Measuring and Changing the Behavior in the Brain

Applications to the Teaching of Verbal Operants

Outline

- Skinner, Behaviorism and Neurosciences
- NeuroBehavioral literature in Behavioral Journals
- Advantages of NeuroBehavioral integration
- Private events made public and possible to modify
- Procedures to study the behavior in the brain
- Translating Neuroscience into Behaviorism through Neuroimaging
- Behavioral measures of brain activity
- The Verbal Operants in the brain
- Methods to modify the behavior in the brain
- The Crossword experiment in Tact and Intraverbals
- Neurofeedback of Intraverbals

Skinner and the Neurosciences

- Eventually we may expect the main features of a behavioral theory to have physiological significance.

As the science of **physiology** advances, it will be possible to show what is happening within the organism during particular behavioral events, and the theoretical systems of the two sciences may also be seen to correspond.

- A similar day may come in **psychology**. But the eventual correspondence should not obscure the present need for a behavioral theory. The hypothetical physiological mechanisms are not acceptable as substitutes for a behavioral theory. On the contrary, because they introduce many irrelevant matters, they stand in the way of effective theory building.
- **Skinner, B.F. (1959). *Cumulative Record*, pp 354-355**

Skinner and the Neurosciences

- We must wait to see what learning processes the physiologists will eventually discover through direct observation, rather than through inferences; meanwhile, the contingencies permit a useful and important distinction.
- Skinner, B.F. (1974) *About Behaviorism*, (pp 66-67)

Skinner and the Neurosciences

- The nervous system is much less accessible than behavior and environment, and the difference takes its toll.
- We know some of the processes which affect large blocks of behavior
- but we are still far short of knowing precisely what is happening when, say, a child learns to call an object by its name
- as we are still far short of making changes in the nervous system as a result of which a child will do these things.

Skinner, B.F. (1974) *About Behaviorism*, (pp.213-214)

Skinner and the Neurosciences

1.Eventually we may expect physiology to study events in the human brain and to produce [theories] that would meet behavioral ones

2.[But] hypothetical physiological mechanisms are not acceptable as substitutes for a behavioral theory.

3.[Even more] they may introduce many irrelevant matters and stand in the way of effective theory building.

4.Shortcomings are also accessibility and interpretability

5. There may be *compensating advantages.*

6.An independent theory of behavior is in no sense opposed to physiological speculation or research.

6. To be of use, brain processes have to be visible through direct observation, rather than through inferences;

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Cognitive Neuroscience from a Behavioral Perspective: A Critique of Chasing Ghosts with Geiger Counters

Steven R Faux, The Behavior Analyst 2002

Cognitive science has evolved into **Cognitive Neuroscience**, by embracing a variety of different disciplines

linguistics - Chomsky 1959
philosophy – Fodor 1975
connectionism - Grossberg 1988

And by using sophisticated brain imaging technology PET, MRI, and EEG-MEG, attractive to scientists and producing spectacular color plates that appear to take the reader a step closer to the "black box" of brain operations

Cognitive Neuroscience from a Behavioral Perspective

Steven R Faux, The Behavior Analyst 2002

Critical Points

1)It Produces inferences about unobserved neural mechanisms from overt behavior (Uttal 2001).

2)Many in cognitive neuroscience attempt to give a brain location to those unobserved processes using gross measures.

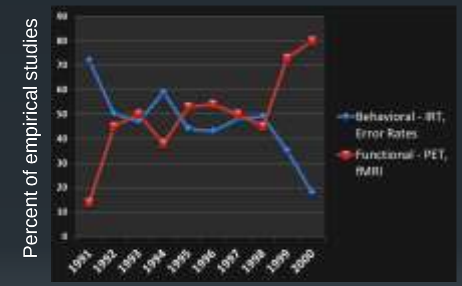
3)Still relies on mentalistic forms of explanation that either explicitly or implicitly appeal to an inner agent, "the ghost in the machine“.

4)This paper updates an argument originally made by Skinner (1938/1991,1950,1953,1974) that superimposing unobserved mechanisms upon the brain, results in a "conceptual nervous system“ with a great potential to misguide.

Cognitive Neuroscience from a Behavioral Perspective

Steven R Faux, The Behavior Analyst 2002

Major Dependent Variables in Journal of Cognitive Neuroscience



Cognitive science has relied upon reaction time as its primary dependent variable, as indirect measure of mental chronometry (Posner 1986).

Cognitive neuroscience now uses brain-imaging techniques (PET, fMRI, and ERP)

Cognitive Neuroscience from a Behavioral Perspective Steven R Faux, The Behavior Analyst 2002

Methods in a particular PET scan study (Mellet, Tzourio, Denis, & Mazoyer, 1995)

8 subjects participate in three behavioral conditions, baseline, perception, mental imagery

Mellet et al. presented regional cerebral blood flow (rCBF) results for all 8 individuals from 6 brain regions

Positive rCBF values indicated brain activation (increased blood flow), and negative values indicated deactivation (decreased blood flow) relative to baseline

In the "perception minus baseline“ data, primary visual cortex, superior occipital cortex, superior parietal and precuneus are activated consistently across all 8 participants.

Cognitive Neuroscience from a Behavioral Perspective Steven R Faux, The Behavior Analyst 2002

Critical Points

Deactivation in the superior temporal and inferior frontal cortex. (Why brain regions are deactivated?)

Strong variability in the "imagery minus baseline“ data is seen across participants.

Misleading representation. Color coded data have the potential to mislead unless carefully analyzed.

Lack of consistency. no consistent pattems of anatomical activation would be evident in all volunteers.

Cognitive Interpretation. Despite large individual variability, the authors concluded that mental imagery is associated with activation of the superior occipital cortex.

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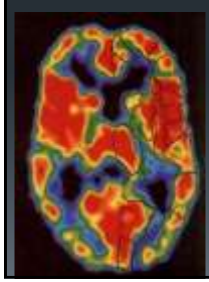
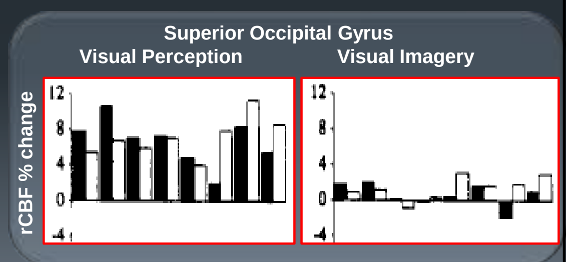
Misleading representation. Color coded data have the potential to mislead unless carefully analyzed. In many activation areas in superior occipital cortex the same data in histogram form revealed very small rCBF values.
Perceptually significant color differences in PET scan graphs do not necessarily equal physiologically important differences.





Cognitive Neuroscience from a Behavioral Perspective Steven R Faux, The Behavior Analyst 2002

This paper is not intended to be a general statement against the study of brain-behavior relations. Instead, this is a proposal that science progresses best when physical brain measurements are tied to overt behaviors.
As Skinner (1938/1991) stated, "Before ... [a neurological] fact may be shown to account for a fact of behavior, both must be quantitatively described and shown to correspond in all their properties".

Cognitive Neuroscience from a Behavioral Perspective
Steven R Faux, The Behavior Analyst 2002

Experimental Design: the Subtraction method

1. Identify a treatment task involving the cognitive process, *P*.
2. Identify a baseline task that is identical to the treatment task but does not involve the cognitive process, *P*.
3. Collect separate brain scans during the baseline and treatment tasks. Compute an average scan for each individual within each task.
4. Subtract average baseline scan results from average treatment scan results. Find brain regions with averages that are statistically different from zero.
5. Conclude that statistically significant brain regions account for cognitive process, *P*.

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Criticism 1: It is difficult to single out "molecular" brain processes

It seems impossible that a treatment task could ever be designed differing from a baseline task by only a single brain operation. The *pure insertion problem* (Sartori & Umiltà, 2000).
"Even simple tasks, hypothesized to index selectively particolar aspects of language processing, often do not tap only one component of language processing but encompass a complex chain of processing" (Bavelier et al., 1997).
Like Smith (1997) states in a spatial working memory task: "Spatial working memory can be decomposed into a pure storage component (a spatial buffer) and a rehearsal component, ... the latter involv[ing] selective attention".
One must wonder how useful it is to break one vague construct into three vague constructs

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Criticism 2: Use of vague cognitive labels for spatially mixed processes

Cognitive neuroscientists have failed to justify why unobserved cognitive constructs make useful labels for particolar brain regions.

Spatial Resolution: PET and tMRI can take us from not knowing what is happening in the whole brain to not knowing what is happening in some particolar gyrus.
Brain-imaging procedures are sensitive only to large regional changes in activation, involving perhaps millions of neurons, while missing smaller regions of activation (Pitzpatrick 1999). for

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Criticism 3: Use of too indirect measures

PET and fMRI are not direct measures of neural activity, only of regional blood flow (rCBF).

It is an assumption that rCBF (a slow process of several seconds after a stimulus) reflects the most relevant neural activity changes.

It is a little frightening when one strings together the assumptions made in PET studies. PET investigators *assume* that increased gamma radiation *represents* increased rCBF, which presumably *represents* neural activity, which presumably *represents* cognitive processing.

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Criticism 4: An untested "Cognitive" framework; Attention to make maps instead of producing changes

Cognitive constructs are not directly tested in the subtraction method but instead, cognitive constructs are only "mapped."

There is no good reason to make cognitive terminology the de facto language of the neuroscience of complex behavior.

There is no indication of how one can go from brain maps to controlling or manipulating behavioral or neurologica! variables.

The goal of the research program appears to be to map and label the brain.

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Criticism 5: Cognitive constructs are build on the presence of an inner agent

Dennett (1991) has argued that a pervasive flaw of cognitive neuroscience models is that they "still presuppose that somewhere, conveniently hidden in the obscure 'center' of the mind/brain, there is a Cartesian Theater, a place where 'it all comes together‘ and consciousness happens“, a "central executive" (Baddeley, 1995), "willed action" (Badgaiyan, 2000), or "supervisory attentional systems" (Bayliss, 2000).

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Criticism 6: The problem of intrinsic variability and averaging

Brain-imaging experiments are not analyzed at the individual level, data are grouped and individual variability is obscured.

Cognitive neuroscience accepts that large variation is intrinsic to the operations of the brain, and that experimental control of individual variation is not possible.

As Sidman (1960) has argued, "Acceptance of variability as unavoidable or, in some sense, as representative of the 'real world' is a philosophy that leads to the ignoring of relevant factors" .

Cognitive Neuroscience from a Behavioral Perspective Steven R Faux, The Behavior Analyst 2002

Criticism 6: The problem of intrinsic variability and averaging

in most PET, fMRI, and ERP studies total variability is mostly swept under the rug. Multiple brain-imaging measurements over time are averaged (a process called signal averaging) within an individual to determine the presence or absence of a neural response. Individual averages are then grouped to create grand averages. Individual results are rarely displayed, and brain maps are never displayed with error bars. Both intraindividual differences and interindividual differences are obscured (Raichle, 1996). With so much variation, it is reasonable to ask how well averages account for individual results.

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Criticism 5: The problem of statistical tests

In PET and fMRI, thousands of measurements make up a single brain image. Further, a single brain scan will produce multiple brain slices several millimeters apart. Standard multivariate statistics are not possible because there are many more measurements than there are participants. Typically, studies use univariate statistical tests on each of the thousands of voxels (pixels) in a PET image.

Not only does Type I error inflate due to multiple correlated tests, but statistical significance, accurate or not, may have little direct relation to neurological significance.

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Criticism 7: The problem of replication

Given these problems, no surprise that replication is difficult in many brain-imaging studies of cognitive neuroscience. Intergroup replication, intrasubject replication, and intersubject replication are rare.

The problem of replication is addressed by Cabeza (1997, 2000) reviewing 73 PET studies. Even when similar tasks were used the variability of findings was striking. For example, five of the studies used comparable versions of the Stroop task (color naming), but no single region of brain activation was common to all five studies.

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Conclusions

Cognitive neuroscience is gaining in popularity because of its attempt to localize traditional cognitive constructs in neuroanatomy. However, too many proposed cognitive mechanisms are vague, unnecessarily complex, and amount to little more than inferred guesswork. Unobservable behaviors of the mind, like volition, central executive function, and mental imagery, do not enhance understanding of empirical brain operations and such terminology obscures more than clarifies. The subtraction method creates significant problems, and brain images are incapable of refuting cognitive constructs. Instead, cognitive constructs are being used as labels to name the proposed functions of the cortex.

Relating Behavior and Neuroscience: Introduction and Synopsis
Timberlake W JEAB 2005

Skinner and the Neuroscience

Skinner, in a chapter on ''Behavior and the Nervous System'' in The Behavior of Organisms (1938) expressed both strong interest and concern about relating behavior and what he termed ''neurology.''

On the positive side, he subscribed to a unified reductionist science: ''One of the objectives of science is presumably the statement of all knowledge in a single language.''

But Skinner spoke strongly against ''proceeding from a behavioral fact to its neural correlates instead of validating the fact as such.'' His goal was first, to establish an independent science of behavior ( ) and then, to bridge the gap between behavior and neurobiology by a comprehensive integration.

Relating Behavior and Neuroscience: Introduction and Synopsis Timberlake W JEAB 2005

Skinner and the Neuroscience

In short, what is missing is the broad conceptual integration that Skinner began pointing toward in 1938.

The potential for integration will be greater as experimenters use causal manipulations and analyses that consider both neuroscience and behavior.

Relating Behavior and Neuroscience: Introduction and Synopsis Timberlake W JEAB 2005

Drug effects on Operant Behavior

1) Facilitation of Operant **Extinction** by chlordiazepoxide, Leslie, JEAB 2005. Extinction was facilitated by drug injections of chlordiazepoxide (**GABA**ergic drug).

2) Dopamine in Reinforcement: Changes in reinforcement sensitivity induced by D1-type and nonselective dopamine receptor agonists, but not D2-type (Bratcher, JEAB 2005).

3) Morphine: General disruption of stimulus control? Ward, JEAB 2005.

Integrating Functional Neuroimaging and Human Operant Research: Brain Activation and Discriminative Stimuli

Schlund MW, Cataldo MF, JEAB 2005

Magnetic resonance imaging (MRI) can study a variety of brain-behavior relations:
(a) the size and position of discrete brain structures (i.e., structural MRI),
(b) changes in activation of specific brain regions under differing stimulus and/or performance conditions (i.e., functional MRI or fMRI),
(c) certain biochemical changes related to neurotransmitters (MR spectroscopy)
(d) the location and direction of neural activity along the fiber tracts that connect brain structures and regions (fiber tract mapping).

Integrating Functional Neuroimaging and Human Operant Research: Brain Activation and Discriminative Stimuli

Schlund MW, Cataldo MF, JEAB 2005

For example, Tremblay and Schultz (2000a) investigated responses of neurons in the caudate to different types of discriminative stimuli.

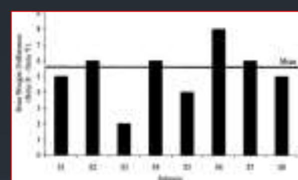
Reinforcement contingencies were used to bring responding under the control of three different discriminative stimuli, each correlated with a different contingency: respond-reinforcer, no respond-reinforcer, and respond-no reinforcer.

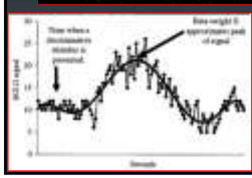
Orbitofrontal and caudate neural activity was consistently greater during the presentation of discriminative stimuli correlated with reinforcement.

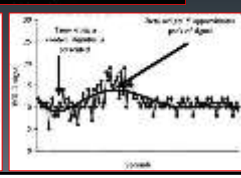
Integrating Functional Neuroimaging and Human Operant Research: Brain Activation and Discriminative Stimuli

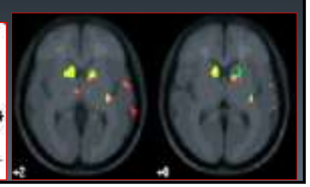
Schlund MW, Cataldo MF, JEAB 2005

Activation correlated with differences in control of discriminative stimuli by learning histories with programmed contingencies









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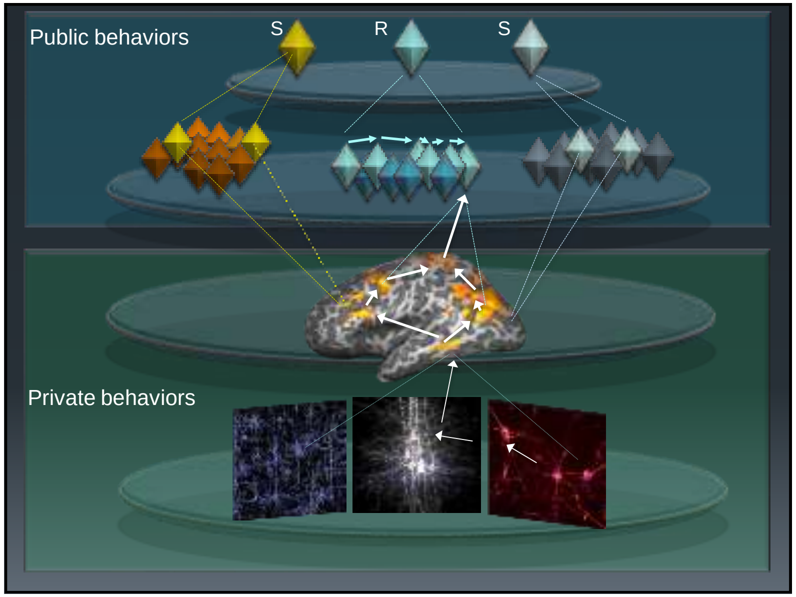
Behaviorism and Neurosciences

- The Science of Behavior has produced a conceptually sistematic analysis of public behaviors, able to explain them and to device high efficacy procedures to induce their modification
- All of this has been done without significant contributions from the Neurosciences
- What can Applied Behavior Analysis gain by sharing information with the Neurosciences?
- Is a constructive interaction between the two disciplines really possible?



