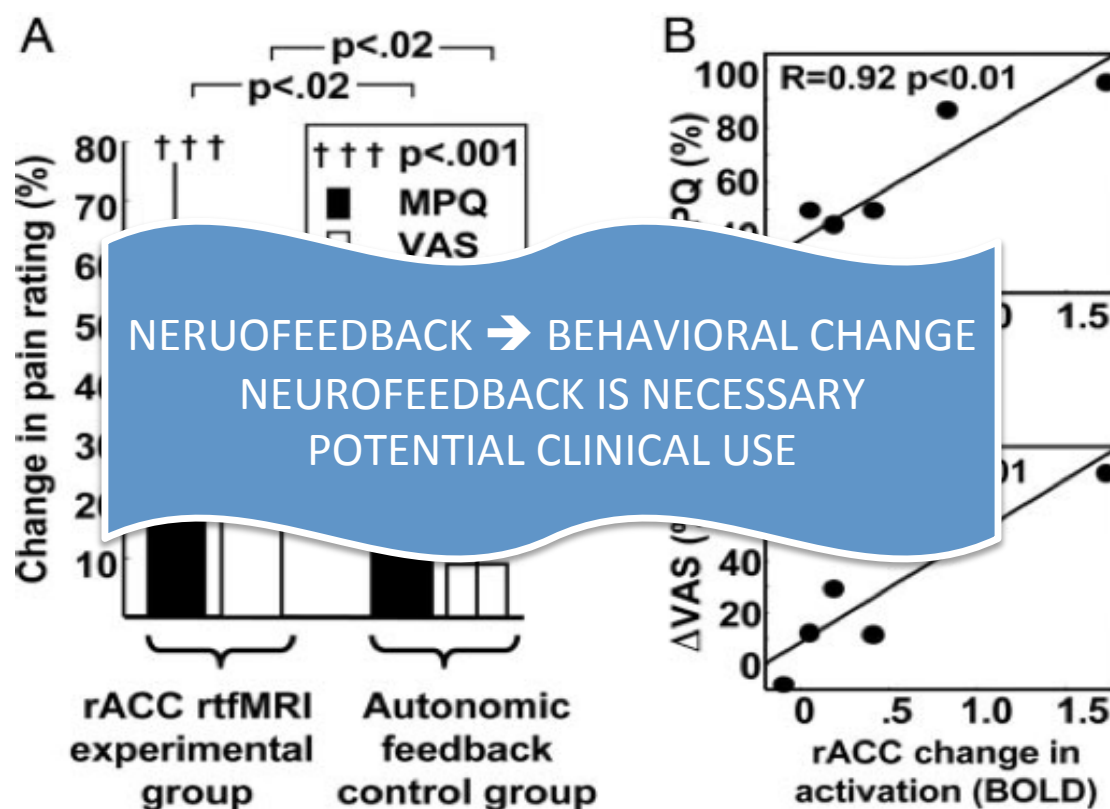




# Neurofeedback (2) – Mitigation of Chronic Pain



## RESULTS: CHRONIC PAIN PATIENTS



“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.”





## Neurofeedback (3) – Other Studies



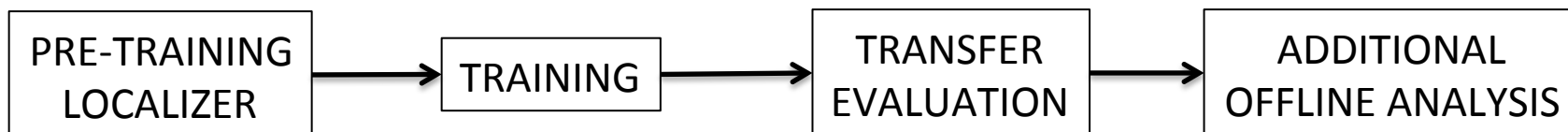
REGION	POPULATION	#SUBJECTS	VOLITIONAL CONTROL	BEHAVIORAL CHANGE	REFERENCE
Amygdala	Healthy	6	YES	YES	Posse et al. 2003
Anterior Insula	Schizophrenia	9	YES	YES	Ruiz et al. 2011
Insula	Healthy	15	YES	N/A	Caria et al. 2007
Suppl. Motor Area	Healthy	1	YES	N/A	Weiskopf et al. 2004
Parahippoc. Place Area	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



## COMMON EXPERIMENTAL SETUP



## 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

	<b>Volitional Control</b>	<b>Behavioral Change</b>
Real Feedback	<b>YES</b>	<b>YES</b>
Sham Feedback	<b>NO</b>	<b>NO</b>



Transfer of Behavioral Change beyond Scanning Sessions



# NIH/AFNI Neurofeedback System



The screenshot displays the AFNI software interface. The main window, titled "[A]u AFNI: ./DummyN27+orig & DummyN27+orig", contains several panels:

- Left Panel:** Shows coordinates (x = 1.250 mm [L], y = 16.250 mm [P], z = 8.750 mm [S]), Xchairs (Multi, X+), Color (green), Gap (5, Wrap), Index, and view options for Axial, Sagittal, and Coronal planes (Image, Graph).
- Middle Panel:** Includes "Original View" (AC-PC Aligned, Talairach View), "Define OverLay ->", "Define Datamode ->", "DataDir" (Switch, Read), "UnderLay" (EditEnv), "OverLay" (NIML), and "Control Surface".
- Right Panel:** Shows "View ULayer Data Brick" and "Warp ULayer on Demand".

A "Plugins Tear-off" window is overlaid on the right, listing various plugins. The "NIH RT Neurofeedback" plugin is circled in red. Other visible plugins include: -- Cancel --, Dataset#N, Deconvolution, NLfit & NLerr, Nudge Dataset, Permutation Test, Power Spectrum, Render Dataset, Reorder, RETROICOR, ROI Average, ROI Plot, RT 3dsvm, RT Options, ScatterPlot, SingleTrial Avg, Threshold, TS Generate, Vol2Surf, Wavelets, 2D Registration, 3D Cluster, 3D Correlation, 3D Dump98, 3D Edit, 3D Registration, 3D+t Extract, 3D+t Statistic, 4D Dump, ASL a3/d3, BRIK Compressor, Coord Order, Dataset Copy, Dataset Dup, Dataset NOTES, Dataset Rename, Dataset#2, Histogram, Histogram: BFit, Histogram: CC, Histogram: Multi, L1\_Fit & Dtr, LSqFit & Dtr, maskcalc, Maxima, and Dataset#N.



# NIH/AFNI Neurofeedback System



[A] NIH RT Neurofeedback

AFNI Plugin: Configuration of NIH-RT Neurofeedback Visual Interface

Quit Save+Keep Save+Close Help

PROGRAM	Executable	FIM Neurofeed	Other							
GENERAL	ROI Input	1 ROI	#Volumes	200	Ignore (#Vols)	5	Baseline (#Vols)	20		
METRICS CONF.	Metric	%SignalChange	StDev Win Size	5						
ROI 1/DIFF CONF.	Max %SChange	50	Max StDev	10						
ROI 2 CONF.	Max %SChange	50	Max StDev	10						
FEEDBACK MODE	Vis. Type	Thermometer								
DISPLAY	Display	StimPC (VNC)	Other		Screen Size [%]	90				
SCREEN	Legend	None								
PARADIGM	Type	Training	Icon Shape	Circle	Icon Color	White	Onsets	Rest Display	Feedback	
TARGET	ROI1 Type	None	ROI1 Value	5	ROI2 Type	None	ROI2 Value	5		
MOTION	Type	None	Weight	0.35	Color Thresh. 1	0.2	Color Thresh. 2	0.4	Color Thresh. 3	0.65
EXPORT	Write PIPE	No	Path							

(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



[A] NIH RT Neurofeedback

AFNI Plugin: Configuration of NIH-RT Neurofeedback Visual Interface

Quit Save+Keep Save+Close Help

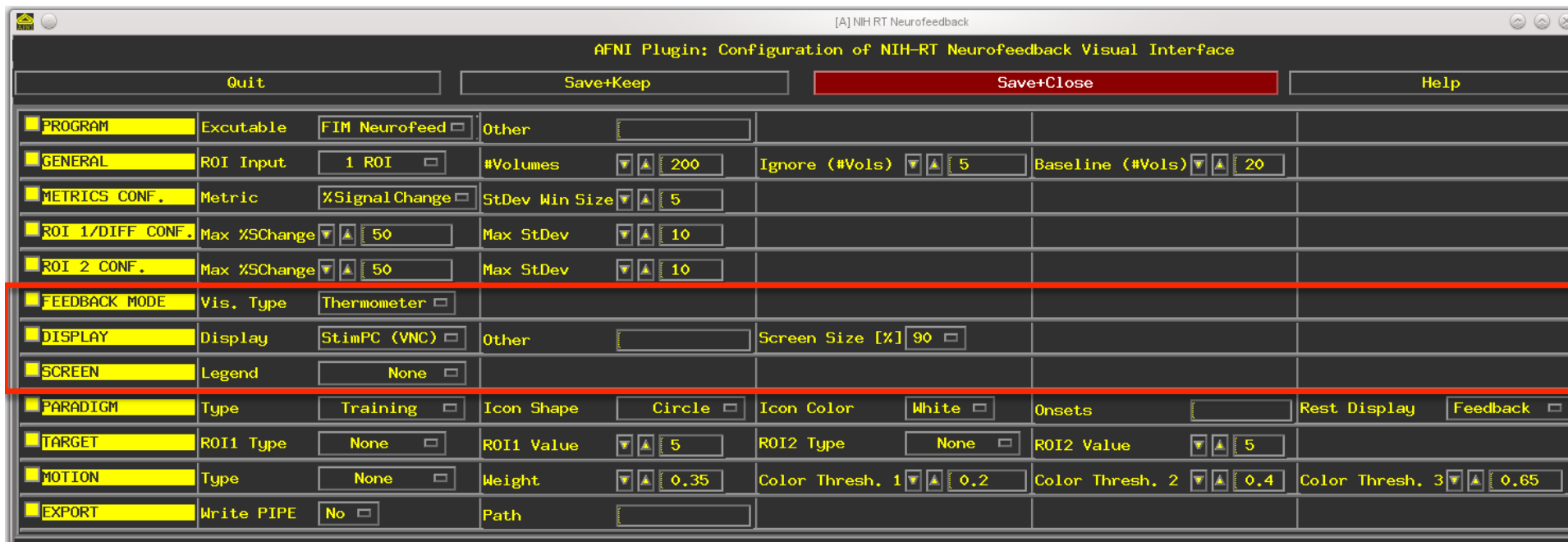
PROGRAM	Executable	FIM Neurofeed	Other							
GENERAL	ROI Input	1 ROI	#Volumes	200	Ignore (#Vols)	5	Baseline (#Vols)	20		
METRICS CONF.	Metric	%SignalChange	StDev Win Size	5						
ROI 1/DIFF CONF.	Max %SChange	50	Max StDev	10						
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FEEDBACK MODE	Vis. Type	Thermometer								
DISPLAY	Display	StimPC (VNC)	Other		Screen Size [%]	90				
SCREEN	Legend	None								
PARADIGM	Type	Training	Icon Shape	Circle	Icon Color	White	Onsets	Rest Display	Feedback	
TARGET	ROI1 Type	None	ROI1 Value	5	ROI2 Type	None	ROI2 Value	5		
MOTION	Type	None	Weight	0.35	Color Thresh. 1	0.2	Color Thresh. 2	0.4	Color Thresh. 3	0.65
EXPORT	Write PIPE	No	Path							