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Behaviorism and Neurosciences

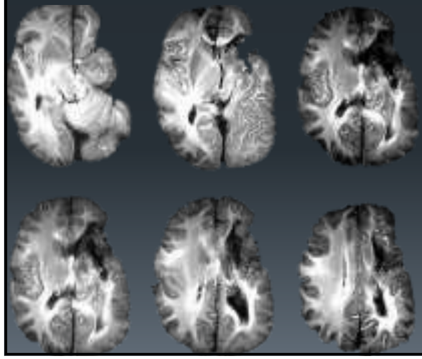
- Making private events public can increase the complexity of the observed responses up to a point where our understanding and the conceptual systematicity of our discipline are difficult to preserve
- Increasing the complexity of observed behavior can produce a new level of understanding
- And new clinical approaches to diseases (ASD)

Private behaviors made public

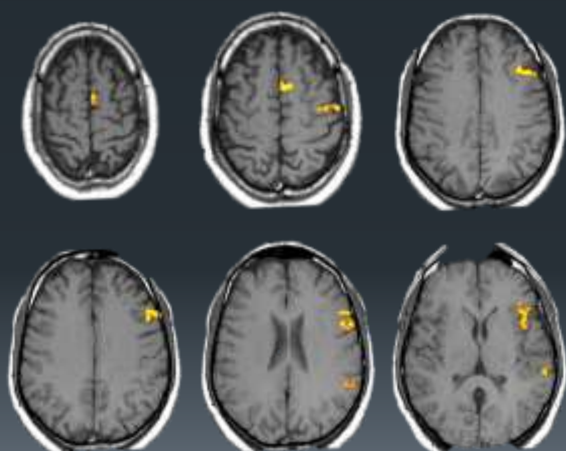
The increased complexity

- The complexity of behavior depends on the level of observation we chose to take. Possible levels of observation of “private” events in the brain are:
- The points of the brain on neuroimages
- The cortical surface and/or its subdivisions
- The “unitary elements” of brain events, the neuronal columns
- The single neurons
- The single synapses

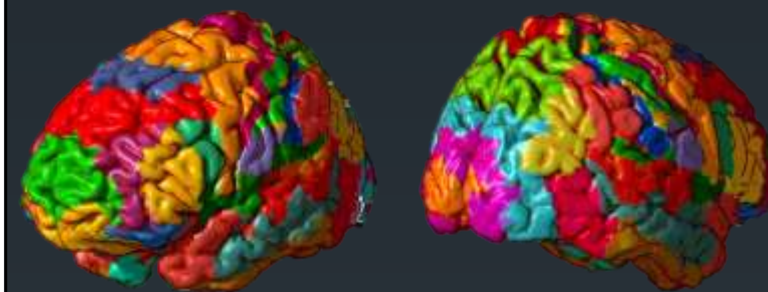
In search of a landmark



Brain pattern of activity in a verbal task identified by fMRI



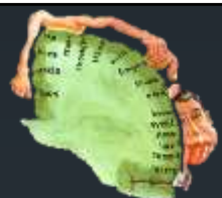
A behavioral dissection of brain cortex

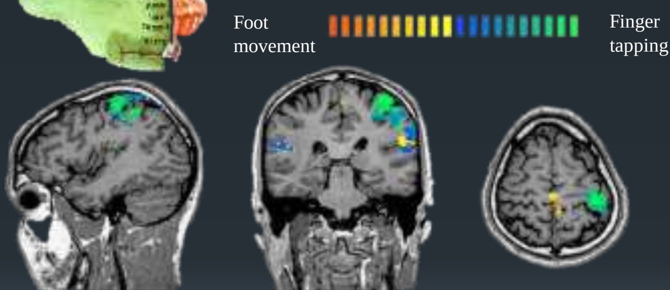


Mark Dow, Brain Development Lab, University of Oregon

Neuroscience define a “Brain Area” as a unit of brain cortex having homogeneous cortical architecture and emitting a topographical response class, but the topographical similarity required is very generic (moving any part of the body, emitting any word etc.)

Motor cortex: Penfield's homunculus

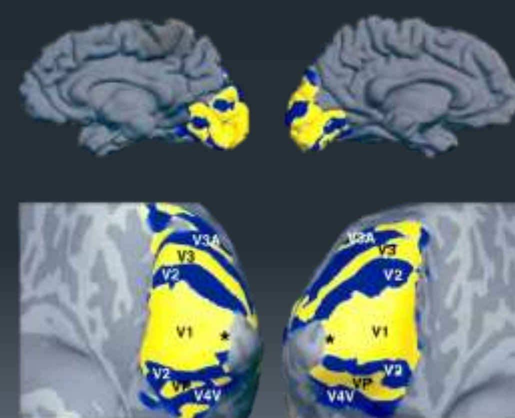




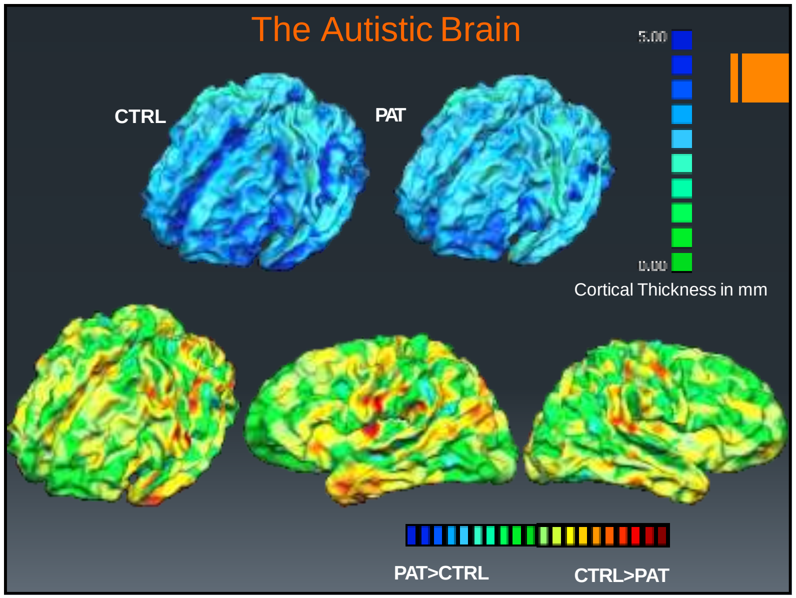
More adherent to the concept of a topographical response class are the subdivisions of brain areas emitting more topographically homogeneous behaviors, like the hand, or the foot, or the face motor areas.

Borders of multiple visual areas in fMRI

Multiple neighbouring areas to respond to visual stimuli: Functional modularity to enhance the efficiency of responding?



Tootell et al. PNAS 1998


The Autistic Brain
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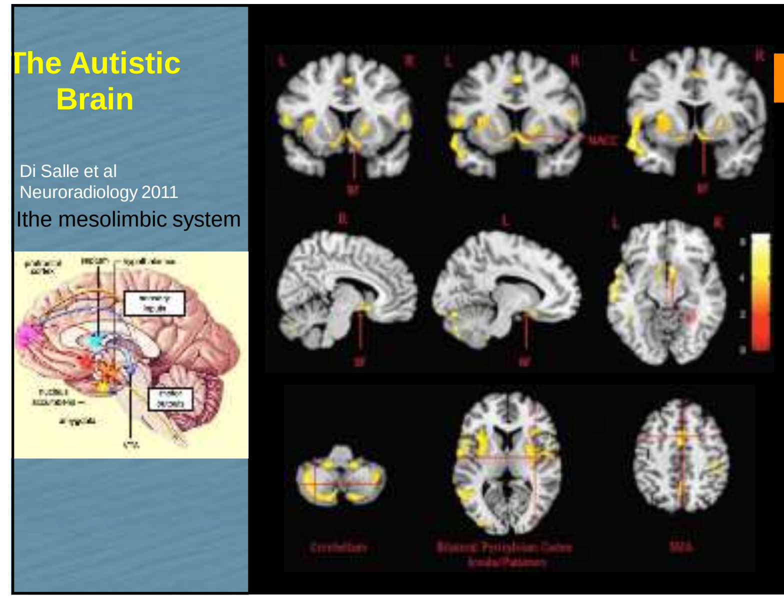
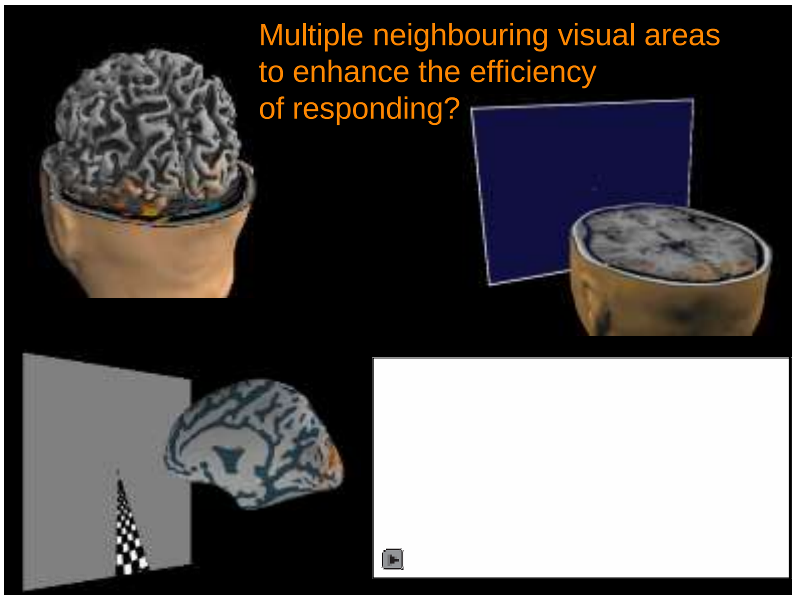

The Autistic Brain
Di Salle et al
Neuroradiology 2011
Ithe mesolimbic system


Multiple neighbouring visual areas
to enhance the efficiency
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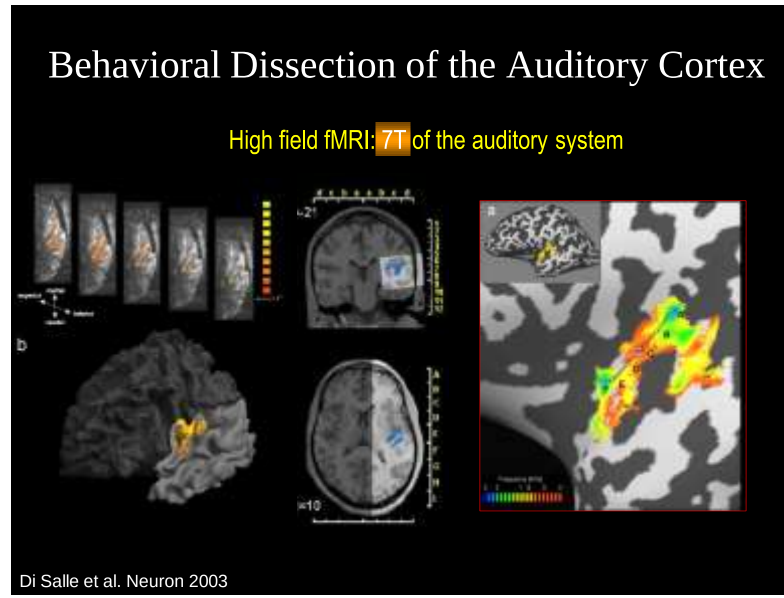
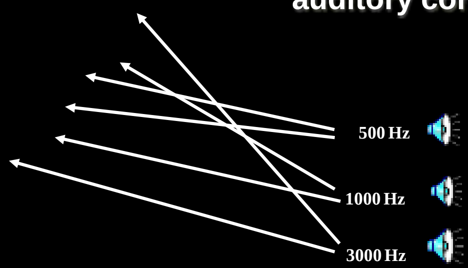

Behavioral Dissection of the Auditory Cortex
High field fMRI: 7T of the auditory system
Di Salle et al. Neuron 2003

Frequency representation (tonotopic maps) in the human auditory cortex



Di Salle et al Neuron 2003

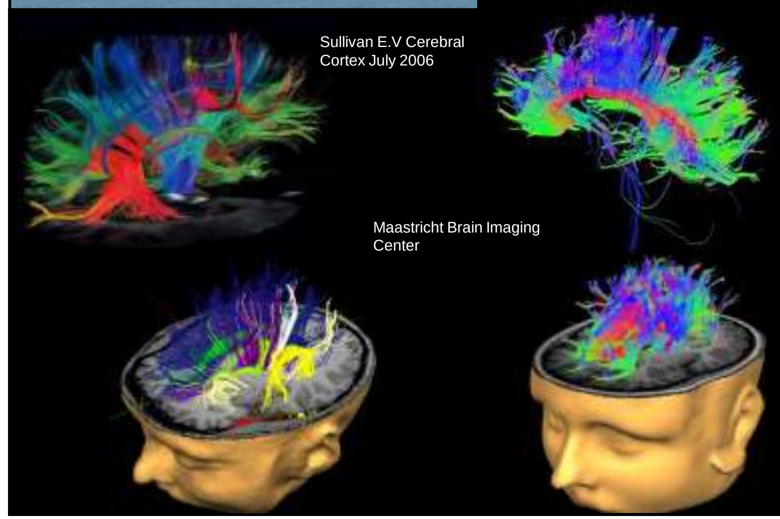
How is behavioral specialization of brain areas established

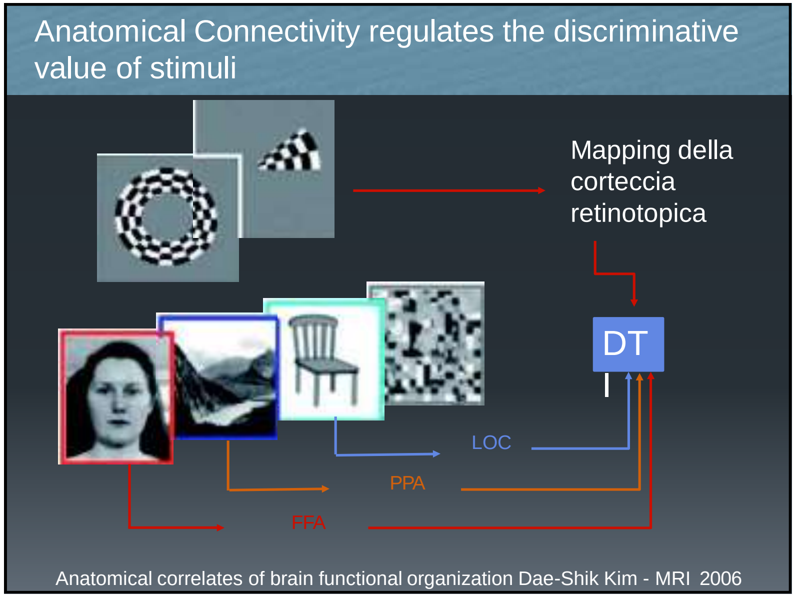
- Broadmann cytoarchitectonic areas reflect a functional specialization of brain areas
- Each area is selectively reached by special categories of stimuli and emits specific responses
- The selective distribution of stimuli in the brain is reached through a specific distribution of white matter connection fibers, mainly governed by phylogenetic factors
- The specificity of responding is mainly governed by the nature of the stimuli that reach each area of the brain cortex

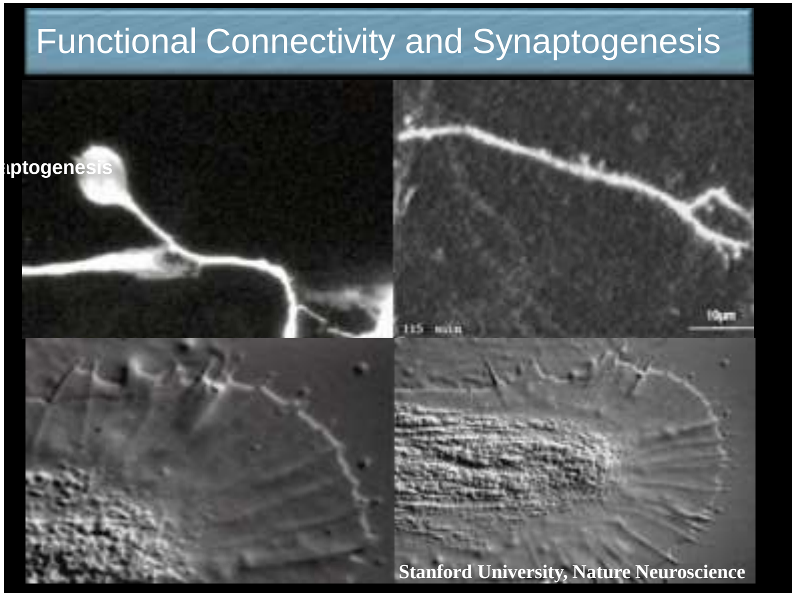
Connectivity Analysis

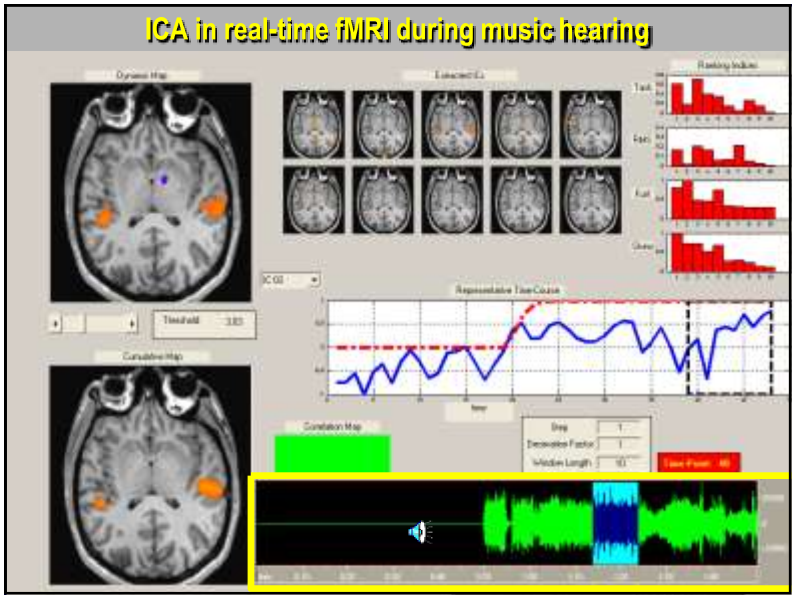
- **Anatomical Connectivity**
- **Functional Connectivity**
- **Effective Connectivity**

Anatomical Connectivity regulates the discriminative value of stimuli




Anatomical Connectivity regulates the discriminative value of stimuli
Mapping della corteccia retinotopica
DT
LOC
PPA
FFA
Anatomical correlates of brain functional organization Dae-Shik Kim - MRI 2006


Functional Connectivity and Synaptogenesis
Stanford University, Nature Neuroscience



Private behaviors made public

The increased complexity

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- The points of the brain on neuroimages
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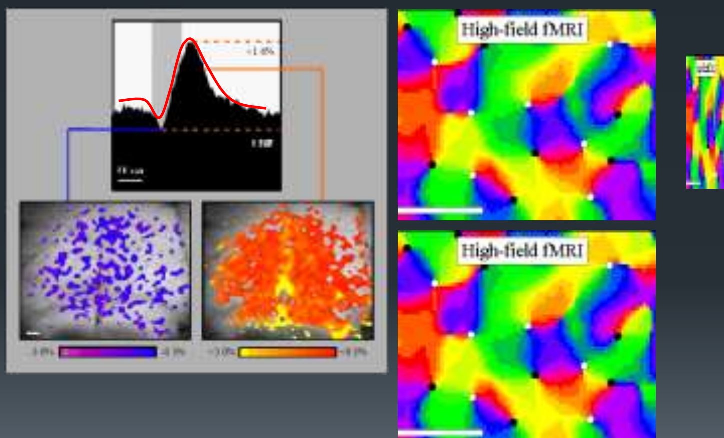
- "Unitary elements" of brain activity, the neuronal columns
- The single neurons 100 billion neurons
- The single synapses 10 thousands per neuron

fMRI at the Columnar level



Dae-Shik Kim – Nature Neuroscience 2000

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Brain Responses measured through the Continuous Measures of Behavior

The motor experiment

The motor experiment

The Motor experiment

Aims of the experiment were to:

a) single out the brain area(s) active in motor behavior
b) analyze the correspondence of Dimentional Quantities in the private and in the public motor behavior
c) examine the presence of a chain of behaviors leading to the public motor behavior

A visual stimulus indicated which finger to move and how long

In the Baseline condition the Stimulus was replaced by a fixation cross and no Response was required

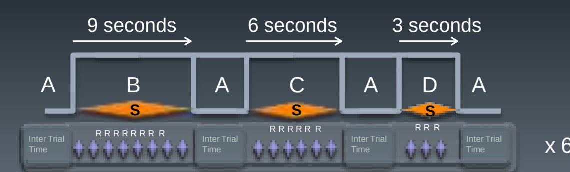
The duration of trials was varied from 3 to 6 and to 9 seconds, each condition repeated 6 times.