## (6) DISPLAY METRIC

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

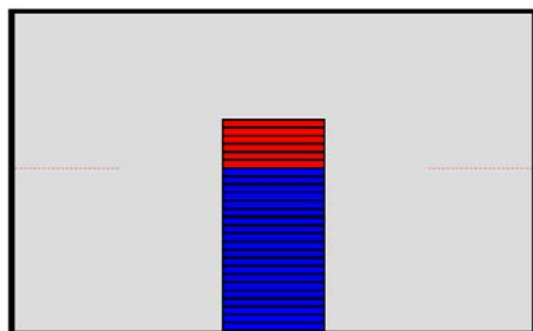


# NIH/AFNI Neurofeedback System

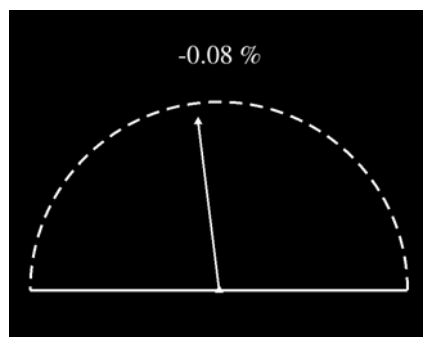


## (7) FEEDBACK DISPLAY CONFIGURATION

### SINGLE ROI

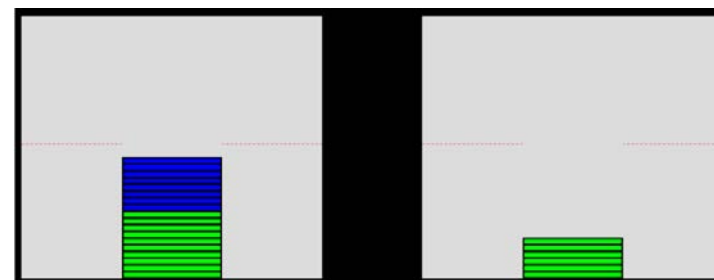


THERMOMETER | LEGEND OFF



GAUGE | LEGEND ON

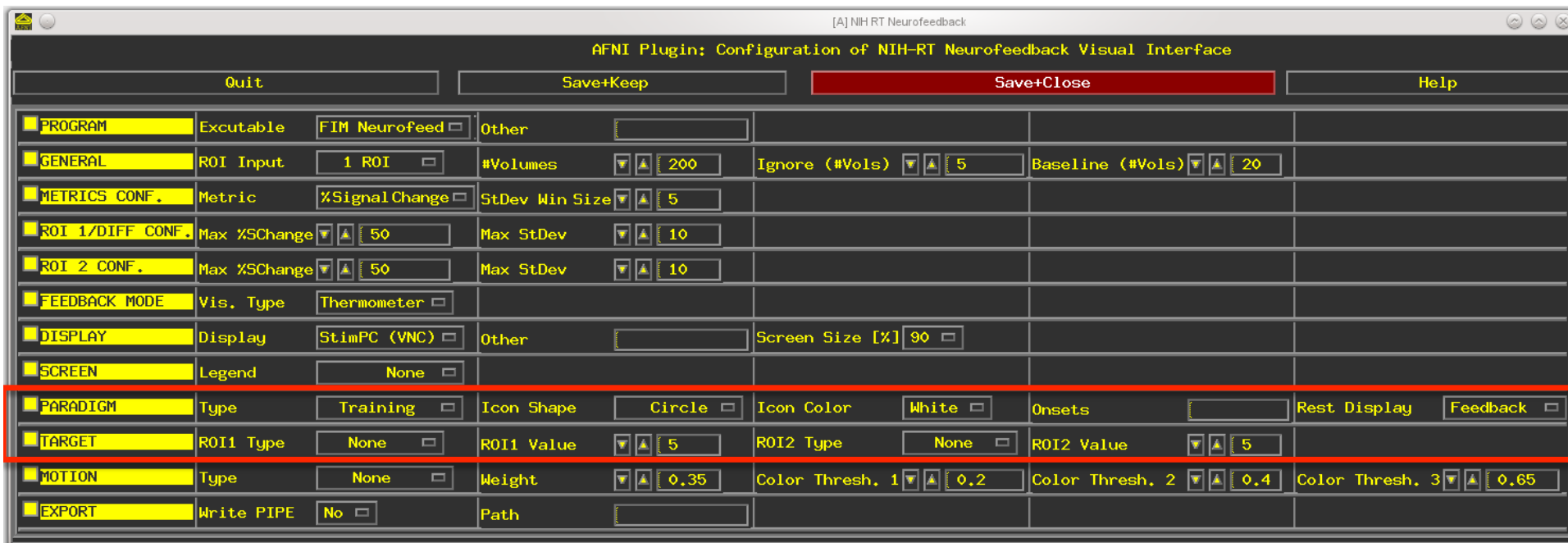
### TWO ROIS



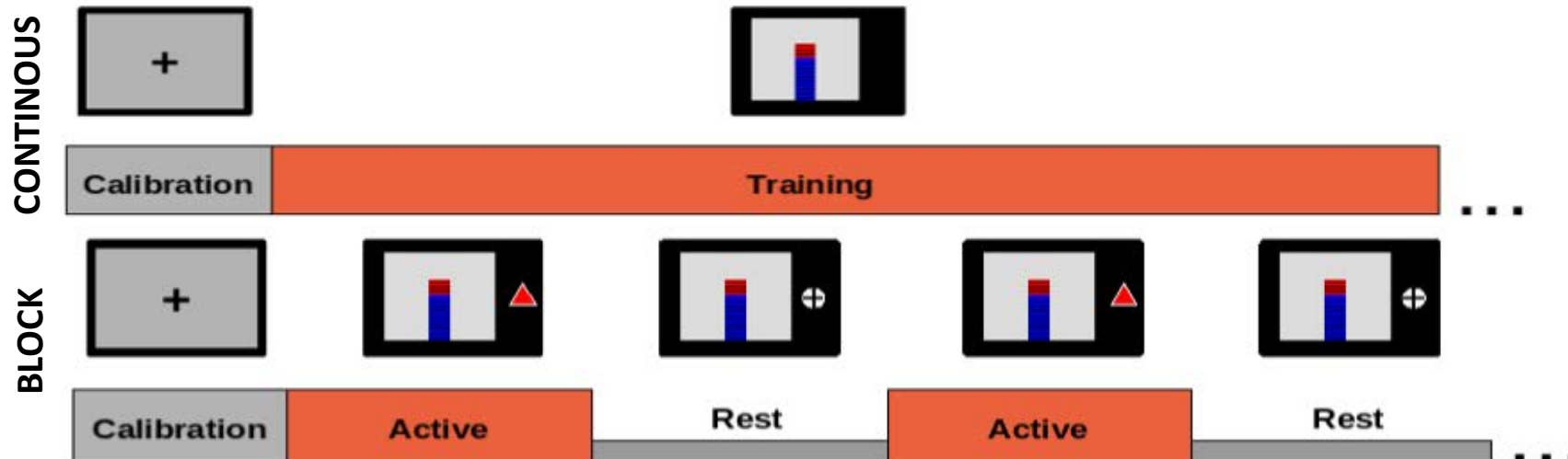
THERMOMETER | LEGEND OFF



# NIH/AFNI Neurofeedback System



## (8) MODE OF OPERATION

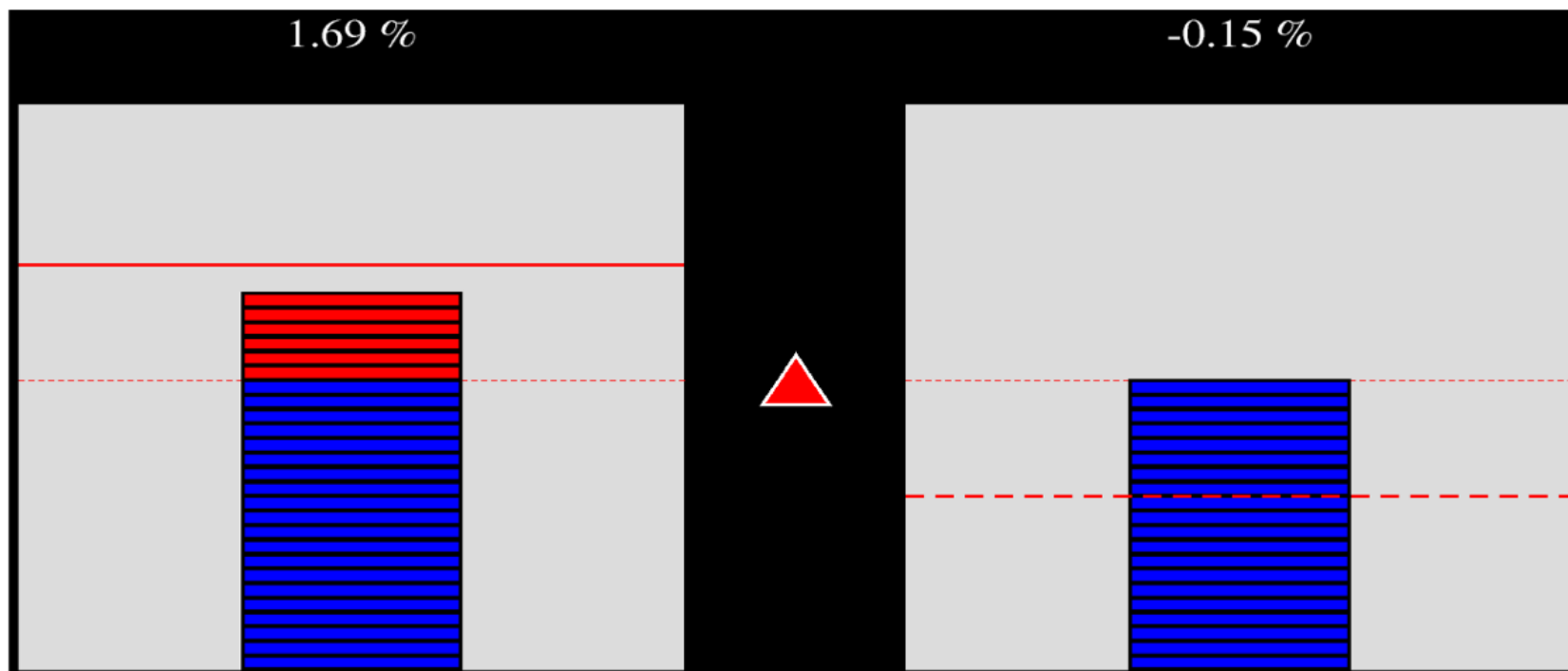




# NIH/AFNI Neurofeedback System



## TARGET VALUES





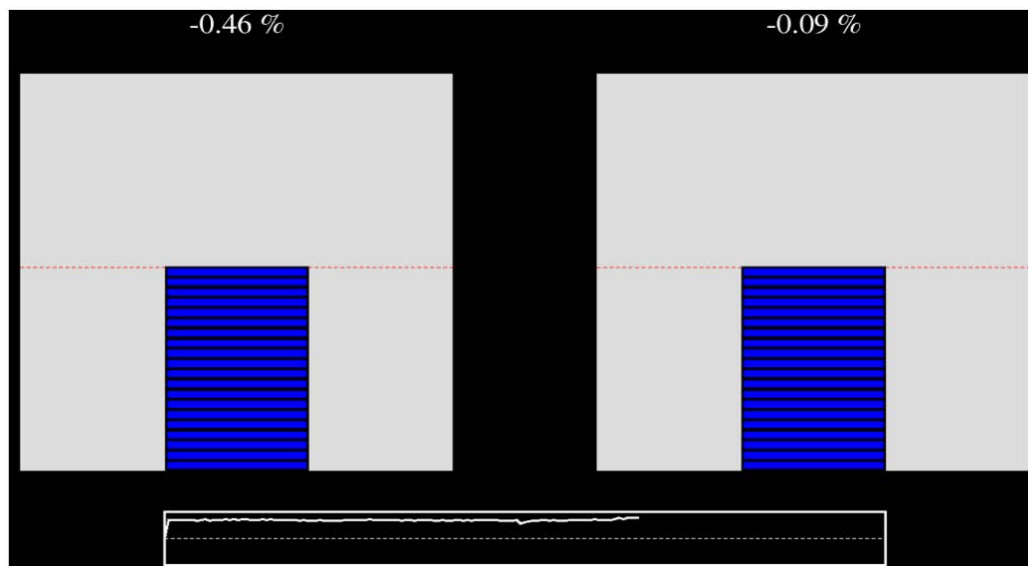


# NIH/AFNI Neurofeedback System

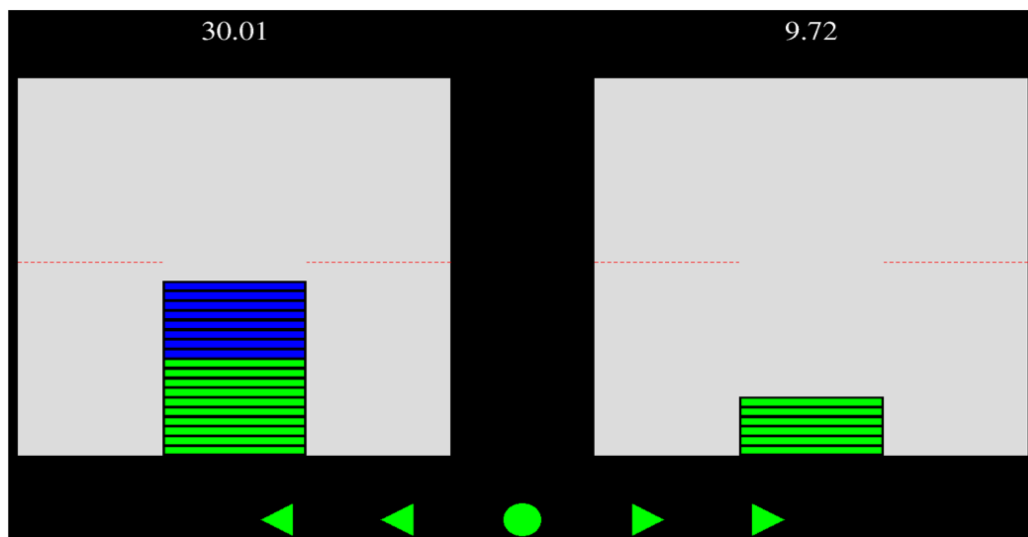


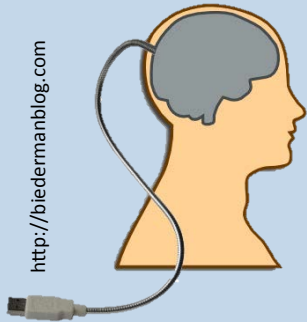
## MOTION FEEDBACK

AS TIMESRIES



AS COLORED DOTS





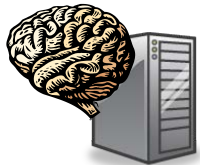
## BRAIN – COMPUTER INTERFACE

“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.
- 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