The temporal resolution of the test was 800 milliseconds

Design of the motor experiment

Conceptually a reversal/withdrawal experiment with many (n 18) applications and withdrowals of the Independent Variable

3 conditions of the Independent Variable are tested, differing for the duration of each trial, (motor episodes lasting 3,6,9 seconds)

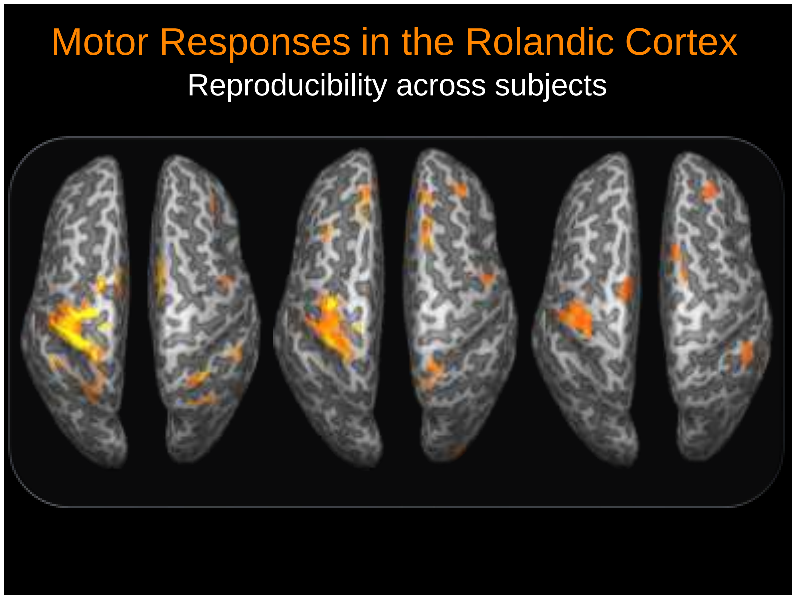


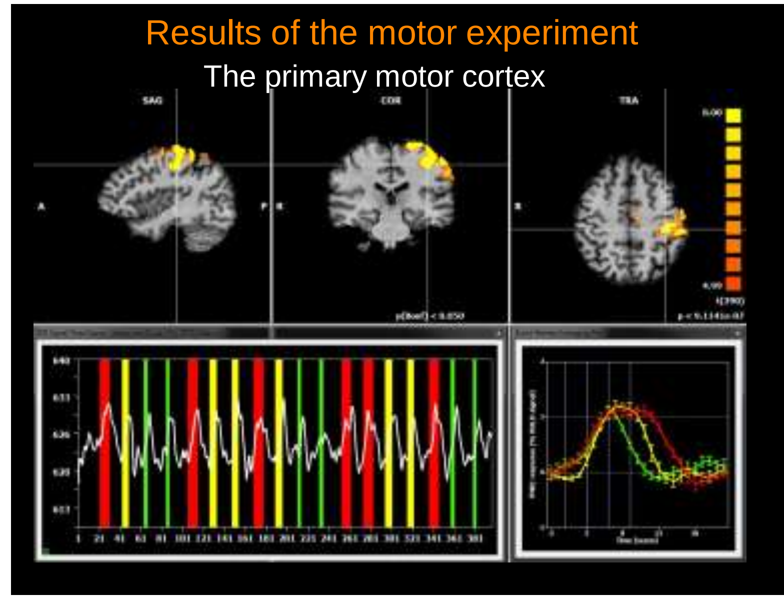
Results of the motor experiment

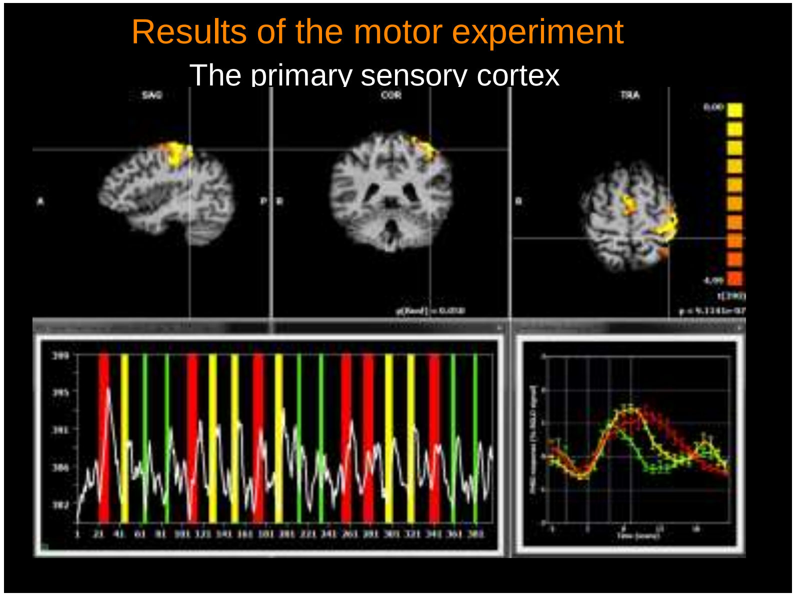
Temporal dissection of the motor behavior in the brain

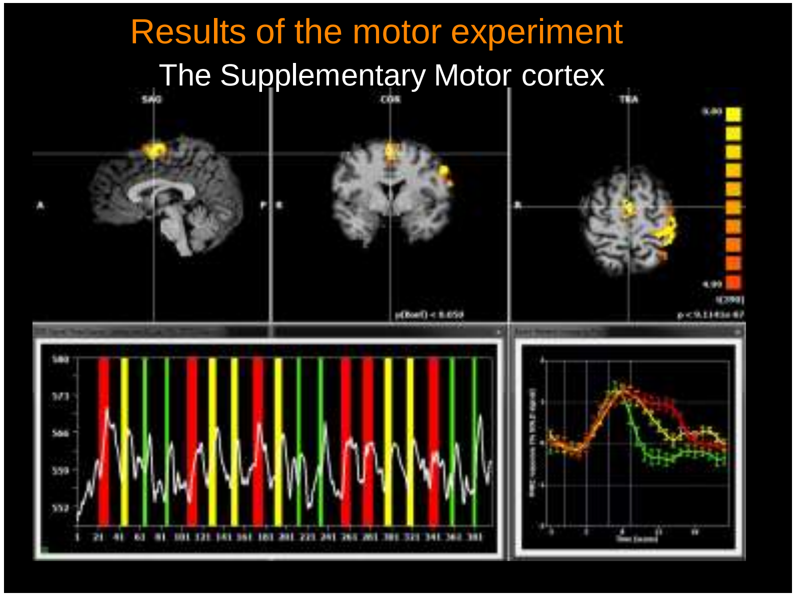
Results of the motor experiment

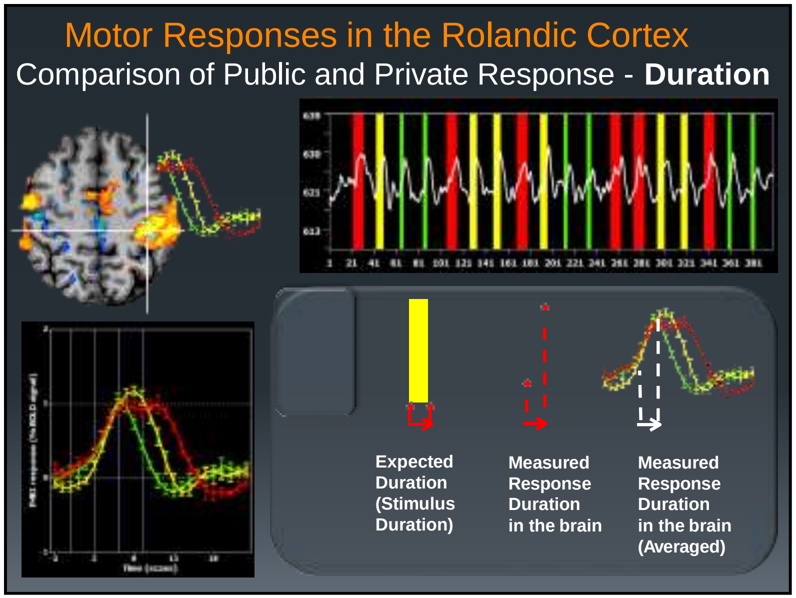
Temporal dissection of the motor behavior in the brain

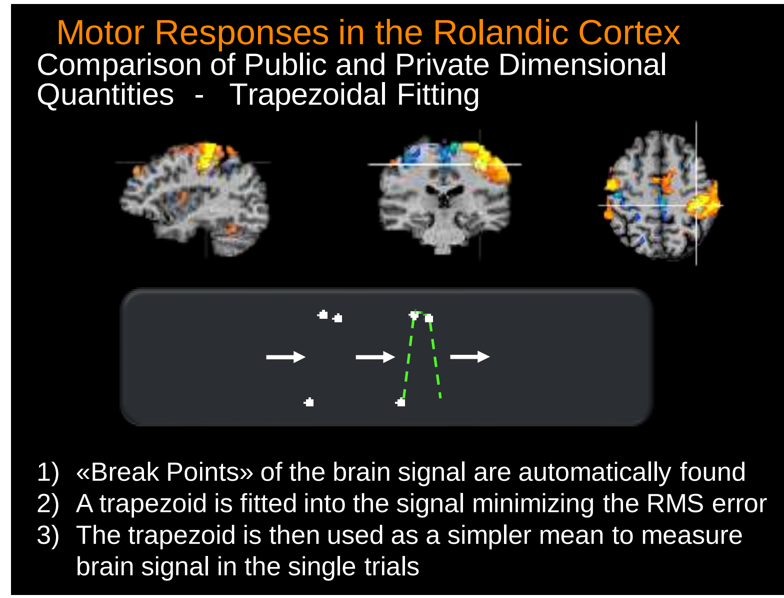

Motor Responses in the Rolandic Cortex
Reproducibility across subjects

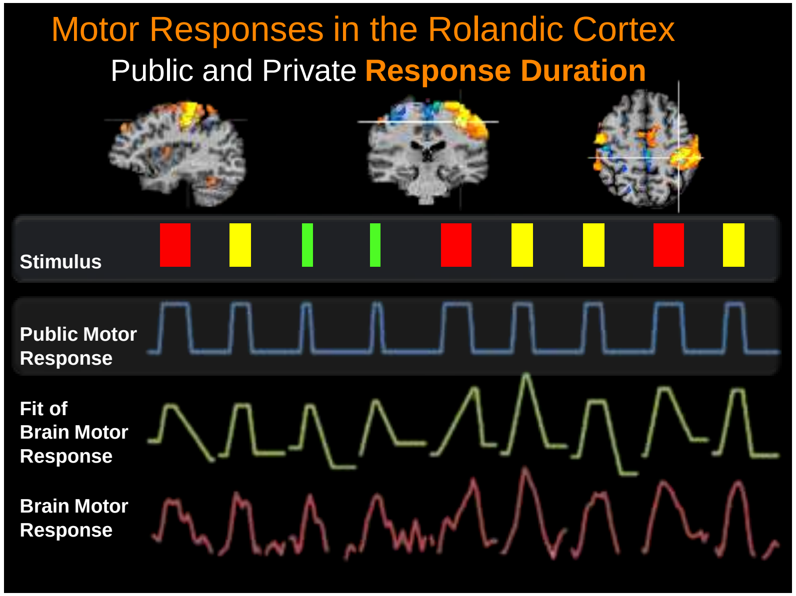

Results of the motor experiment
The primary motor cortex

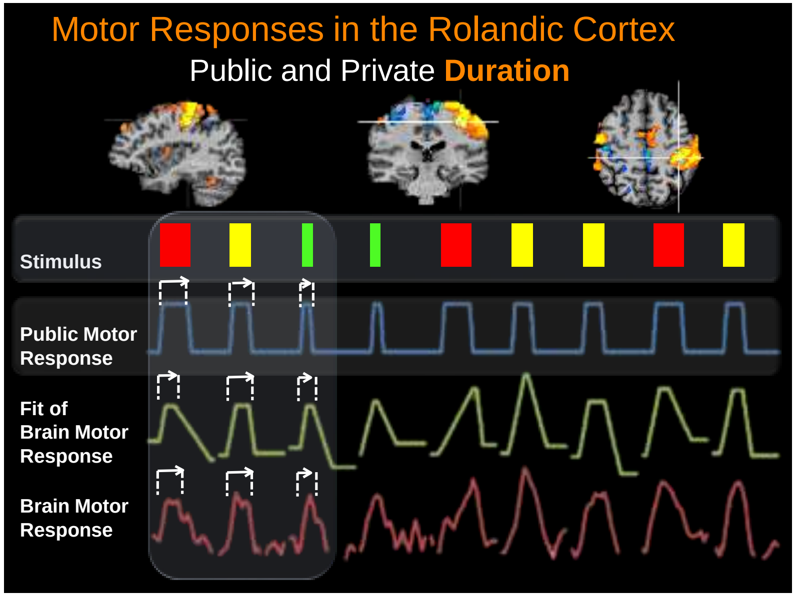

Results of the motor experiment
The primary sensory cortex

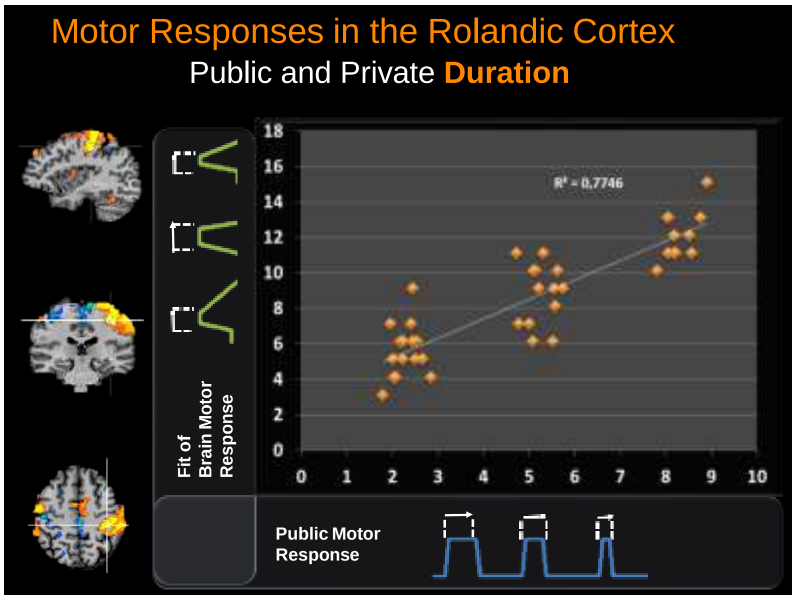

Results of the motor experiment
The Supplementary Motor cortex

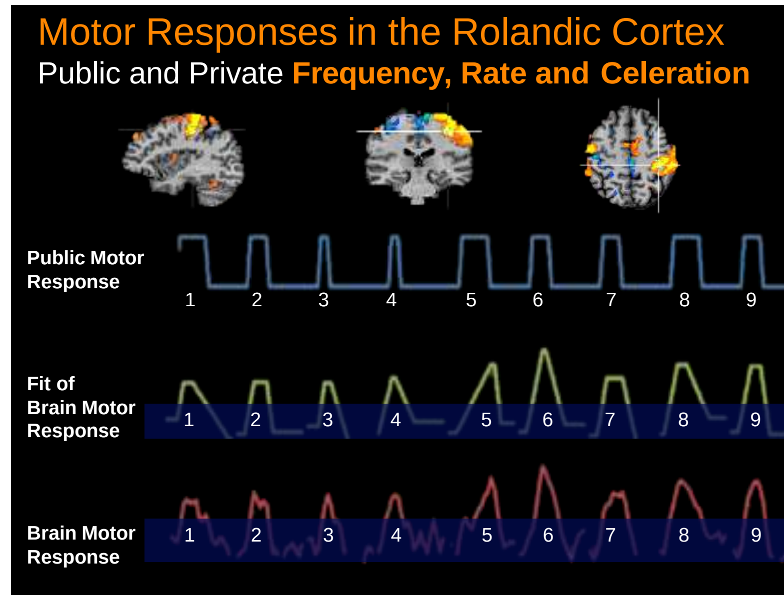

Motor Responses in the Rolandic Cortex
Comparison of Public and Private Response - Duration
Expected Duration (Stimulus Duration)
Measured Response Duration in the brain
Measured Response Duration in the brain (Averaged)

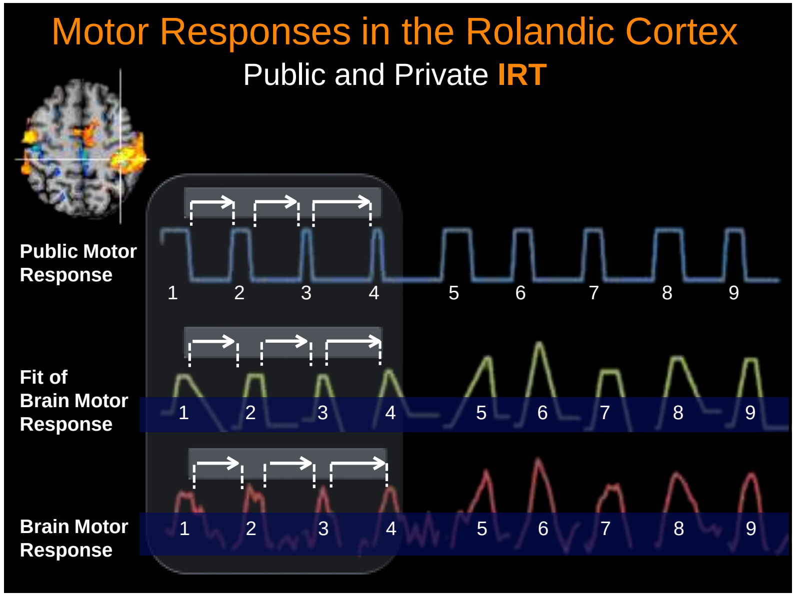

Motor Responses in the Rolandic Cortex
Comparison of Public and Private Dimensional Quantities - Trapezoidal Fitting
1) «Break Points» of the brain signal are automatically found
2) A trapezoid is fitted into the signal minimizing the RMS error
3) The trapezoid is then used as a simpler mean to measure brain signal in the single trials

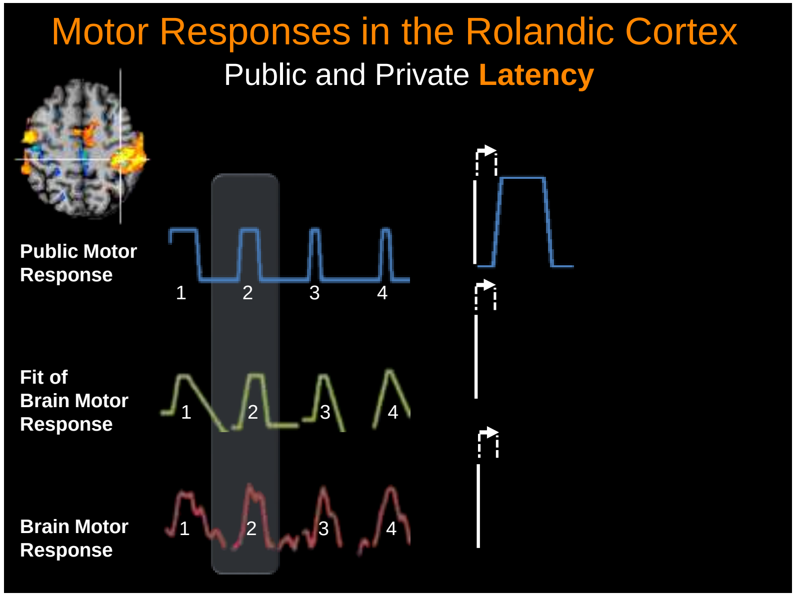

Motor Responses in the Rolandic Cortex
Public and Private Response Duration
Stimulus
Public Motor Response
Fit of Brain Motor Response
Brain Motor Response

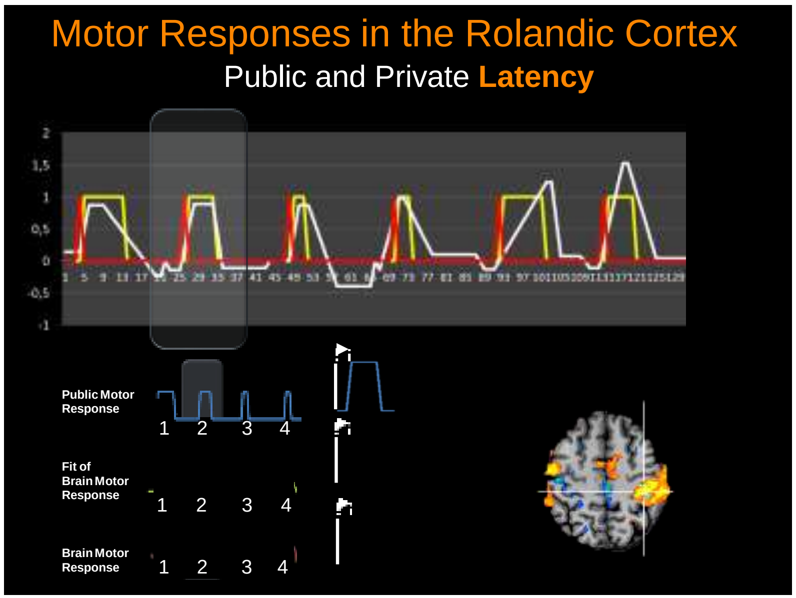

Motor Responses in the Rolandic Cortex
Public and Private Duration
Stimulus
Public Motor Response
Fit of Brain Motor Response
Brain Motor Response


Motor Responses in the Rolandic Cortex
Public and Private Duration
Fit of Brain Motor Response
R² = 0,7746
18 16 14 12 10 8 6 4 2 0
0 1 2 3 4 5 6 7 8 9 10
Public Motor Response


Motor Responses in the Rolandic Cortex
Public and Private Frequency, Rate and Celeration
Public Motor Response
1 2 3 4 5 6 7 8 9
Fit of Brain Motor Response
1 2 3 4 5 6 7 8 9
Brain Motor Response
1 2 3 4 5 6 7 8 9


Motor Responses in the Rolandic Cortex
Public and Private IRT
Public Motor Response
1 2 3 4 5 6 7 8 9
Fit of Brain Motor Response
1 2 3 4 5 6 7 8 9
Brain Motor Response
1 2 3 4 5 6 7 8 9


Motor Responses in the Rolandic Cortex
Public and Private Latency
Public Motor Response
1 2 3 4
Fit of Brain Motor Response
1 2 3 4
Brain Motor Response
1 2 3 4


Motor Responses in the Rolandic Cortex
Public and Private Latency
Public Motor Response
1 2 3 4
Fit of Brain Motor Response
1 2 3 4
Brain Motor Response
1 2 3 4


MRI vs Public Event Registration

Motor experiment: TR 2000 Count

- Number of events registered by MRI (MRI Count): 19
- Number of events registered by the «public observer» («public observer» Count): 18
- Total Count IOA: 94.7%

	Observers	Count	Total count IOA
Signal	Time course	19	94.7%
Log	Public observer	18	

The Motor experiment

Conclusions

a) Brain areas where the private behavior was emitted were easy to single out and reproducible across subjects

b) Dimentional Quantities are well correlated in the private compared to the public motor behavior, and perfectly measurable in the single episodes

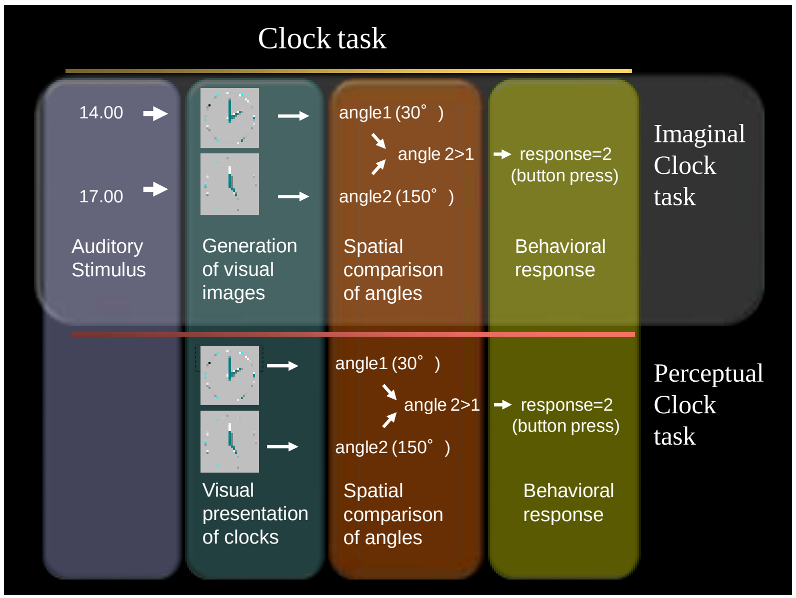
c) The temporal dissection of the motor episode in the brain showed a temporal succession of private behaviors from the IntraParietal sulcus to the Primary Motor, and to the Supplementary Motor regions.

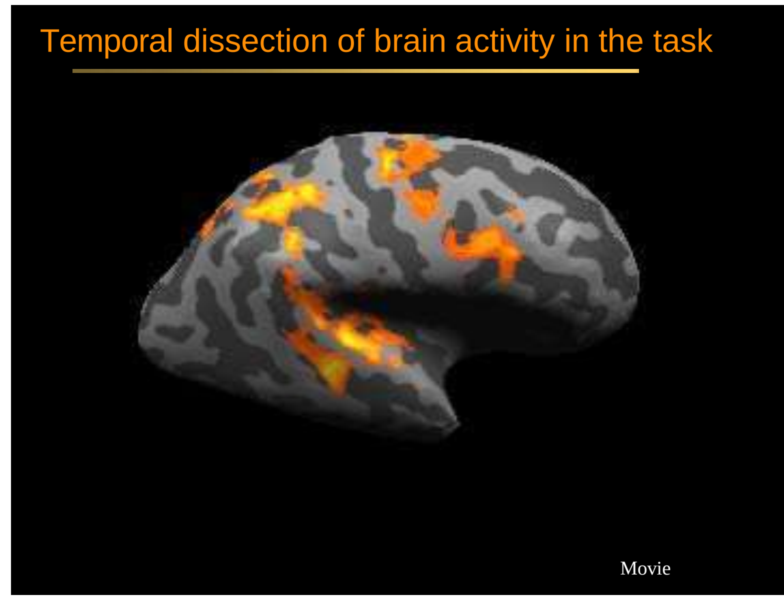
Brain Responses measured through the Continuous Measures of Behavior

The visual imagery experiment

The imaginal clock task

- **General purpose:** To trace the spatio-temporal pattern of brain activation during a single trial of a fMRI brain (mental) chronometry framework.
- **Design:** Time-resolved event-related fMRI; correlation of reaction times with BOLD delay in different brain areas.
- **Paradigm:** The "mental clock task" (Paivio, 1978, *J Exp Psychol HumPerc*, **4**, 61-71).
- **Specific purpose:** Investigate hemispheric specialization in the posterior parietal cortex (PPC) for generation and analysis of mental images.
- **Details:** Di Salle et al, (2002). Tracking the mind's image in the brain I. *Neuron*, **35**, 185-194.


Clock task
14.00
17.00
Auditory Stimulus
Generation of visual images
angle1 (30˚)
angle 2>1
angle2 (150˚)
Spatial comparison of angles
response=2 (button press)
Behavioral response
Imaginal Clock task
angle1 (30˚)
angle 2>1
angle2 (150˚)
response=2 (button press)
Visual presentation of clocks
Spatial comparison of angles
Behavioral response
Perceptual Clock task

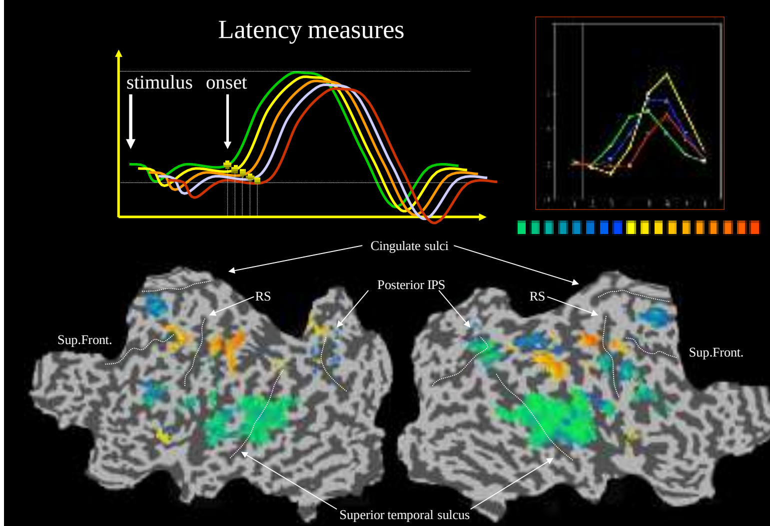

Temporal dissection of brain activity in the task
Movie

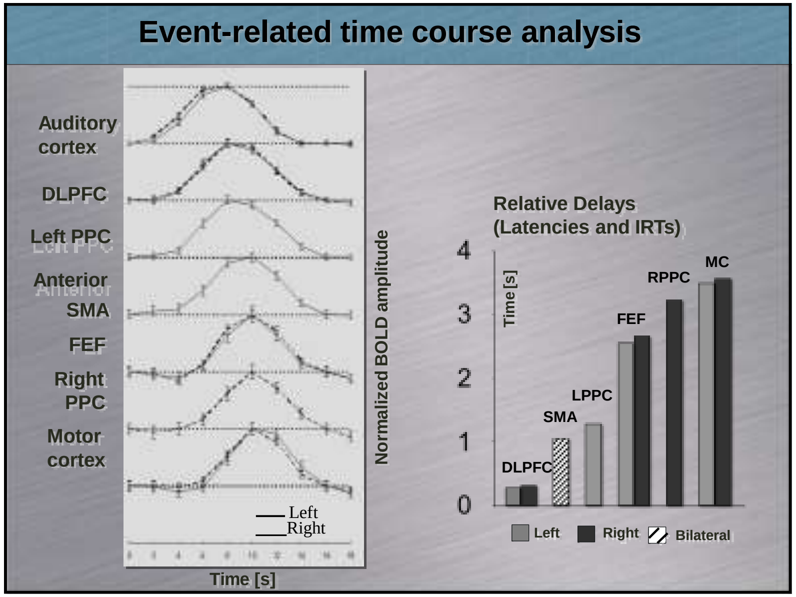
BOLD latency mapping

Separating physiological delays from latency in responding

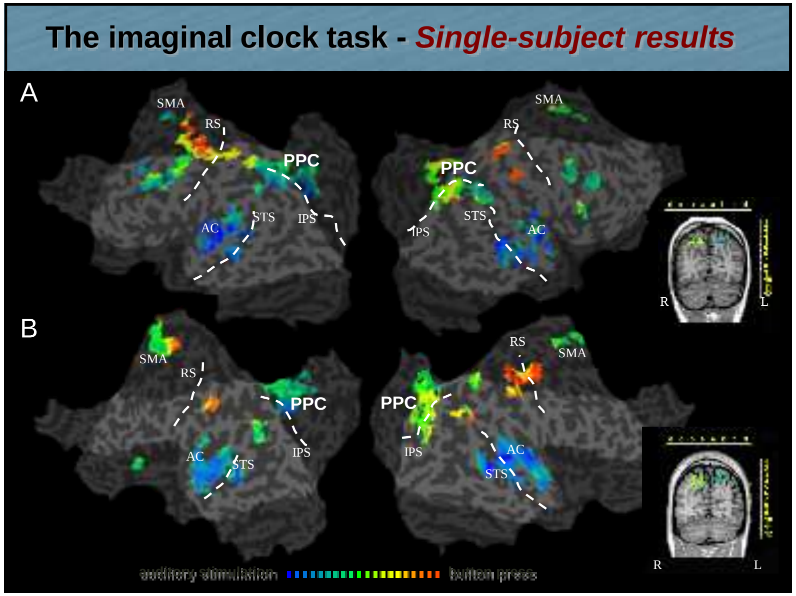
- Since hemodynamic properties remain constant within a brain area, any ***task-dependent change*** reflects responding timing effects.
- Task-dependent changes in timing can be revealed by correlation of single-trial BOLD latencies with reaction times, by changing the order of cognitive tasks etc.

Temporal dissection of brain activity in the task



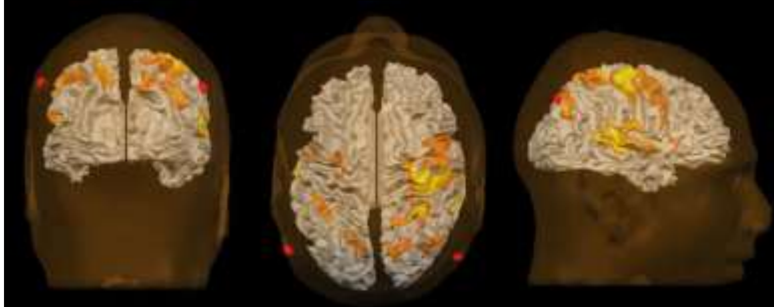


Event-related time course analysis
Auditory cortex
DLPFC
Left PPC
Anterior SMA
FEF
Right PPC
Motor cortex
Left
Right
Time [s]
Normalized BOLD amplitude
Relative Delays (Latencies and IRTs)
Time [s]
4
3
2
1
0
DLPFC
SMA
LPPC
FEF
RPPC
MC
Left
Right
Bilateral



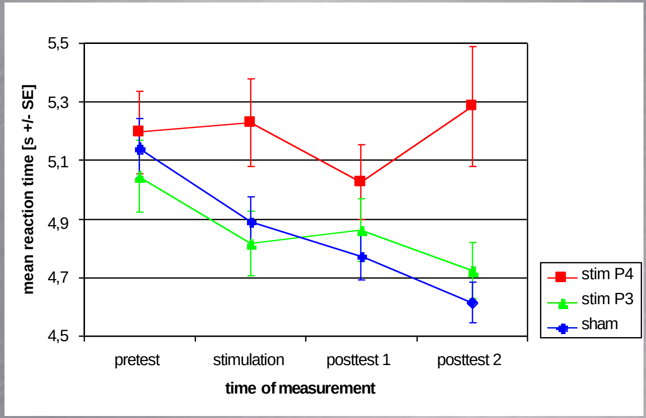
The imaginal clock task - *Single-subject results*
A
B
SMA
RS
PPC
STS
IPS
AC
R
L
auditory stimulation
button press

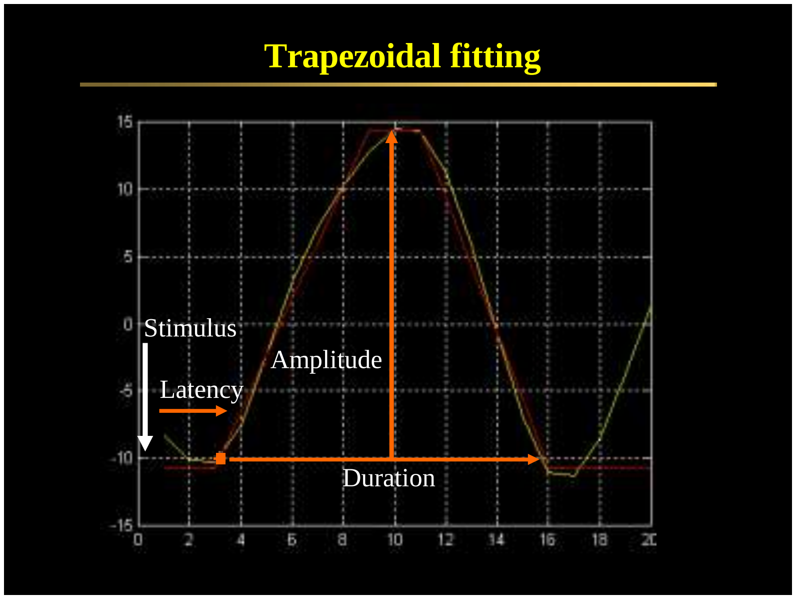
Imaginal clock task - *Combined fMRI and rTMS*

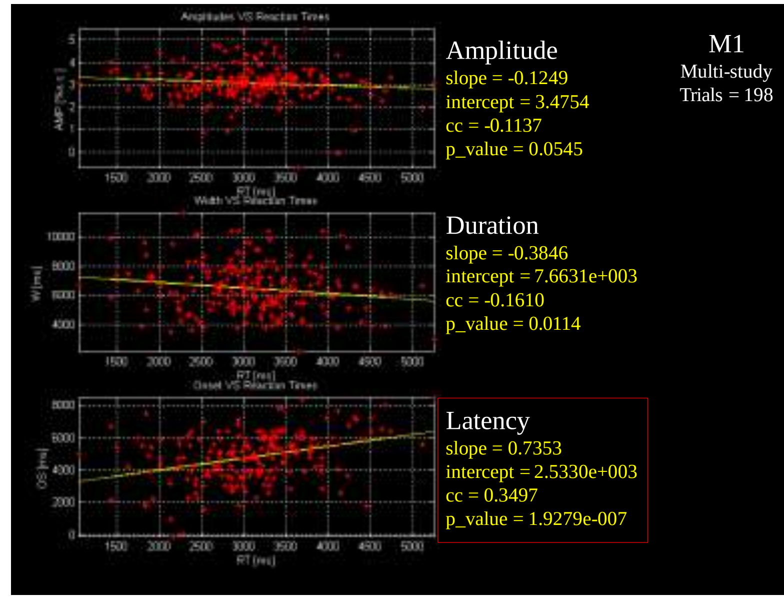


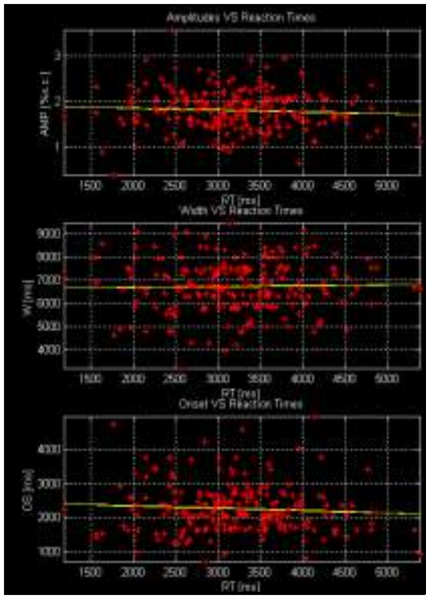
Sack A, Di Salle F. et al., (2002), Tracking the mind's image in the brain II, *Neuron*, **35**, 195-204.