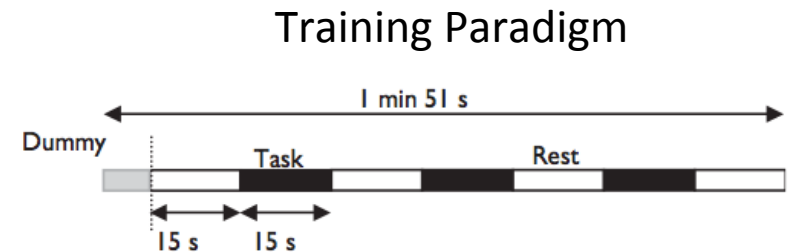
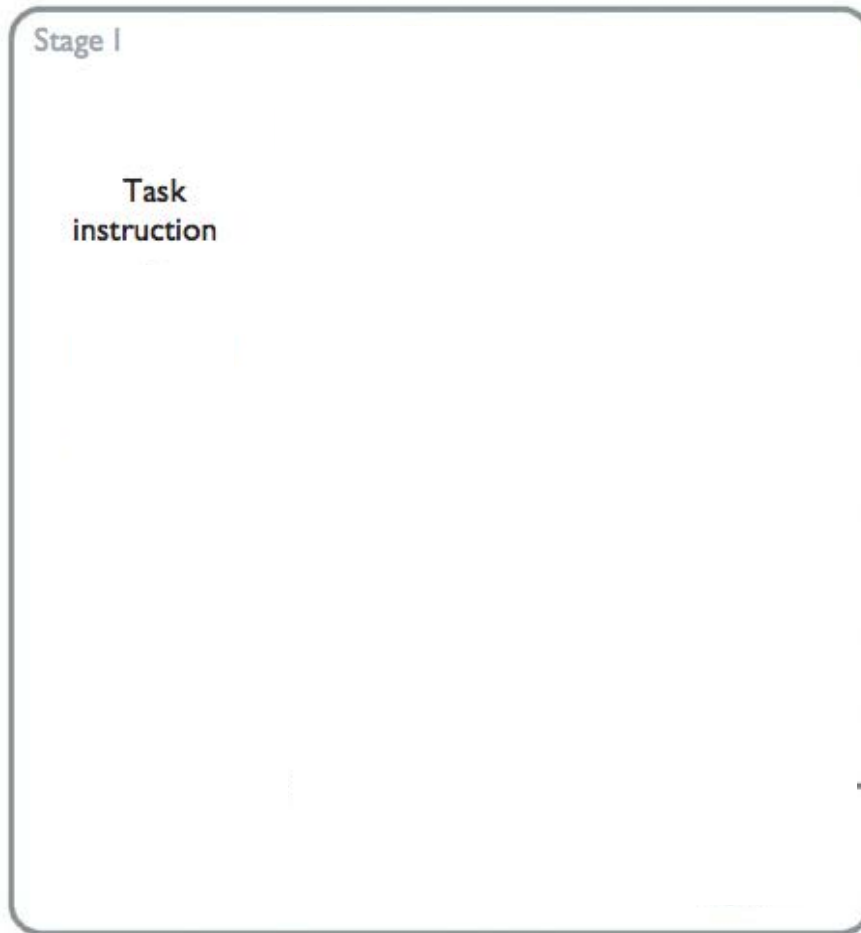


# Neuro-control (1) – Cursor Control



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



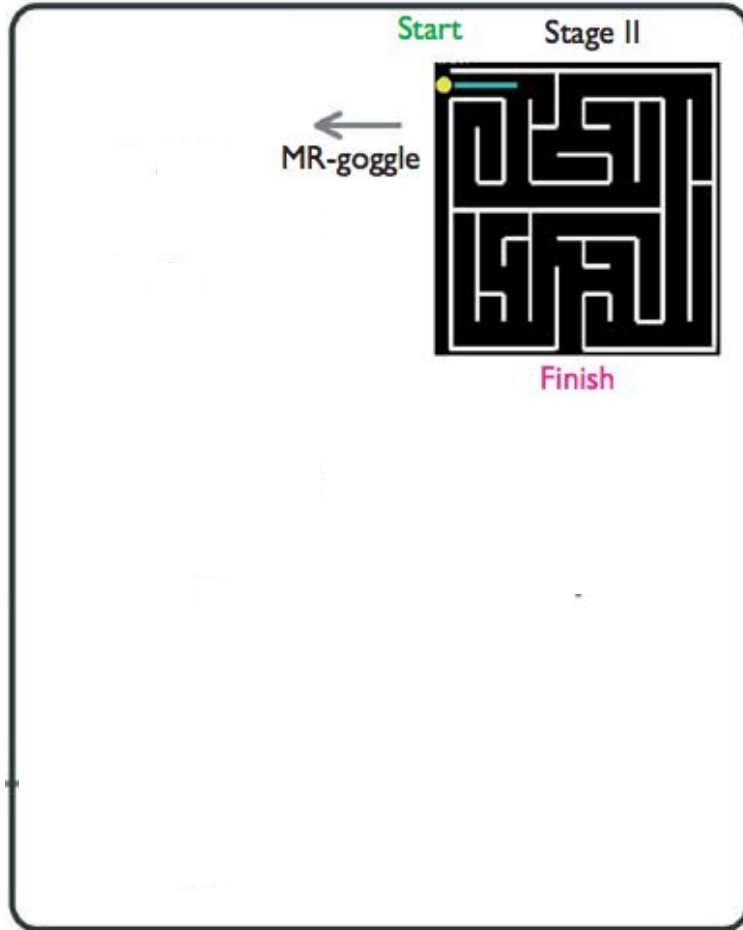
S.S. Yoo, T. Fairney, N.K. Chen, S.E. Choo, L.P. Panych, H. Park, S.Y. Lee, F.A. Jolesz, Brain-computer interface using fMRI: spatial navigation by thoughts, *Neuroreport* 15 (2004) 1591–1595.



# Neuro-control (1) – Cursor Control

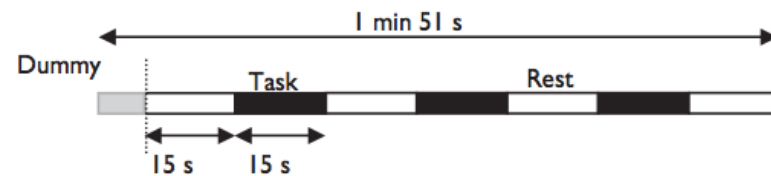
BOLD activity patterns from 4 different tasks were measured and translated into four directional cursor commands for navigation through a 2D maze presented to the subjects.