Imaginal clock task - *TMS results*




Trapezoidal fitting
Stimulus
Latency
Amplitude
Duration


Amplitude
slope = -0.1249
intercept = 3.4754
cc = -0.1137
p_value = 0.0545
M1
Multi-study
Trials = 198
Duration
slope = -0.3846
intercept = 7.6631e+003
cc = -0.1610
p_value = 0.0114
Latency
slope = 0.7353
intercept = 2.5330e+003
cc = 0.3497
p_value = 1.9279e-007

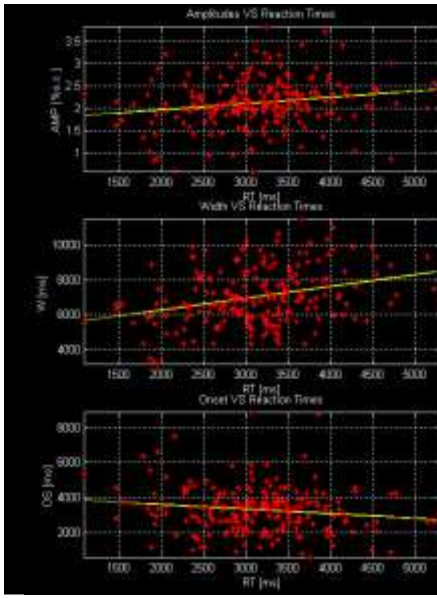


Amplitude
slope = -0.0409
intercept = 1.9387
cc = -0.0692
p_value = 0.1611

A1
Multi-study
Trials = 205

Duration
slope = 0.0316
intercept = 6.6267e+003
cc = 0.0213
p_value = 0.3801

Latency
slope = -0.0688
intercept = 2.4826e+003
cc = -0.0718
p_value = 0.1521



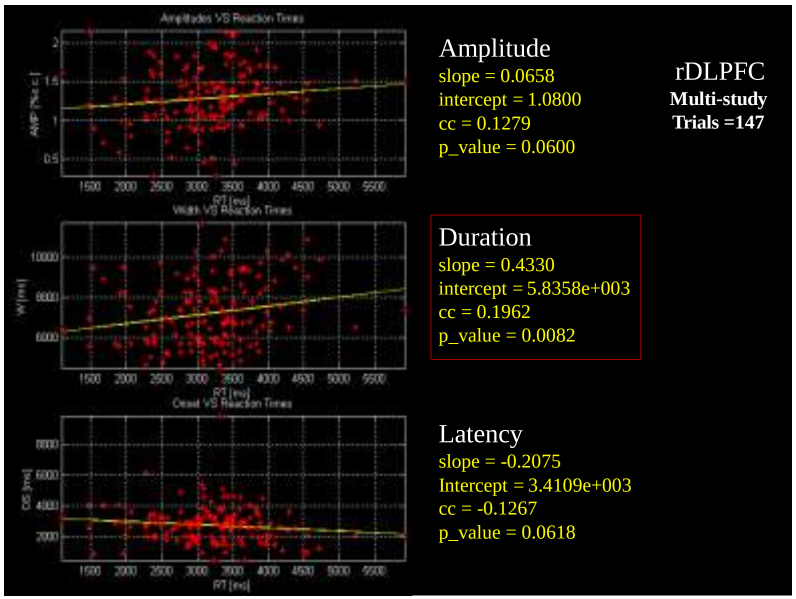
Amplitude
slope = 0.1404
intercept = 1.6803
cc = 0.1868
p_value = 0.0037

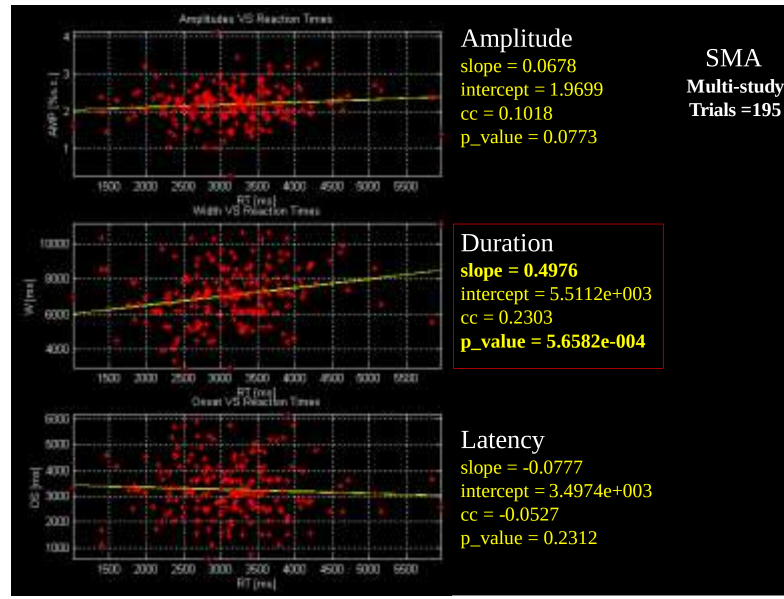
Left Intra Parietal Sulcus

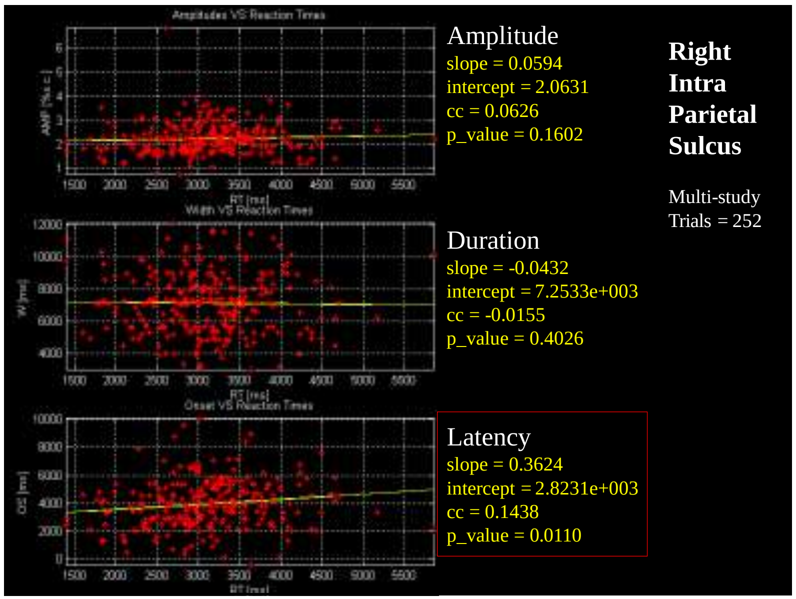
Multi-study
Trials = 203

Duration
slope = 0.6749
intercept = 4.9200e+003
cc = 0.3041
p_value = 4.6479e-006

Latency
slope = -0.2618
intercept = 4.1257e+003
cc = -0.1440
p_value = 0.0197


Amplitude
slope = 0.0658
intercept = 1.0800
cc = 0.1279
p_value = 0.0600
rDLPFC
Multi-study
Trials =147
Duration
slope = 0.4330
intercept = 5.8358e+003
cc = 0.1962
p_value = 0.0082
Latency
slope = -0.2075
Intercept = 3.4109e+003
cc = -0.1267
p_value = 0.0618


Amplitude
slope = 0.0678
intercept = 1.9699
cc = 0.1018
p_value = 0.0773
SMA
Multi-study
Trials =195
Duration
slope = 0.4976
intercept = 5.5112e+003
cc = 0.2303
p_value = 5.6582e-004
Latency
slope = -0.0777
intercept = 3.4974e+003
cc = -0.0527
p_value = 0.2312



Outline

- Skinner, Behaviorism and Neurosciences
- NeuroBehavioral literature in Behavioral Journals
- Advantages of NeuroBehavioral integration
- Private events made public and possible to modify
- Procedures to study the behavior in the brain
- Translating Neuroscience into Behaviorism through Neuroimaging
- Behavioral measures of brain activity
- Neural activity in the verbal operants
- Methods to modify the behavior in the brain
- The Crossword experiment in Tact and Intraverbals
- Neurofeedback of Intraverbals

Neural Activity in Verbal Operants

1) Pattern
2) Source of control
3) Training

The Pattern experiment on Verbal Operants

Aims

- Aims of the experiment were to:
- a) single out the brain area(s) were the brain behavior subserving the Verbal Operants (Echoic, Tact, Intraverbal and Textual) is emitted
- b) analyze the differences among the patterns of activity in search of a unique pattern for each Operant
- c) examine the differences in brain activity in conditions of private and public (overt) behavior and of private only (covert) behavior.

The Verbal Operants experiment

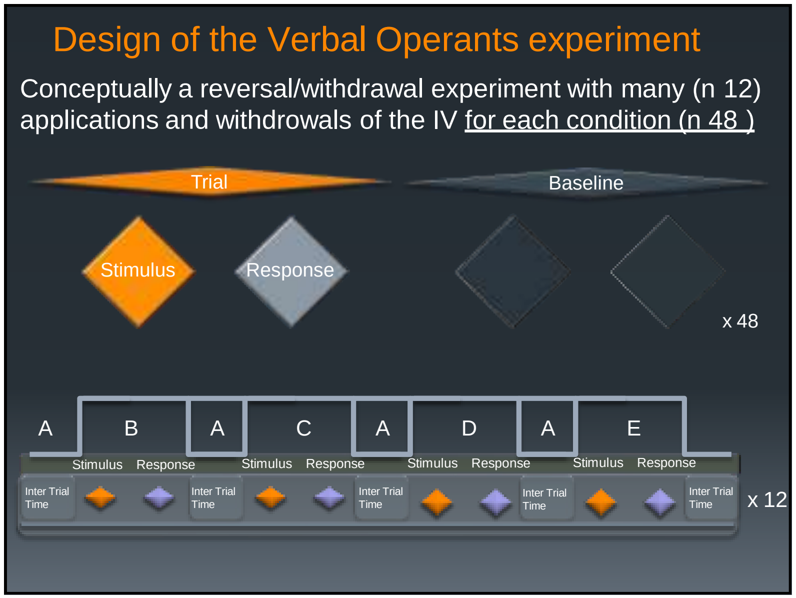
The Stimuli

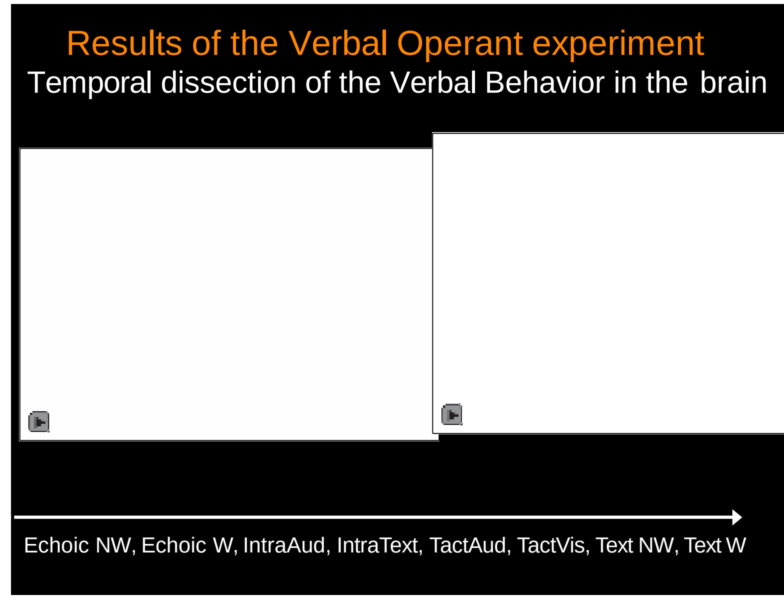
1) In the Echoic condition the activity was evoked by vocal antecedent stimuli in the form of both words and not words
2) In the Tact condition half of the antecedent stimuli were in auditory and half in visual form
3) In the Intraverbal condition, half of the stimuli were in vocal and half in text form
4) In the Textual condition, half of the stimuli were words and half non words
5) In the Baseline condition no Stimulus was given to the subjects and no Response required.

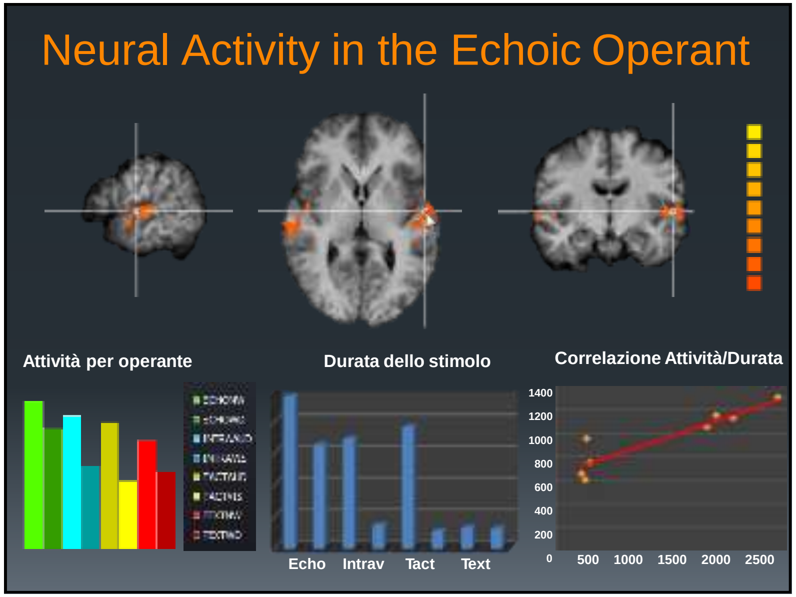
The Verbal Operants experiment

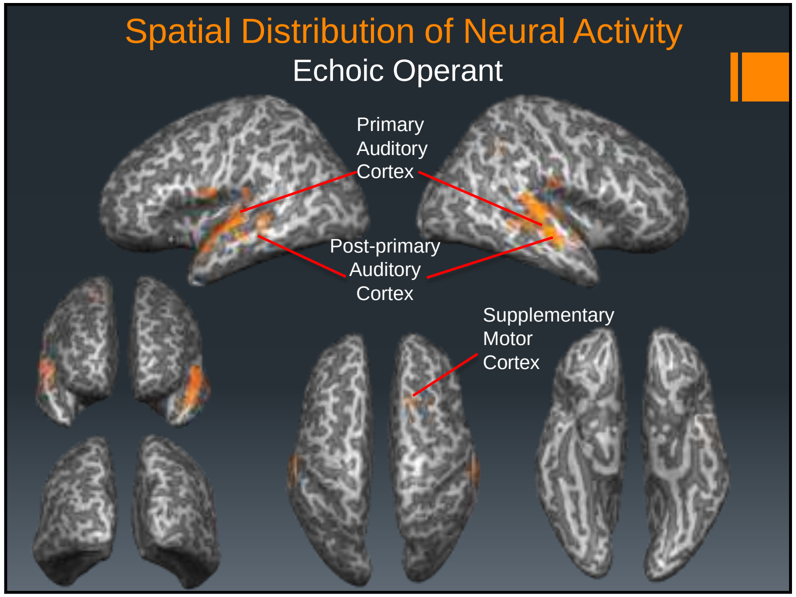
Topography and Trials

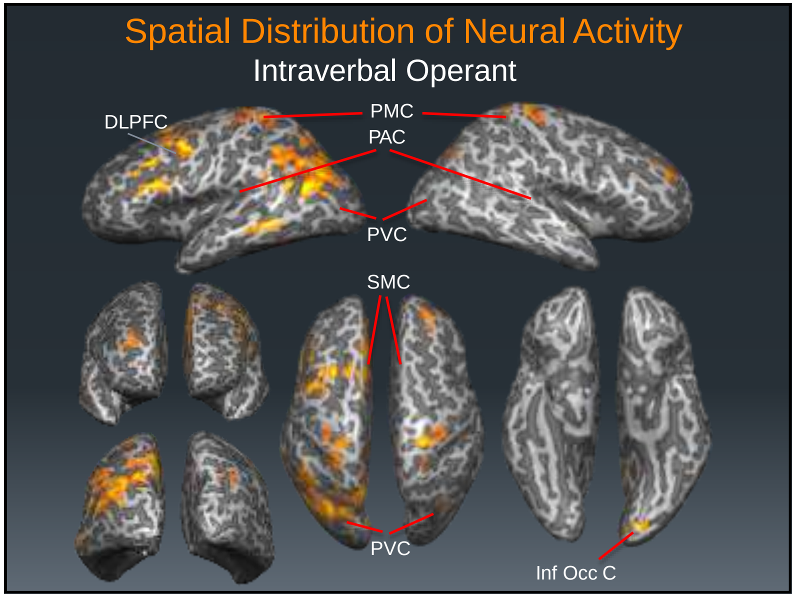
1) For half of the trials, the topography was the same across all operants, in the remaining half the topography varied.
2) The duration of trials was of 20 seconds and each condition was repeated 12 times
3) in order to avoid additional activity, no consequence was given to the behavior

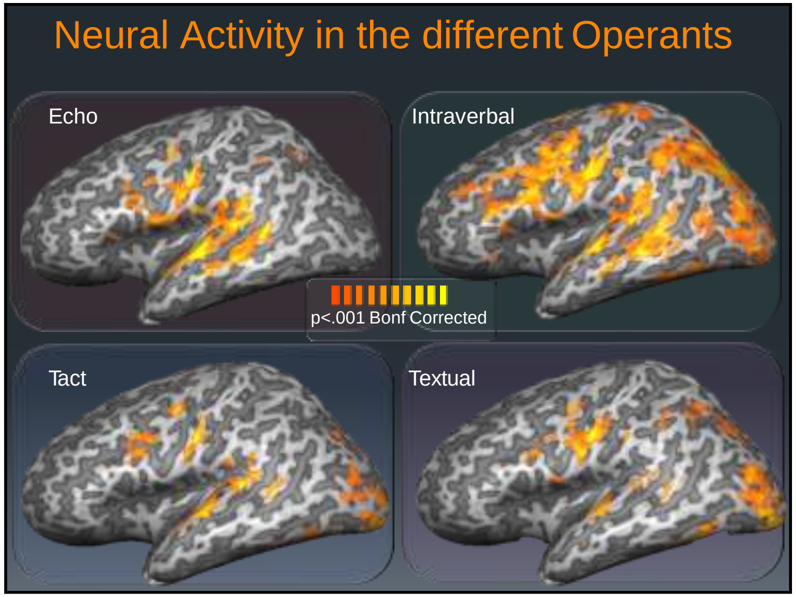

Design of the Verbal Operants experiment
Conceptually a reversal/withdrawal experiment with many (n 12) applications and withdrowals of the IV for each condition (n 48)
Trial
Baseline
Stimulus
Response
x 48
A
B
A
C
A
D
A
E
Stimulus
Response
Stimulus
Response
Stimulus
Response
Stimulus
Response
Inter Trial Time
Inter Trial Time
Inter Trial Time
Inter Trial Time
Inter Trial Time
x 12

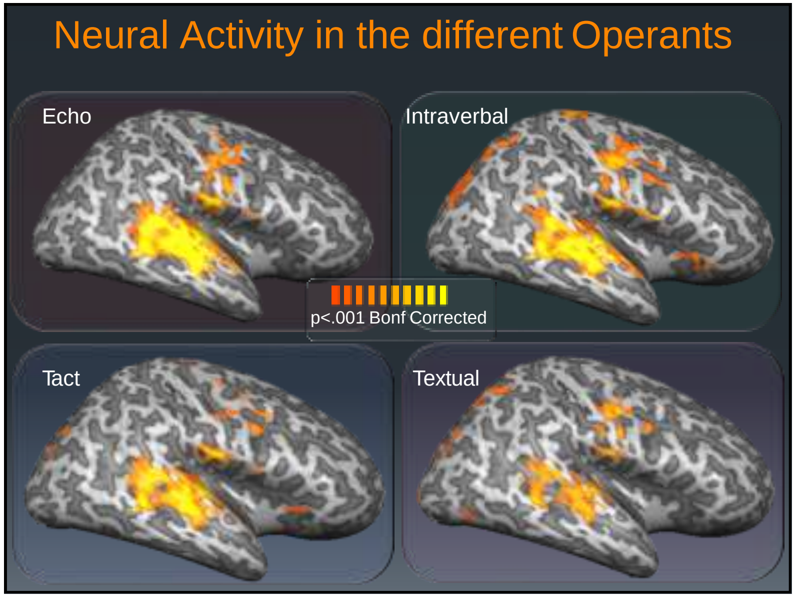

Results of the Verbal Operant experiment
Temporal dissection of the Verbal Behavior in the brain
Echoic NW, Echoic W, IntraAud, IntraText, TactAud, TactVis, Text NW, Text W

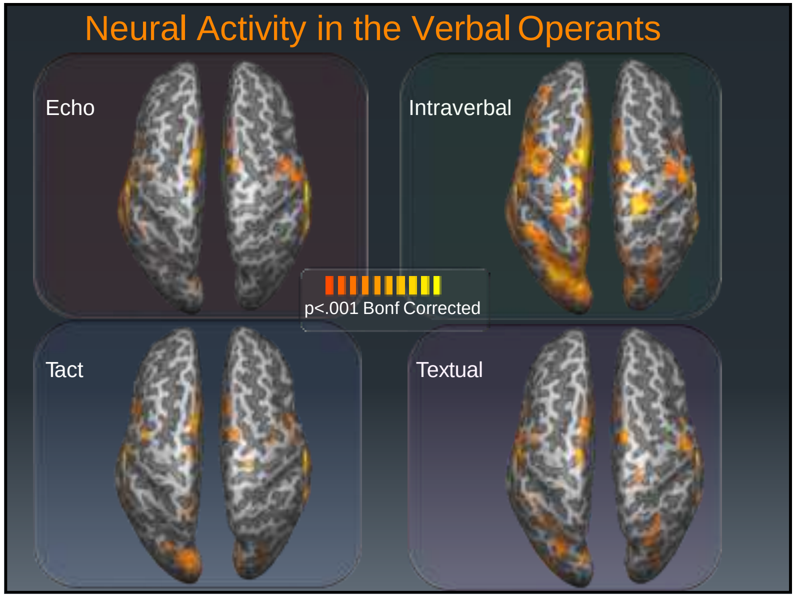

Neural Activity in the Echoic Operant
Attività per operante
Durata dello stimolo
Correlazione Attività/Durata
Echo
Intrav
Tact
Text
1400
1200
1000
800
600
400
200
0
500
1000
1500
2000
2500

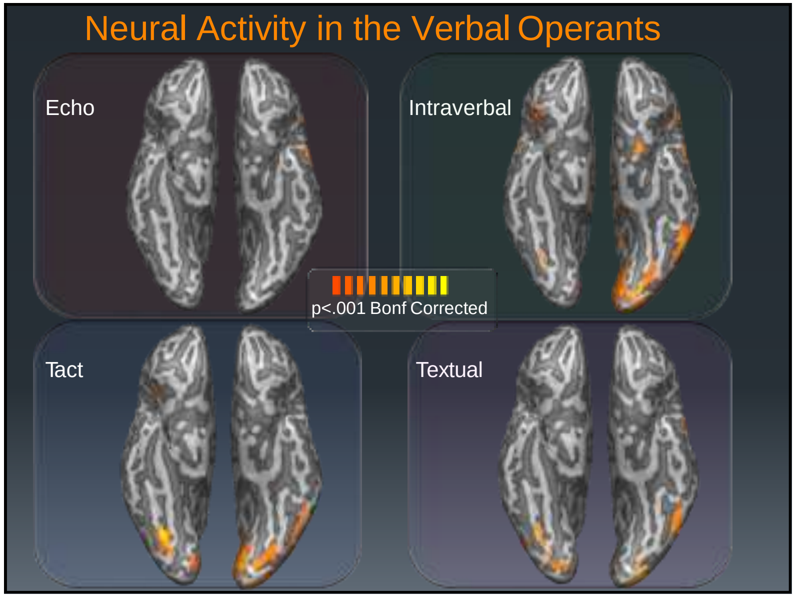

Spatial Distribution of Neural Activity
Echoic Operant
Primary Auditory Cortex
Post-primary Auditory Cortex
Supplementary Motor Cortex


Spatial Distribution of Neural Activity
Intraverbal Operant
DLPFC
PMC
PAC
PVC
SMC
PVC
Inf Occ C

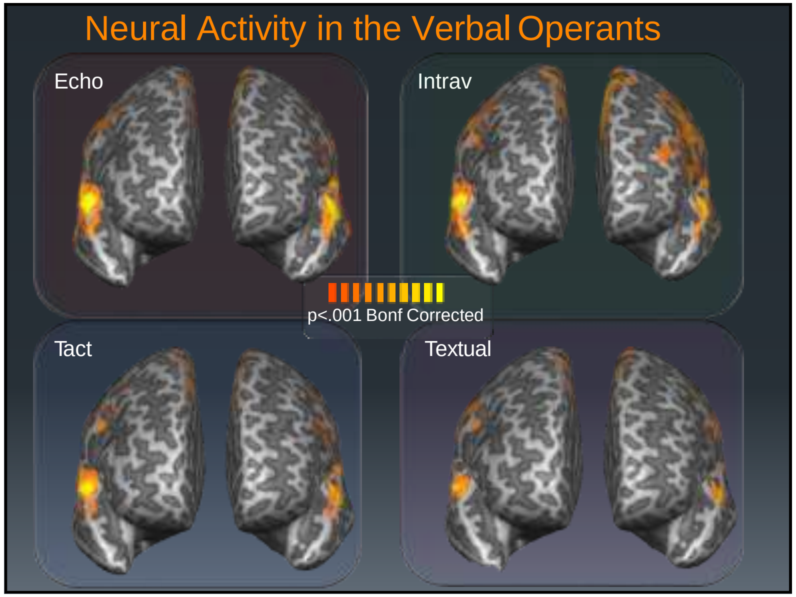

Neural Activity in the different Operants
Echo
Intraverbal
p<.001 Bonf Corrected
Tact
Textual


Neural Activity in the different Operants
Echo
Intraverbal
p<.001 Bonf Corrected
Tact
Textual

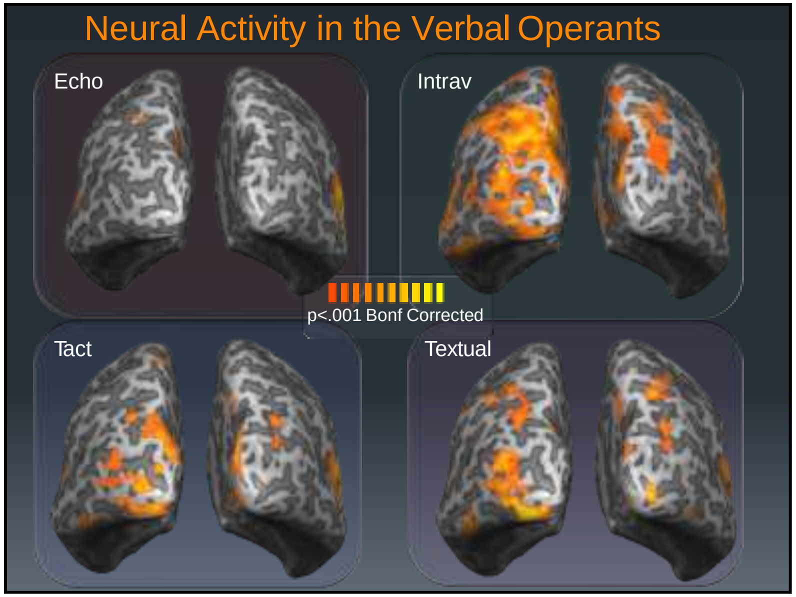

Neural Activity in the Verbal Operants
Echo
Intraverbal
p<.001 Bonf Corrected
Tact
Textual

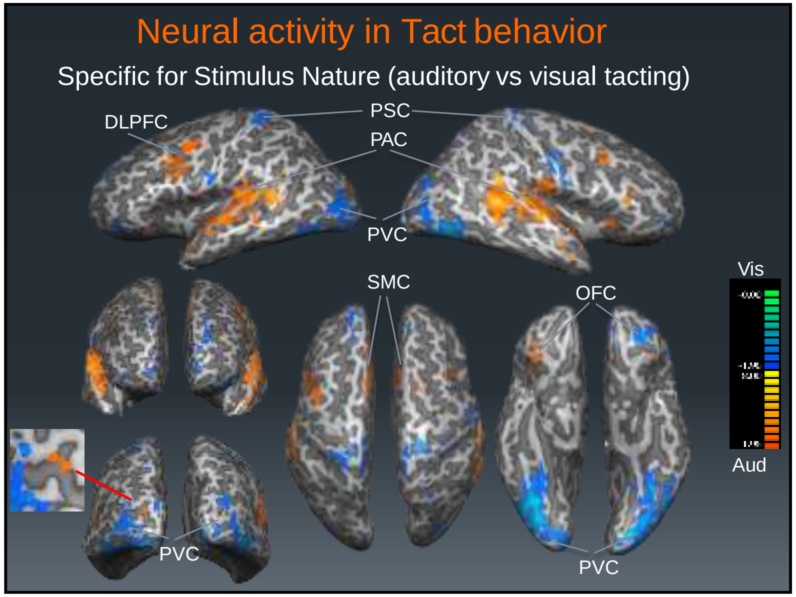


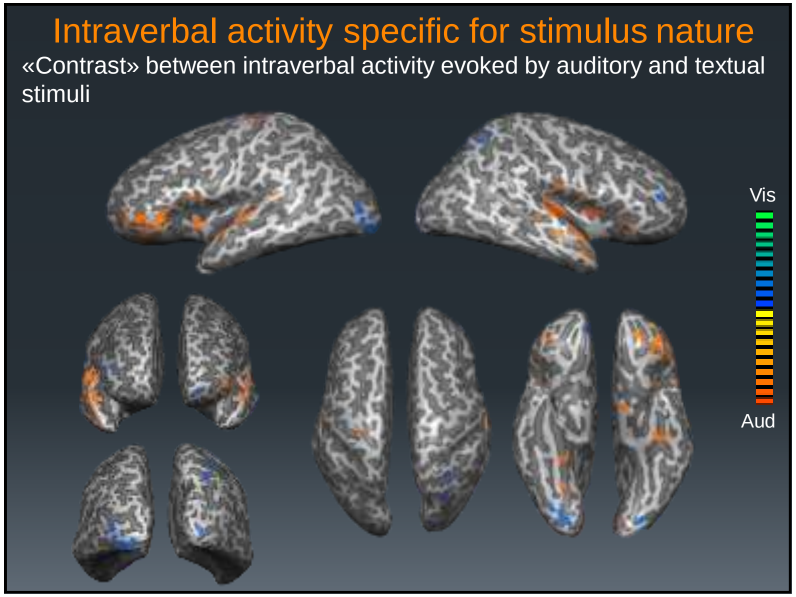
Neural Activity in the Verbal Operants
Echo
Intraverbal
p<.001 Bonf Corrected
Tact
Textual

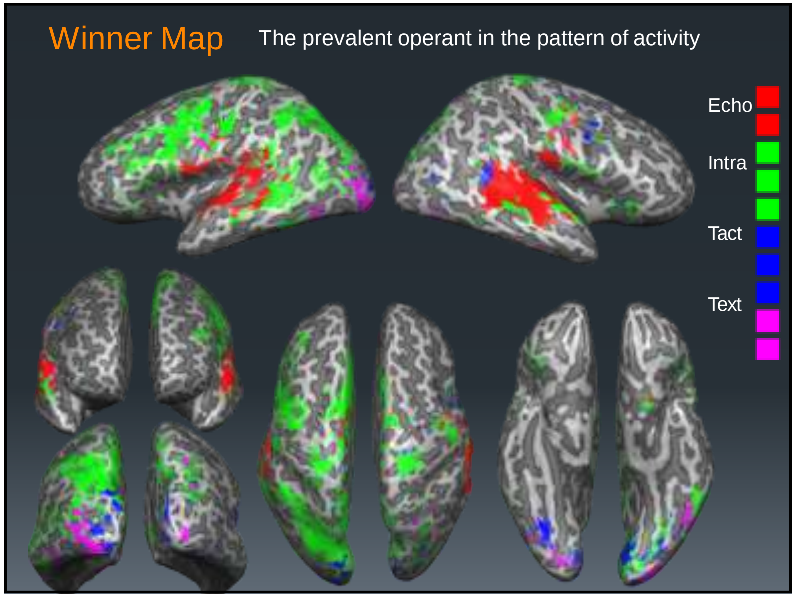


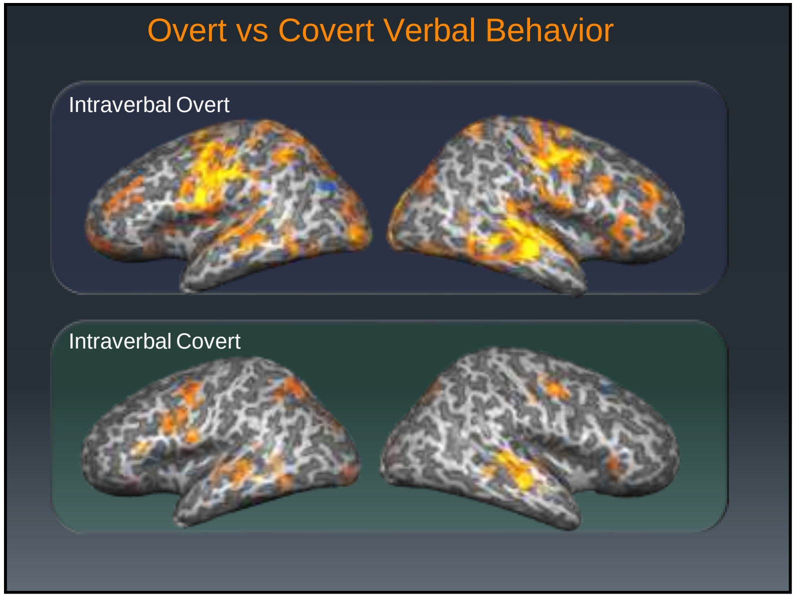
Neural Activity in the Verbal Operants
Echo
Intrav
p<.001 Bonf Corrected
Tact
Textual

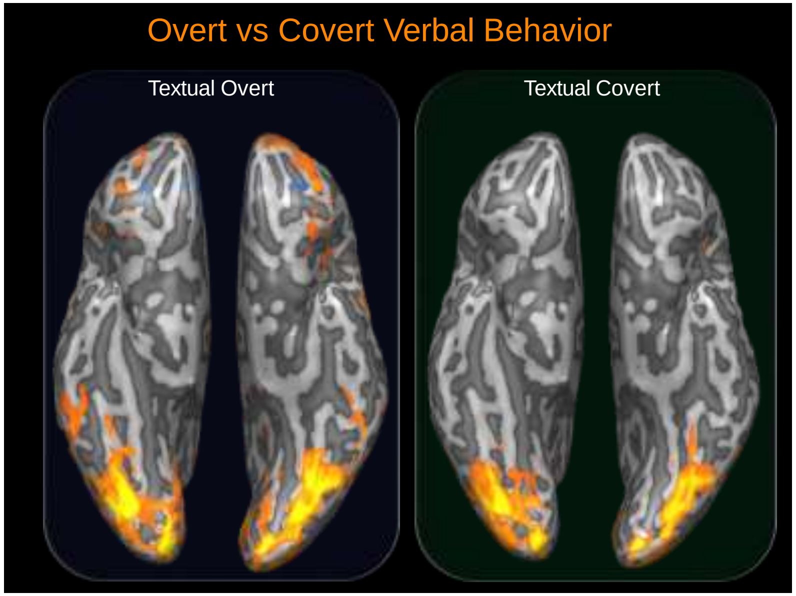

Neural Activity in the Verbal Operants
Echo
Intrav
p<.001 Bonf Corrected
Tact
Textual


Neural activity in Tact behavior
Specific for Stimulus Nature (auditory vs visual tacting)
DLPFC
PSC
PAC
PVC
SMC
OFC
Vis
Aud
PVC
PVC


Intraverbal activity specific for stimulus nature
«Contrast» between intraverbal activity evoked by auditory and textual stimuli
Vis
Aud