PHASE II  
ATTEMPT TO NAVIGATE THE MAZE

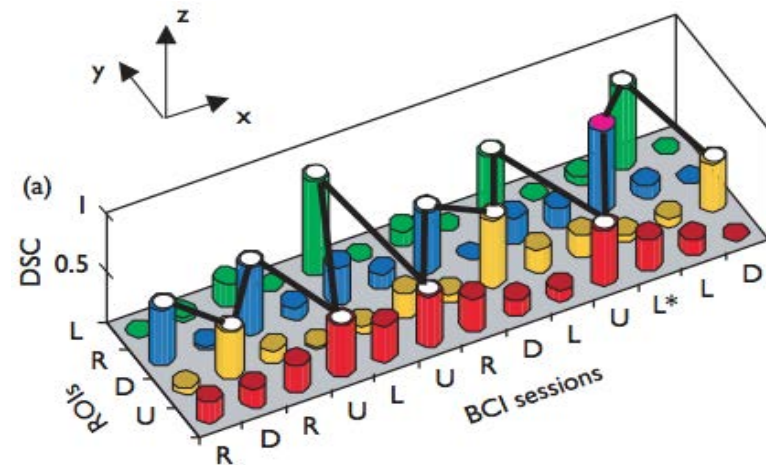


TR=1.5s | 3.75x3.75x5mm

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



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

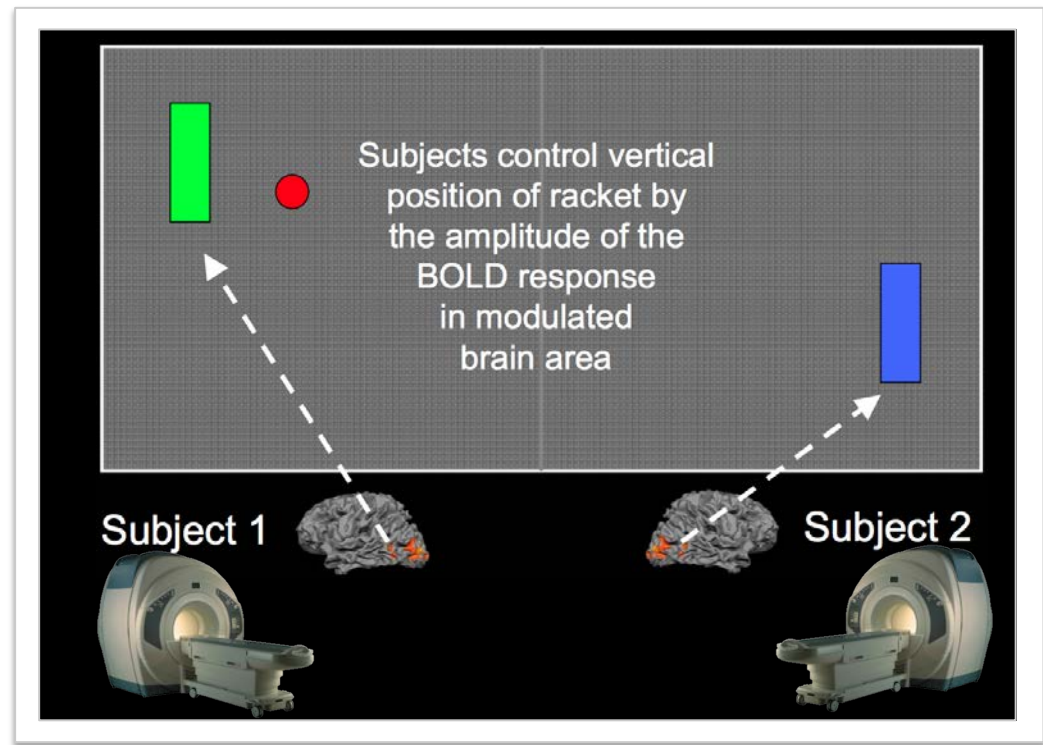


No errors for 2 subjects | 1 error for 1 subject



## 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?

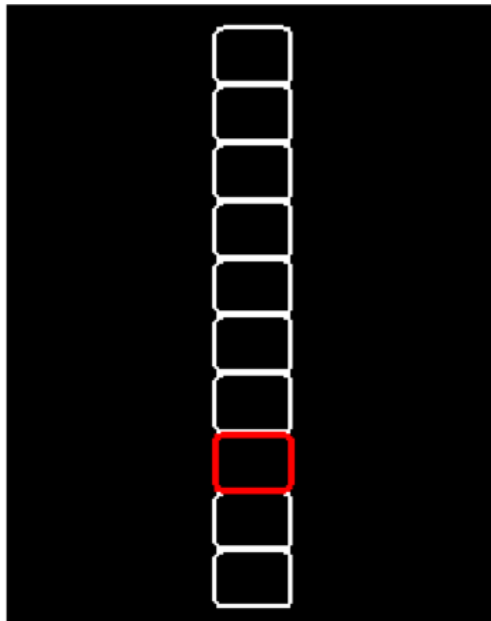
Goebel R, Sorger B, Kaiser J, Birbaumer N, Weiskopf N. BOLD Brain Pong: self-regulation of local brain activity during synchronously scanned, interacting subjects" Washington (DC) Society for Neuroscience; 2004.



# Neuro-control (2) - BOLD Brain-Pong

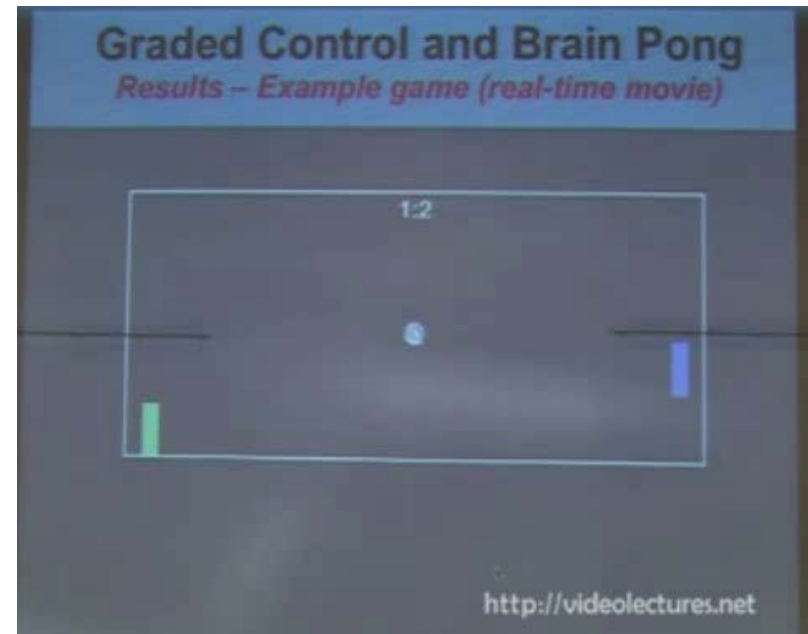


## TRAINING SESSION



- (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.



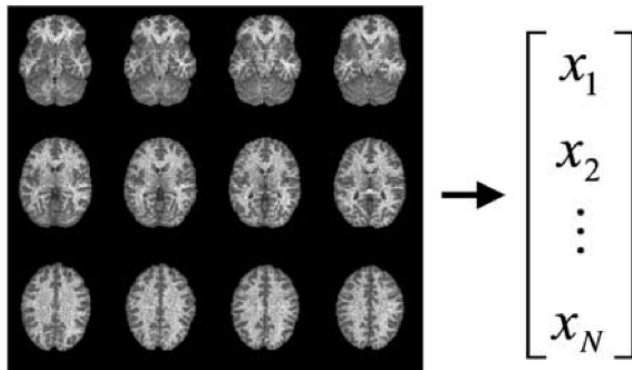
# Neuro-control (3) – SVM



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

High Dimensional Input Space

$x_t$

**CLASSIFICATION MODEL**

Scalar

$\hat{g}$

Brain Volume

Mental State/  
Action

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



# Neuro-control (3) – SVM

## CLASSIFIER TRAINING

fMRI Training Data

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

N = # of Voxels  
T = # of Volumes

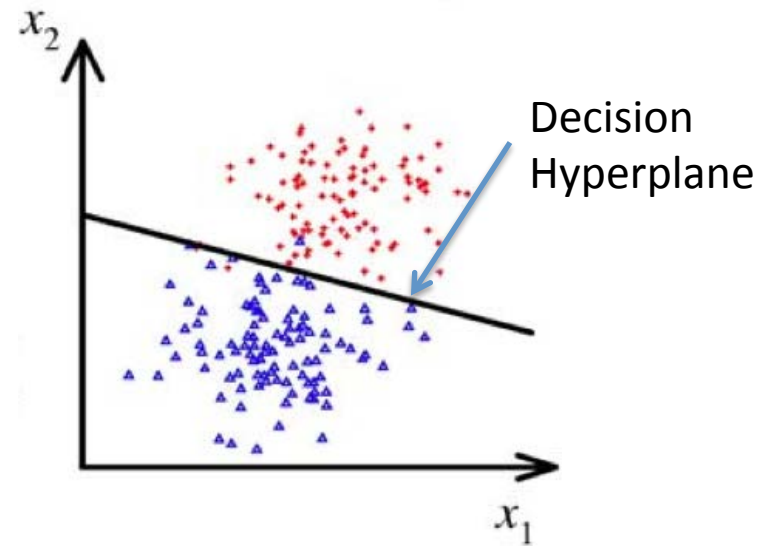
Training Labels

$$[ Y_1 \ Y_2 \ Y_3 \ \dots \ Y_T ]$$

Mask

**SUPPORT VECTOR MACHINE**

## OUTPUT: CLASSIFICATION MODEL



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

SVM Map:



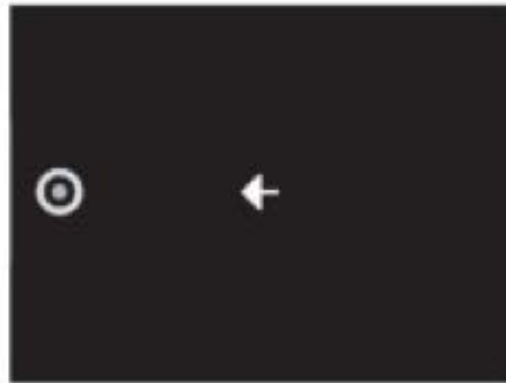




# Neuro-control (3) – SVM for Cursor Control



## TRAINING RUN



OR



Left Button Press

OR

Sad Thoughts

OR

English Inner Speech

OR

Left Motor Imagery

Right Button Press

OR

Happy Thoughts

OR

Chinese Inner Speech

OR

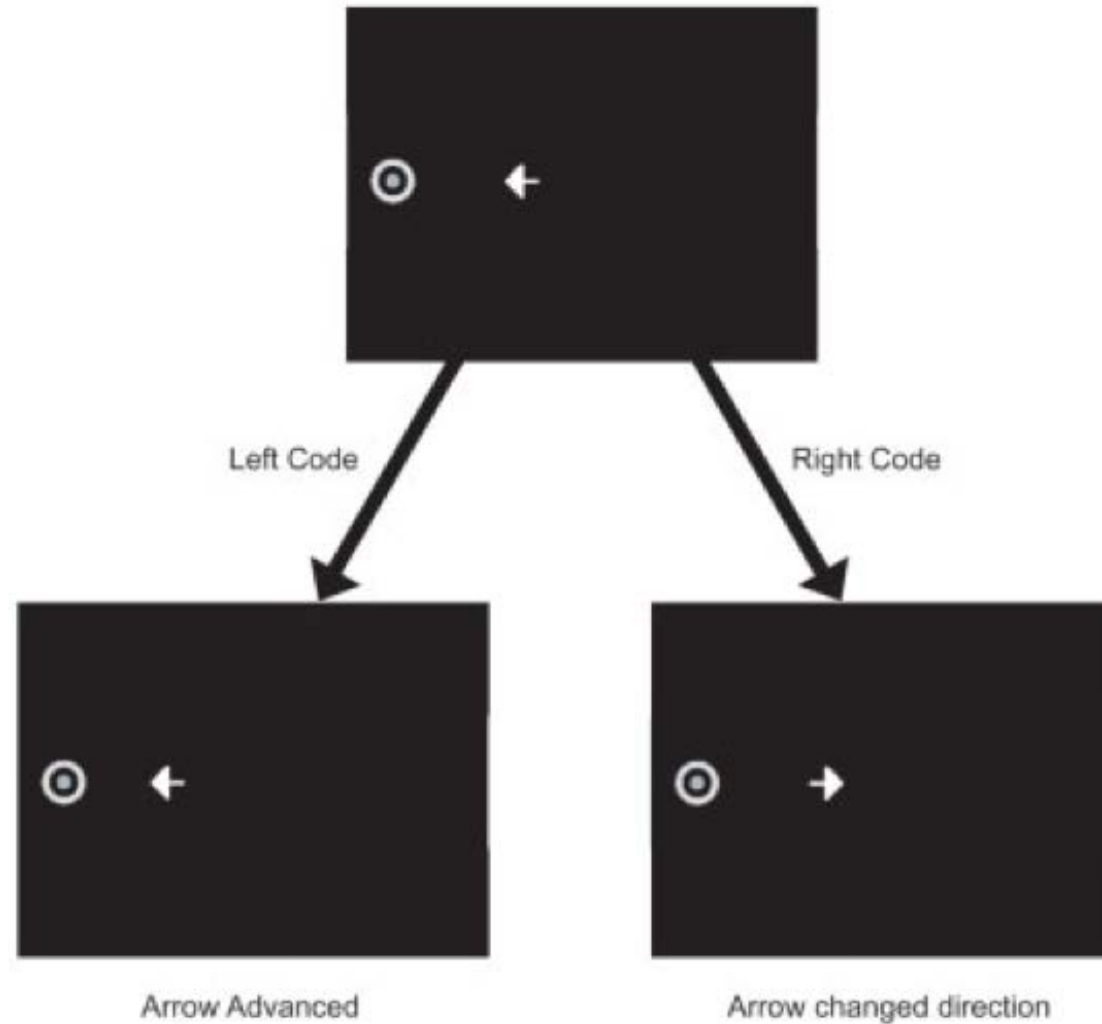
Right Motor Imagery



# Neuro-control (3) – SVM for Cursor Control

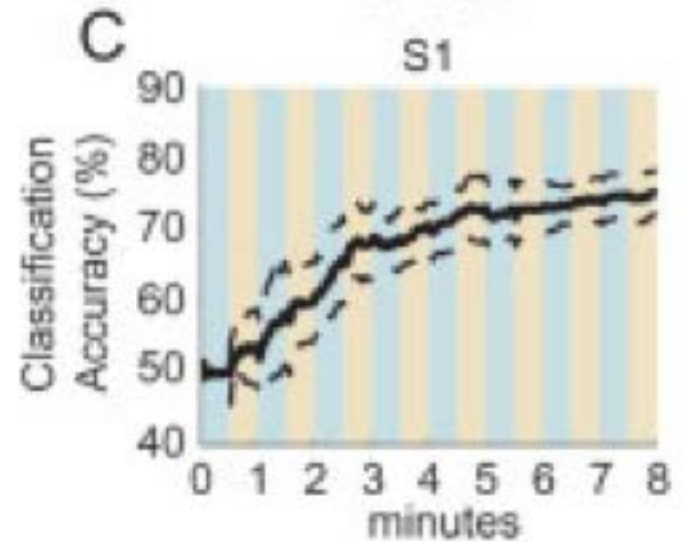
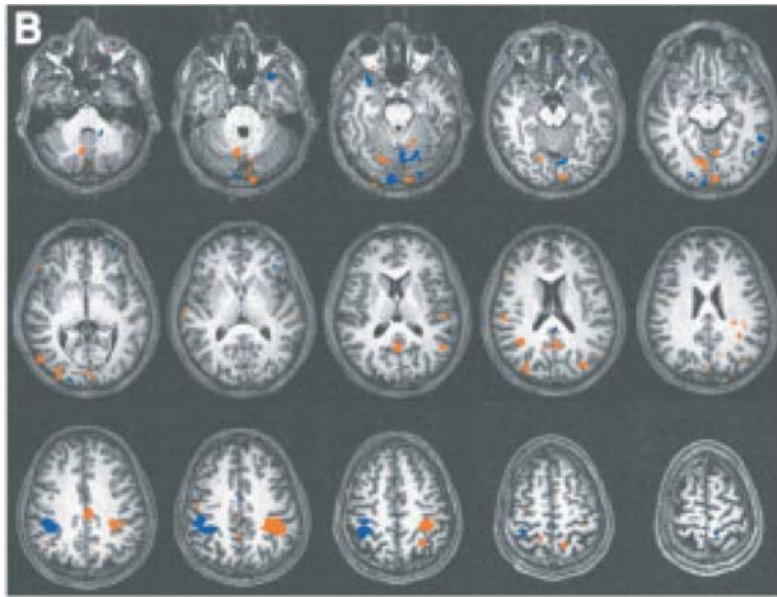
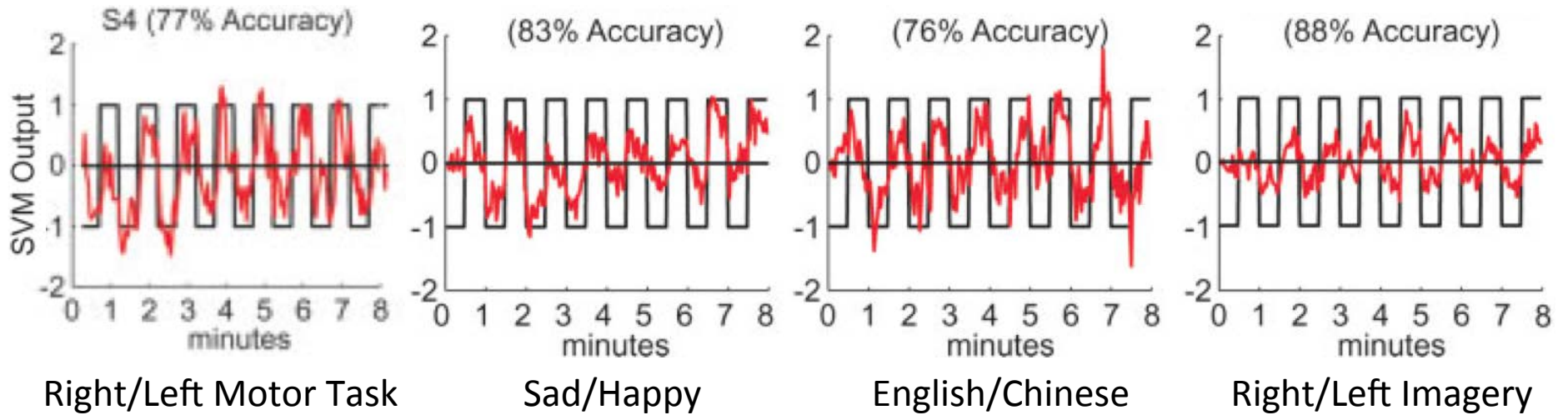


## TEST RUN





# Neuro-control (3) – SVM for Cursor Control





# AFNI Realtime SVM Support

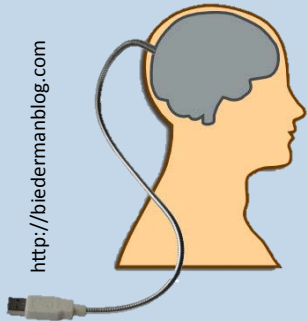


[A] RT 3dsvm

AFNI Plugin: Set Real-Time Options for 3dsvm - An AFNI SVM-Light Plugin

Quit Run+Keep Run+Close Help

<input checked="" type="checkbox"/> Real-time				
<input checked="" type="checkbox"/> Training	Type	classification		
<input checked="" type="checkbox"/> Train Data	Labels	-- Choose Timeseries --	Censors	-- Choose Timeseries --
<input checked="" type="checkbox"/> Train Params	Mask	-- Choose Dataset --	C	Epsilon
			1000	0.001
<input checked="" type="checkbox"/> Kernel Params	Kernel Type	linear	poly order (d)	rbf gamma (g)
			3	1
<input checked="" type="checkbox"/> Model Output	Prefix			
<input checked="" type="checkbox"/> Model Inspection	FIM Prefix		Alpha Prix (.1D)	
<input checked="" type="checkbox"/> Testing				
<input checked="" type="checkbox"/> Test Data	Model	-- Choose Dataset --		
<input checked="" type="checkbox"/> Predictions	Prefix (.1D)			
<input checked="" type="checkbox"/> Stimulus	IP		PORT	



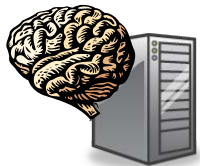
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- Specific kind of Biofeedback
- Conscious control of activity within a region of one’s own brain.
- Applications: Therapy and Learning



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



### COMMUNICATION

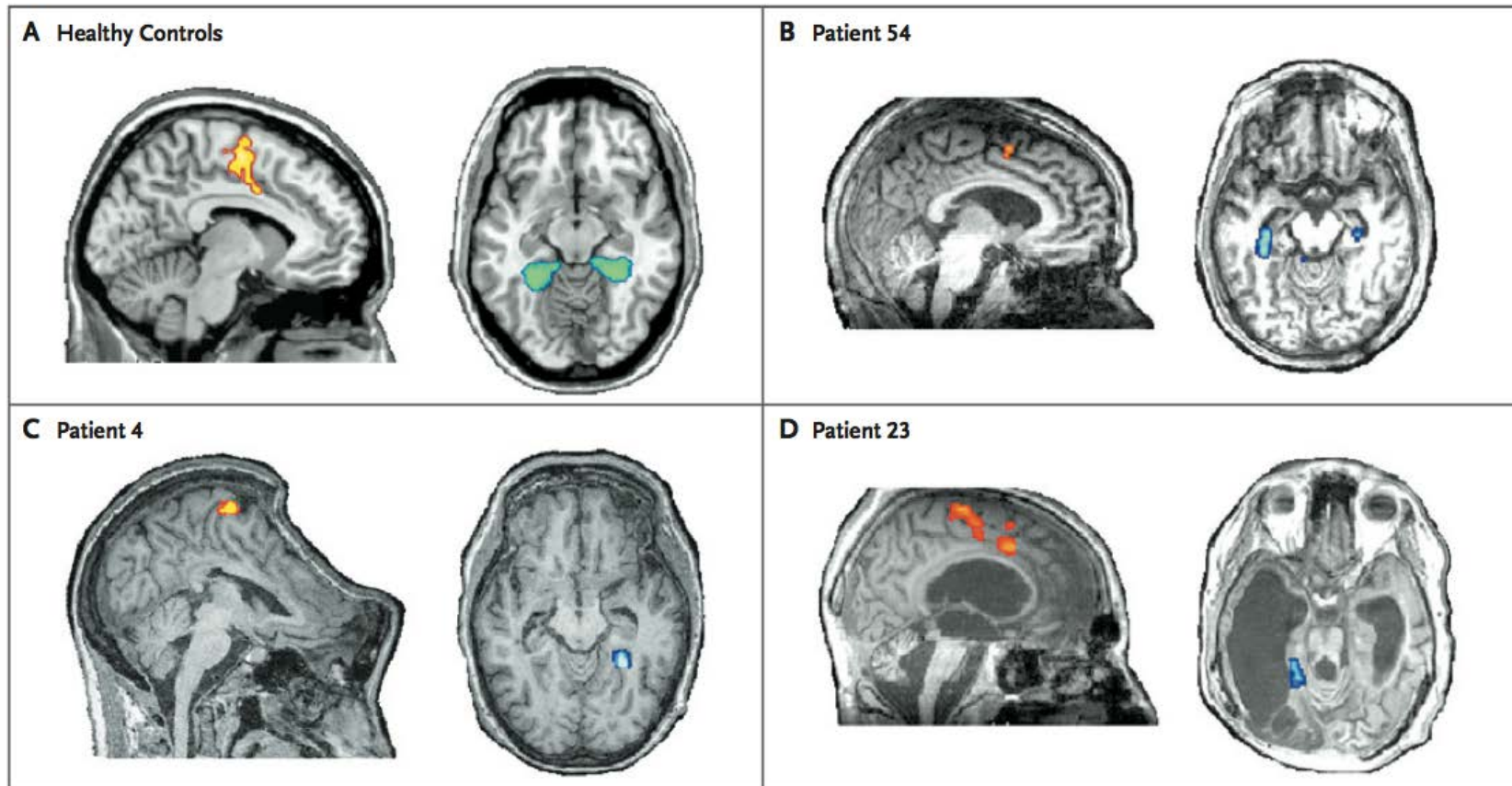
- Use “thoughts” as a communication act.
- Applications: communicate with vegetative-state patients