Winner Map
The prevalent operant in the pattern of activity
Echo
Intra
Tact
Text


Overt vs Covert Verbal Behavior
Intraverbal Overt
Intraverbal Covert


Overt vs Covert Verbal Behavior
Textual Overt
Textual Covert

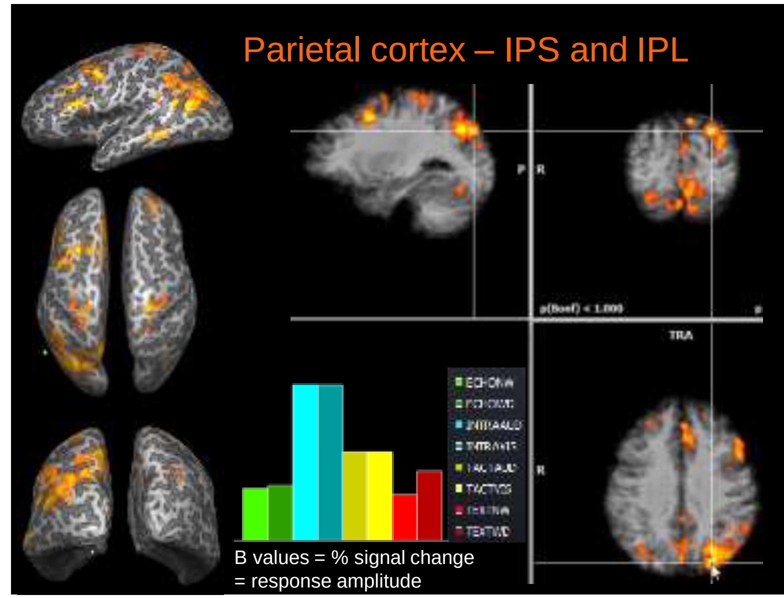
The Verbal Operants experiment
Conclusions

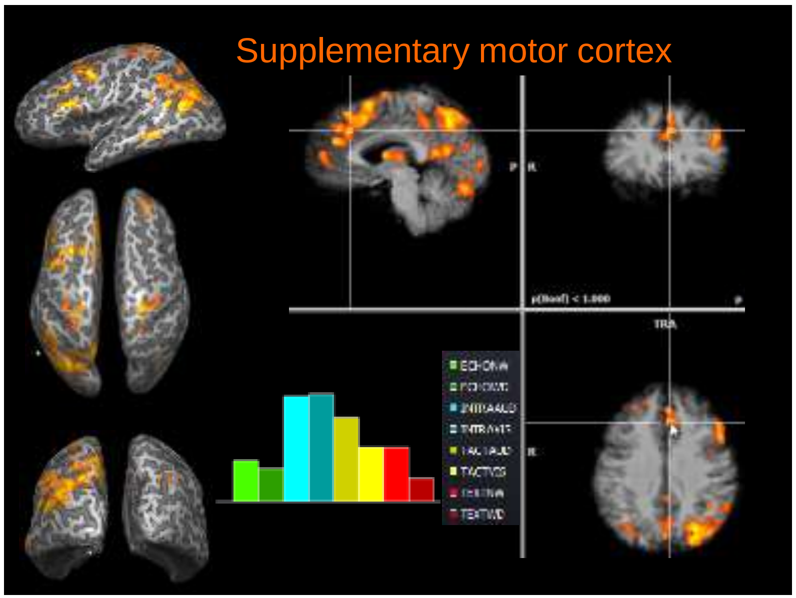
a) The single Verbal Operants are associated each to a peculiar pattern of brain activity. It is possible to recognize what operant a subject is emitting just from her/his brain activity pattern.
b) From a neurobiological perspective, the peculiarity imply the presence of specific neural activities distinctive of the different operants (Independence of Verbal Operants)
c) The Echoic operant has the simplest pattern of activity, encompassing mainly the temporal lobe (Auditory) regions
d) The Intraverbal operant shows by far the most complex pattern of activity, that includes massively parietal lobe regions, highly active in visual imagery, with implication for teaching Ivs

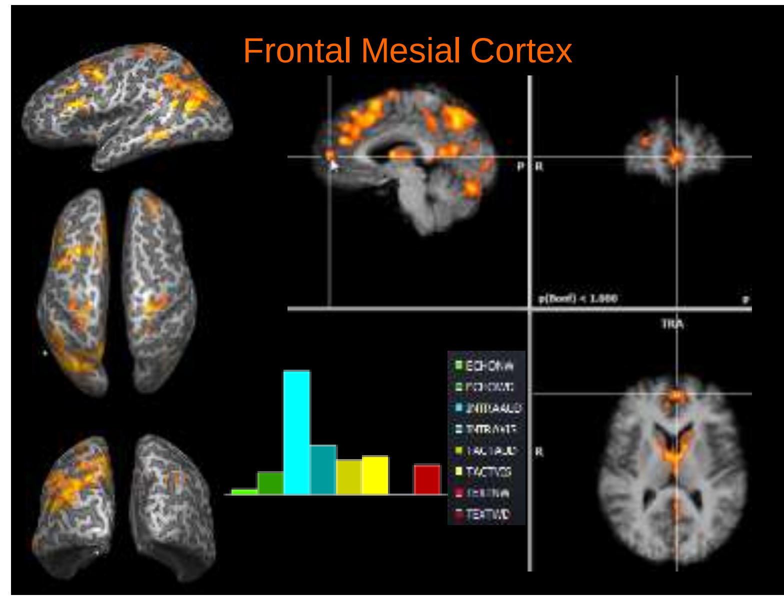
The Verbal Operants experiment
Conclusions

e) The Iv activity in the Occipital lobe is similar to the Tact-related activity
f) Both Tact-related and Textual-related activities use massively the visual regions, but differ in the Primary Visual Cortex, in the Occipital Pole, and in the Ventral Stream
g) A common substrate of neural activity, though, is present in all Verbal Operants, e.g. in the auditory cortex and the supplementary motor region. The similarities possibly represent the neural basis for Stimulus Control transfer procedures

Neural Activity related to different Verbal Operants in single brain areas




Supplementary motor cortex
TRA

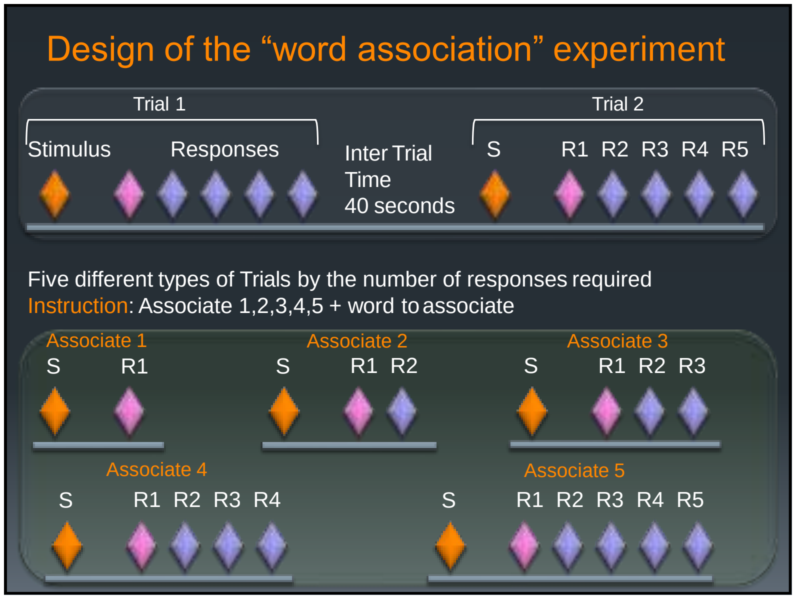

Frontal Mesial Cortex
TRA

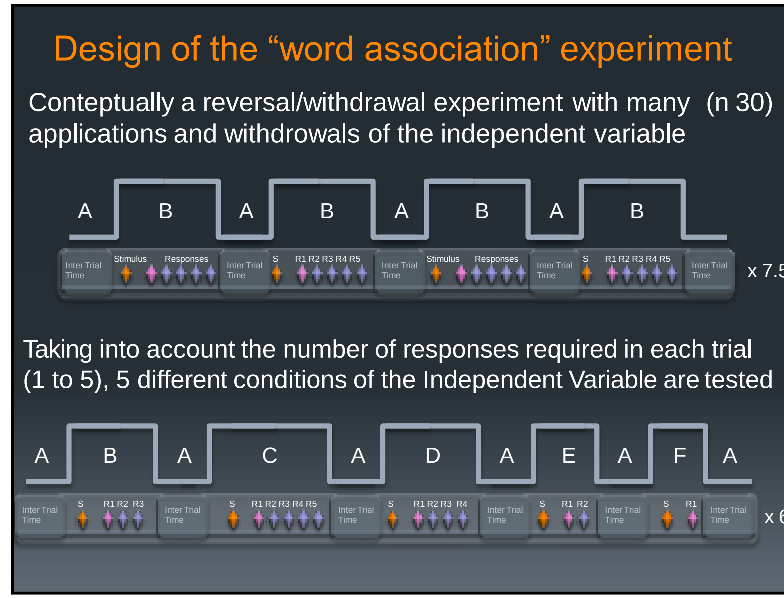
The Intraverbal Behavior time-course in the brain

The "word association" experiment analysed by the source of control of the associations

The "word association" experiment

- A word association in response to a verbal antecedent is Intraverbal Behavior (Skinner, Verbal Behavior p.72)
- The source of control in a word association experiment is never only in the verbal antecedent
- The word association experiment has been reproduced in an fMRI environment in order to:
  a) single out the brain area(s) were the behavior is emitted
  b) analyze the source of control
  c) identify the chain of behaviors that leads to the final behavior


Design of the "word association" experiment
Trial 1
Stimulus
Responses
Inter Trial Time 40 seconds
Trial 2
S
R1 R2 R3 R4 R5
Five different types of Trials by the number of responses required
Instruction: Associate 1,2,3,4,5 + word to associate
Associate 1
S R1
Associate 2
S R1 R2
Associate 3
S R1 R2 R3
Associate 4
S R1 R2 R3 R4
Associate 5
S R1 R2 R3 R4 R5


Design of the "word association" experiment
Conteptually a reversal/withdrawal experiment with many (n 30) applications and withdrowals of the independent variable
A B A B A B A B
x 7.5
Taking into account the number of responses required in each trial (1 to 5), 5 different conditions of the Independent Variable are tested
A B A C A D A E A F A
x 6

The “word association” experiment

Movie

Sources of control identified “post hoc” from the responses

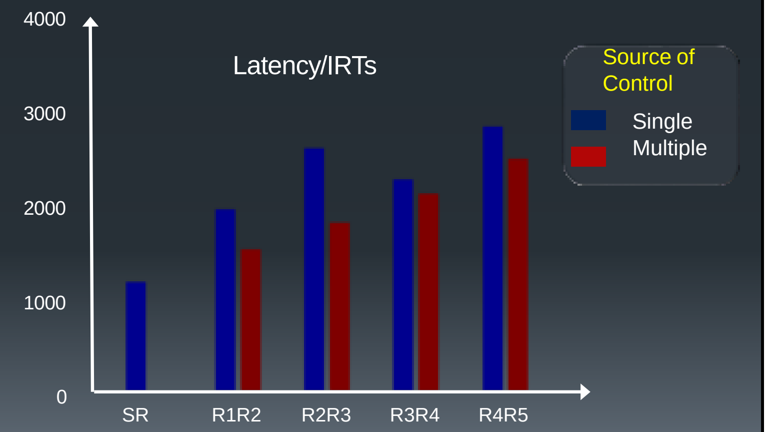
1. The initial Stimulus
2. The other words emitted previously in the same trial

The single trials are spaced enough in time (40 seconds) to reduce their strength as sources of control for the responces of the following trials

Categorization of the Responses by their source of control

1. The first word is controlled mainly by the initial stimulus and is categorized as “S” (stimulus)
2. The following words can be controlled (mainly) by the initial stimulus, if no clear association can be derived “post hoc” with the words emitted previously. These responses are also categorized as “S” (stimulus)
3. The following words can be controlled (also) by the other words emitted previously. These responses are categorized as “M” (multiple)
4. Each word can be controlled solely by the immediately preceding one. These are named “R” (response)

Categorization of the Responses by their source of control



Categorization of the Trials by the source of control of their single responses

A trial-level analysis has been performed to comply with the difficulty of a response-level analysis

- Trials are cathegorized as "S" if they contain only Responses type S (mainly controlled by the initial stimulus)
- Trials are cathegorized as "SM" if they contain one or more Responses type S (except R1) and one or more Responses type M (partly controlled by previous Responses)
- Trials are cathegorized as "M" if they contain only Responses type M and no Responses type S (except R1)

Categorization of the Trials by the source of control of their single responses

Examples

Trials type S

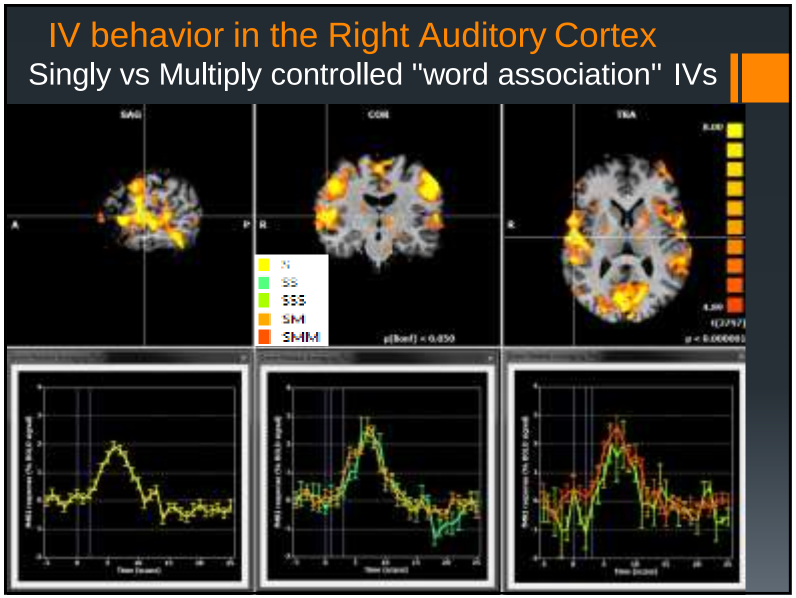
S	RS	RS	RS	RS
Close	**Door**	**Pack**	**Situation**	**Book**

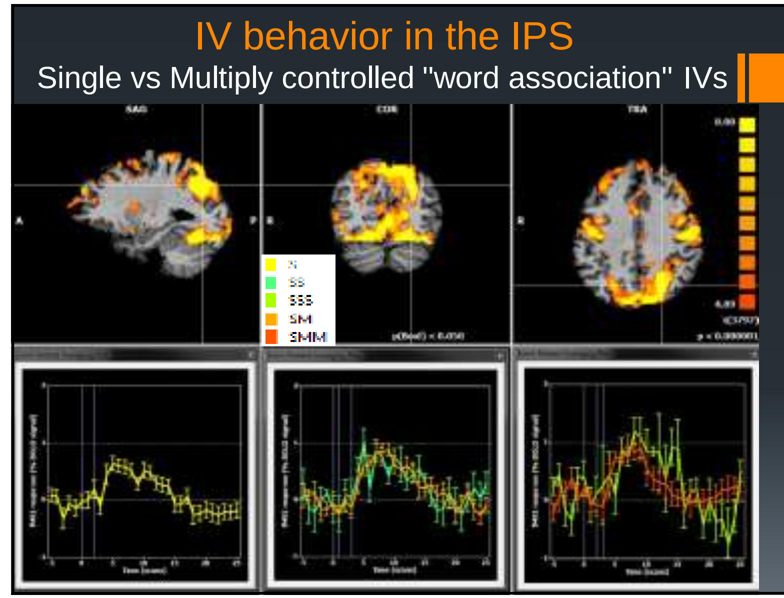
Trials type SM

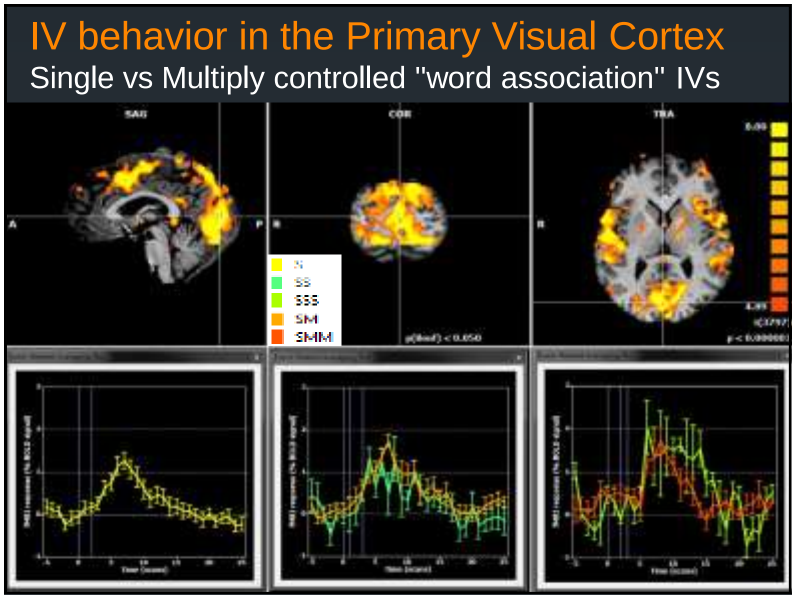
S	RS	RM	RM	RS	RM
Past	**Far**	**Girls**	**Friends**	**Future**	**Present**

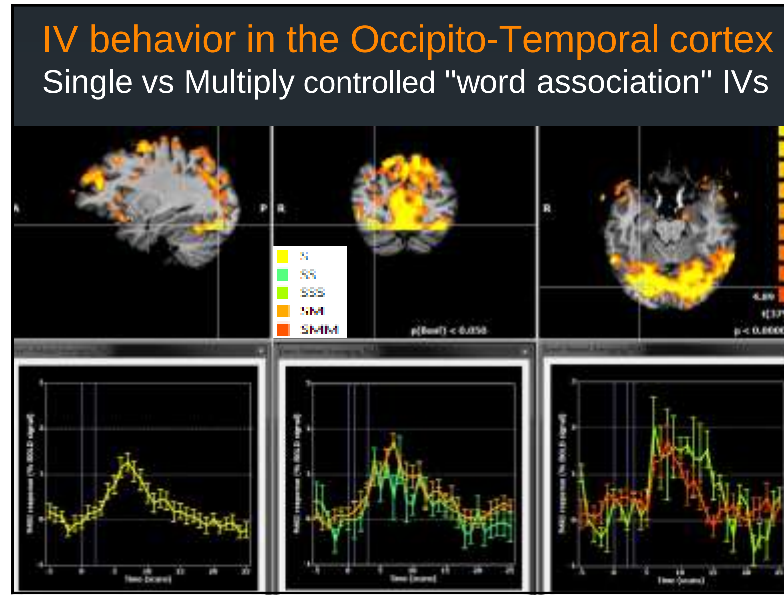
Trials type M

S	RS	RM	RM	RM	RM
Referee	**Match**	**Ball**	**Player**	**Goalkeeper**	**Goal**


IV behavior in the Right Auditory Cortex
Singly vs Multiply controlled "word association" IVs
S
SS
SSS
SM
SMM