# Neuro-Communication

## 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)

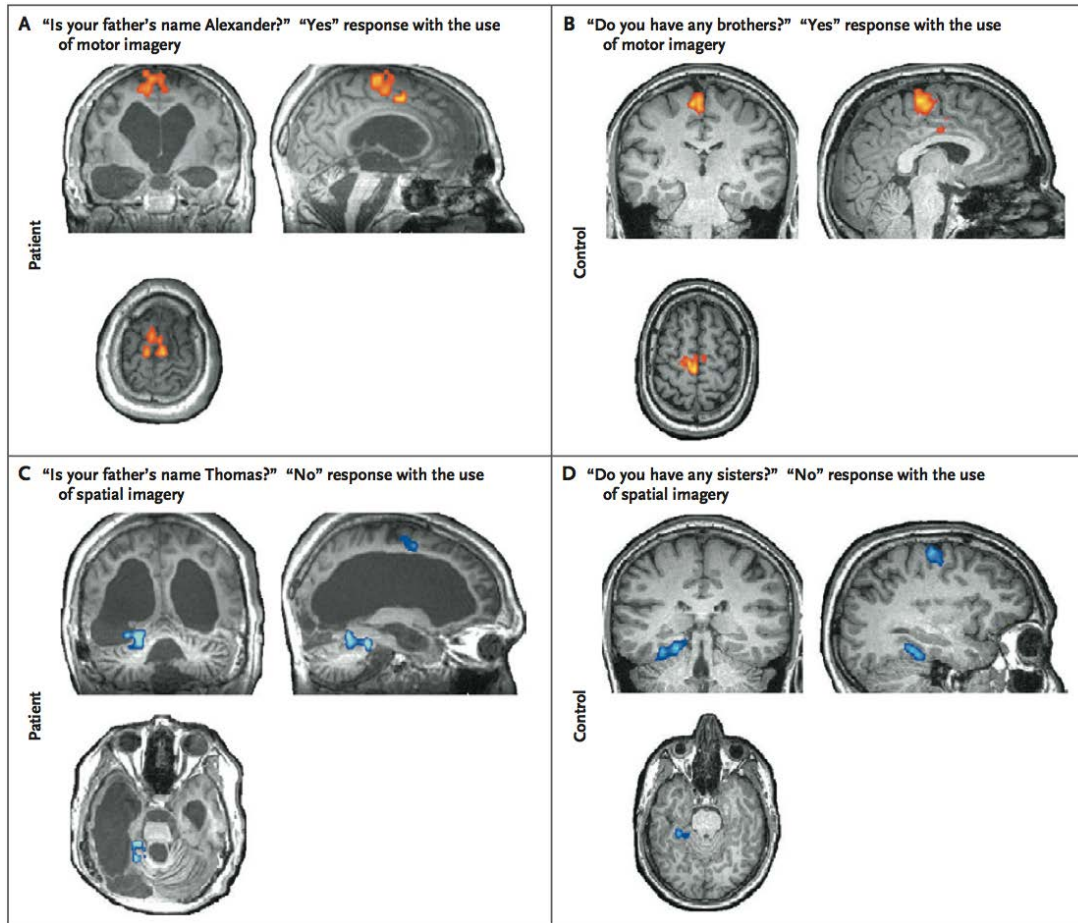
Monti M, Vanhaudenhuyse A, Coleman M, Boly M, Pickard J, Tshibanda L, Owen A, Laureys S. "Willful modulation of brain activity in disorders of consciousness" *The New England Journal of Medicine*. 2010: 579-589



## 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



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

## MULTI-DIMENSIONAL CODING TECHNIQUE

		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 calculation  ROIs	I	J	K	L	M	N	O	P	Q
	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)

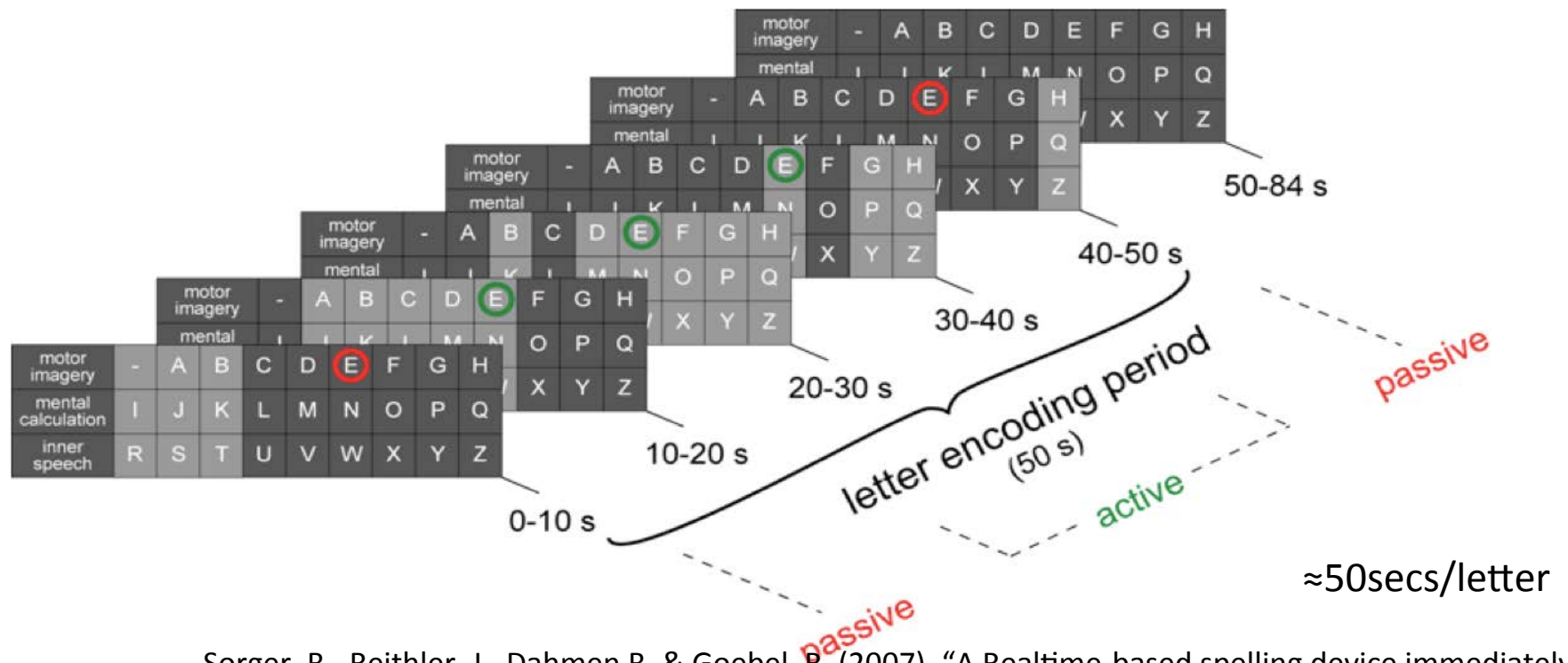




# Neuro-Communication – BOLD Spelling



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



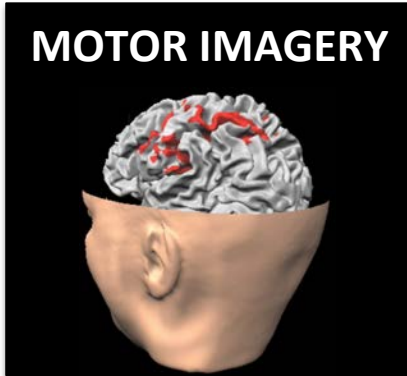
Sorger, B., Reithler, J., Dahmen B. & Goebel, R. (2007). "A Realtime-based spelling device immediately enabling robust motor-independent communication". Current Biology (22):14, 1333-1338 (2012)



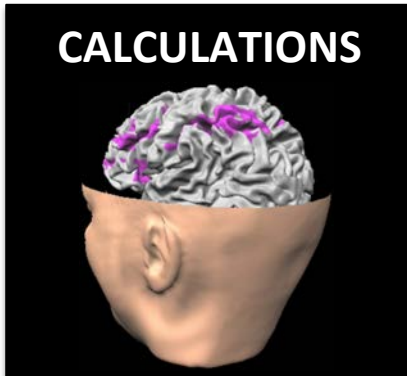
# Neuro-Communication – BOLD Spelling



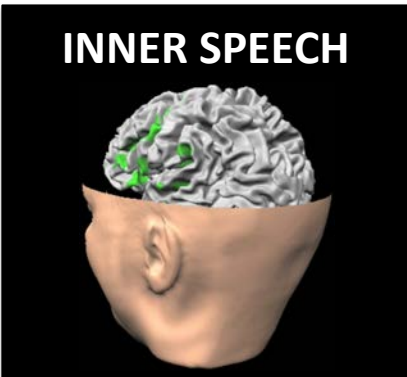
## MOTOR IMAGERY



## CALCULATIONS



## INNER SPEECH



Word encoding and automated letter decoding

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

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

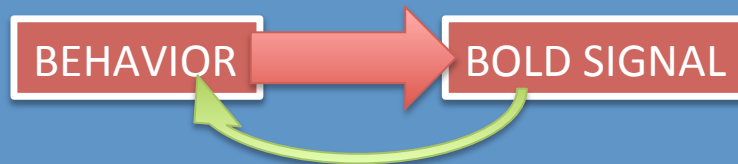
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# Conclusions

## 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....

VOLITIONAL CONTROL  
OF MOTOR REGION

USE THOUGHTS TO  
COMMUNICATE/CONTROL

## 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]

## 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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