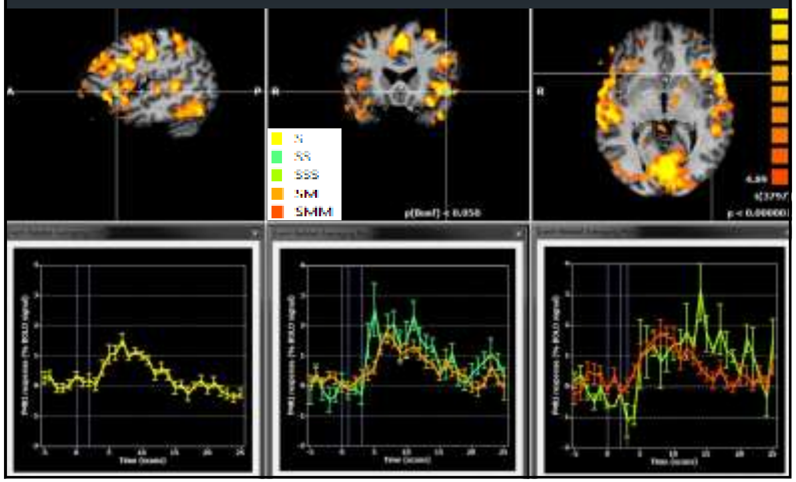

IV behavior in the IPS
Single vs Multiply controlled "word association" IVs
S
SS
SSS
SM
SMM


IV behavior in the Primary Visual Cortex
Single vs Multiply controlled "word association" IVs
S
SS
SSS
SM
SMM


IV behavior in the Occipito-Temporal cortex
Single vs Multiply controlled "word association" IVs
S
SS
SSS
SM
SMM

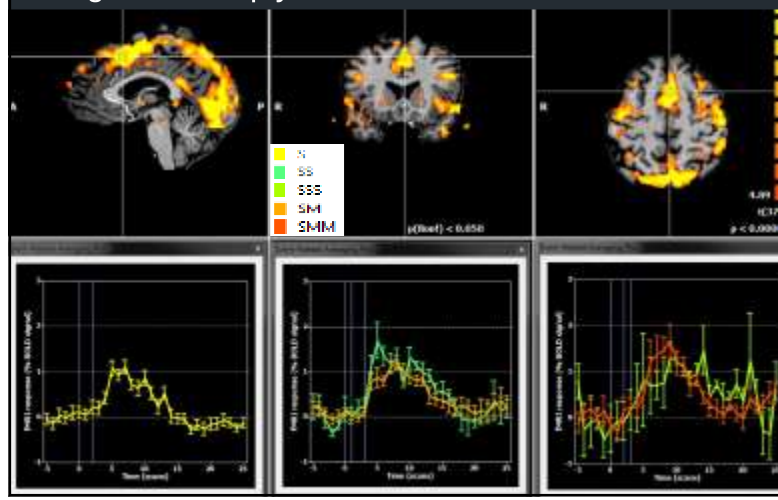
IV behavior in the Left Inferior Frontal

Single vs Multiply controlled "word association" IVs



IV behavior in the SMA

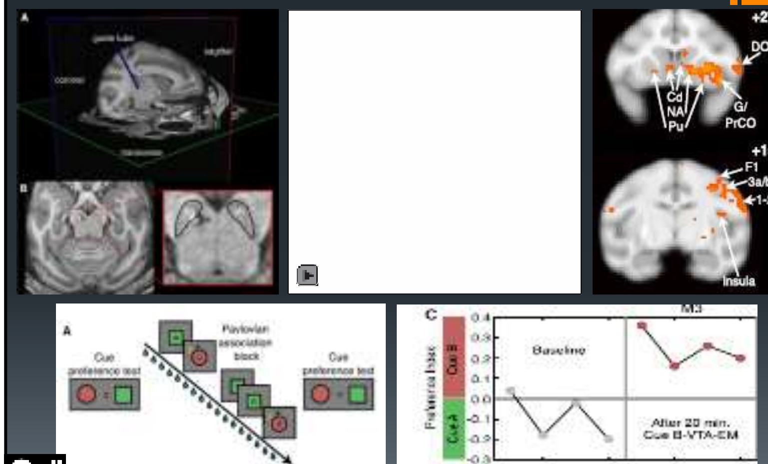
Single vs Multiply controlled "word association" IVs



Outline

- Skinner, Behaviorism and the Neurosciences
- NeuroBehavioral literature in Behavioral Journals
- Advantages of NeuroBehavioral integration
- Private events made public and possible to modify
- Procedures to study the behavior in the brain
- Translating Neuroscience into Behaviorism through Neuroimaging
- Behavioral measures of brain activity
- The verbal operants in the brain
- Methods to modify the behavior in the brain
- The Crossword experiment in Tact and Intraverbals
- Neurofeedback of Intraverbals

The Primate Ventral Tegmental Area in Reinforcement and Motivation



Arsenault JT, 2014, *Current Biology*

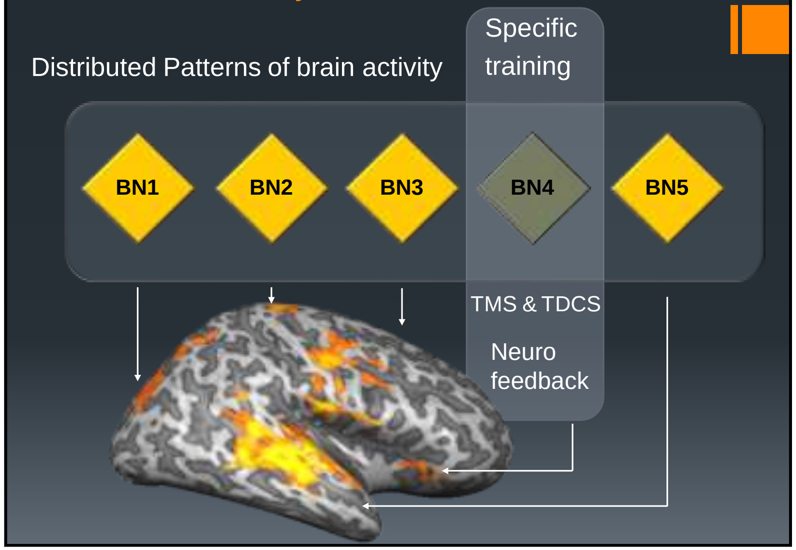
Methods to modify behaviors in the brain

The focus of many discussions with friends Behavior Analysists has often been the possible application of knowing more about Behavior in the brain.

Beside the potential deriving from an expanded knowledge itself, which can be of substantial value, we can examine 4 possible ways to modify brain functioning directly with neuroscience derived methods, in a convergent action with Applied Behavior Analysis procedures:

a) Specific training
b) Neurofeedback
c) TDCS (Transcranial Direct Current Stimulation
d) TMS (Transcranial Magnetic Stimulation)

Methods to modify behaviors in the brain



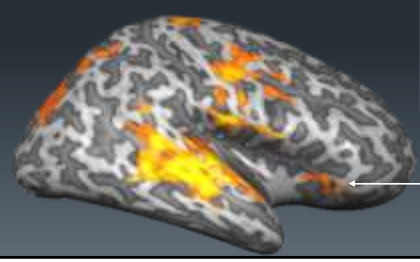
Methods to modify behaviors in the brain

Specific training

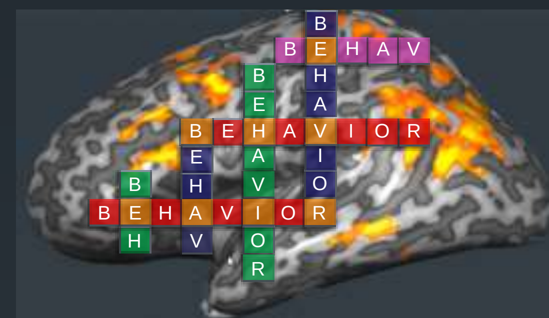
Design Interventions that provide independent training of BN4 outside the behavioral chain

Return to teaching the chain when measures of BN4 are substantially higher

BN4



The Crossword Strategy



- Different behaviors are differentiated in the brain by their pattern of activity
- Neural patterns of different behaviors can cross in several brain areas.
- Training the common nodes in one behavior can result in the improvement (upregulation) of another behavior

Piano playing and Typing

Pianists play their instruments as fast as experienced typists on a QWERTY keyboard

Anna Maria Feit, Antti Oulasvirta
Max Planck Institute for Informatics, Saarbrücken

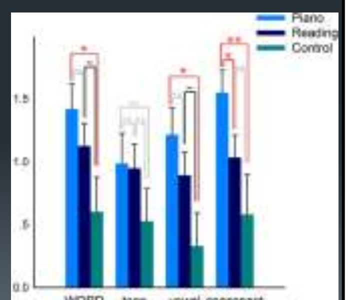
Neural pathways of playing piano and typing

Music and Language

Piano training enhances the neural processing of pitch and improves speech perception in Mandarin-speaking children

Yun Nan, PNAS 2018

Music and language share many aspects of sensory, motor, and cognitive processing of sound. The shared acoustic features of music and speech sound are the likely basis of the cross-domain transfer effects of musical training. Musical training confers advantages in speech-sound processing, which could play an important role in early childhood education



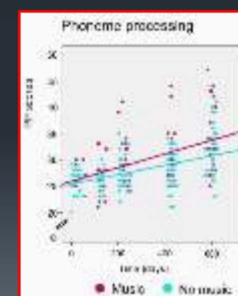
Music and Language

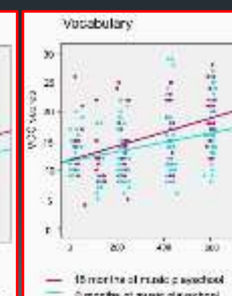
Music playschool enhances children's linguistic skills

Linnavalli T., Sci Rep 2018

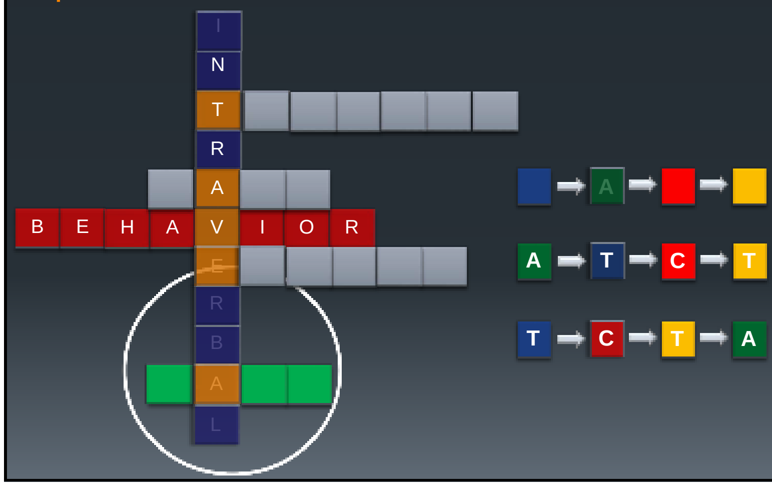
Musicians outperform non-musicians in:

- syllable discrimination
- detecting speech in noise
- verbal memory
- detection of prosody
- reading skills
- Vocabulary
- foreign language sound acquisition





The Crossword Strategy and the Verbal Operants



Intraverbal training (Carbone, NAC 2018)

Sequence of Methods for teaching Intraverbal Behavior

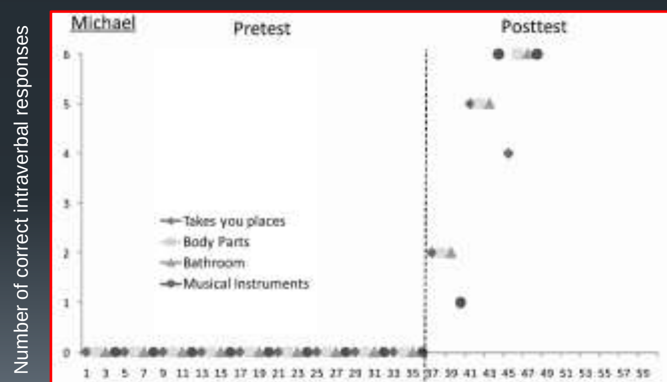
I. Teach early intraverbal discriminations through fill-ins, songs, nursery rhymes and associations.
II. Teach many tact-to-intraverbal responses
III. Emphasize the development of convergent and divergent multiple stimulus control by forming stimulus and response classes. A webbing procedure can be helpful in developing flexibility and avoiding rote responding
IV. Teach verbal conditional discriminations to overcome rote responding
V. Use various teaching methods to increase verbal conditional discrimination responses and novel responding.
VI. Teach problem solving to increase intraverbal control

Intraverbal training

Grannan L and Rehfeldt RA JABA 2012

Emergent Intraverbal Responses via Tact and MTS Instruction

Acquisition of Intraverbal listing after Simple and Category Tact and Category MTS training



Intraverbal training

Emergent Intraverbal Responses via Tact and Match-to-Sample Instruction Leigh Grannan L and Rehfeldt RA, JABA 2012

Effectiveness of category tact and match-to-sample instruction in facilitating the emergence of untaught intraverbal category responses without direct instruction

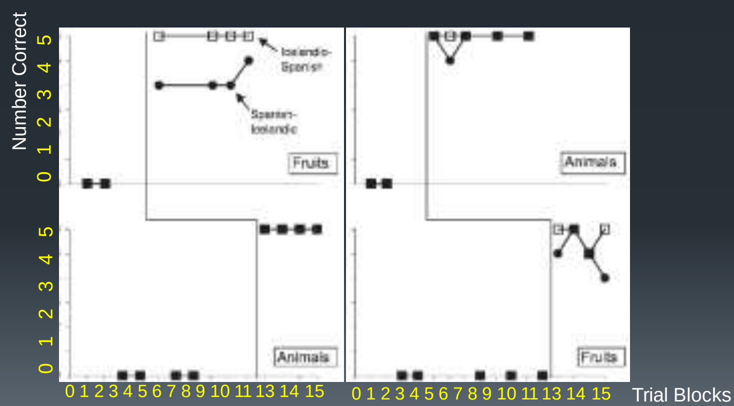
The results lend support to the teaching of tacting and categorization skills to facilitate emergent intraverbals (Miguel & Petursdottir, 2009) and have implications for an approach to teaching children with autism.

This approach stands in contrast to instructional approaches that use transfer-of-stimulus-control procedures to establish intraverbal responses (Goldsmith et al., 2007; Luciano, 1986).

The Effects of Tact and Listener Training on the Emergence of Bidirectional Intraverbal Relations

Petursdottir IA, JABA 2013

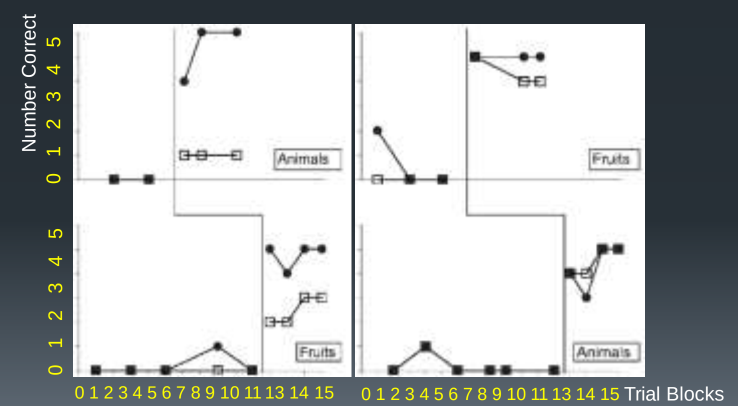
Tact Training



The Effects of Tact and Listener Training on the Emergence of Bidirectional Intraverbal Relations

Petursdottir IA, JABA 2013

Listener Training



The Effects of Tact and Listener Training on the Emergence of Bidirectional Intraverbal Relations

Petursdottir IA, JABA 2013

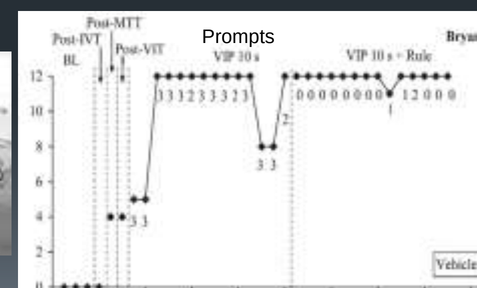
Students may derive novel intraverbal relations from the reinforcement of other relations

3 studies examined, Miguel, 2005; Partington, 1993 evaluated the effects of training multiple tact relations. Miguel additionally trained listener selection as did Petursdottir (2008).

TRAINING VISUAL IMAGINING FOR COMPLEX CATEGORIZATION TASKS

Kisamore AN, JABA 2011

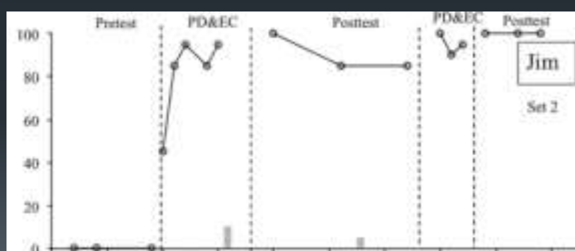
The study Incorporated tact training and the presentation of visual scenes. The participants were prompted to imagine visual scenes to evoke responses learned through a prior history of MTT and intraverbal subcategorization.



TEACHING MULTIPLY CONTROLLED INTRAVERBALS

Kisamore AN, JABA 2016

Effects of Prompt Delay with Error Correction, a differential observing response (DOR), and a DOR plus blocked trials on the acquisition of intraverbals

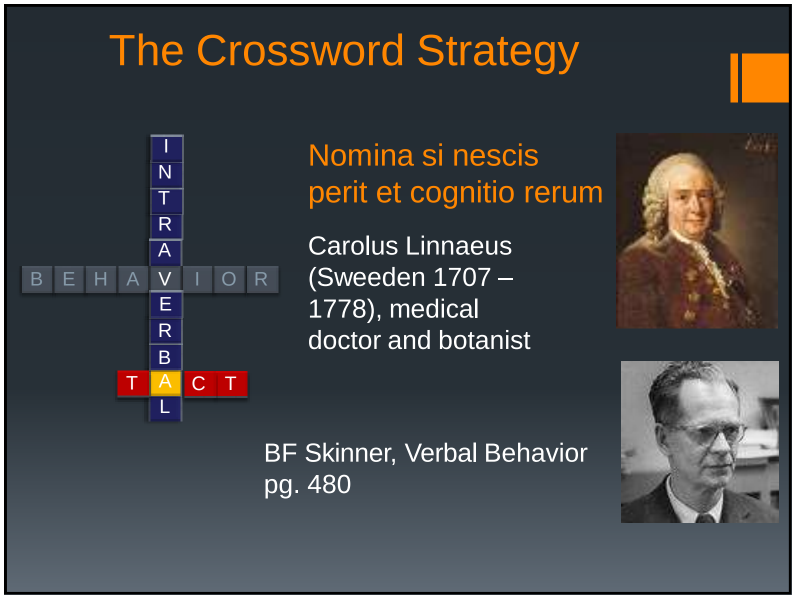


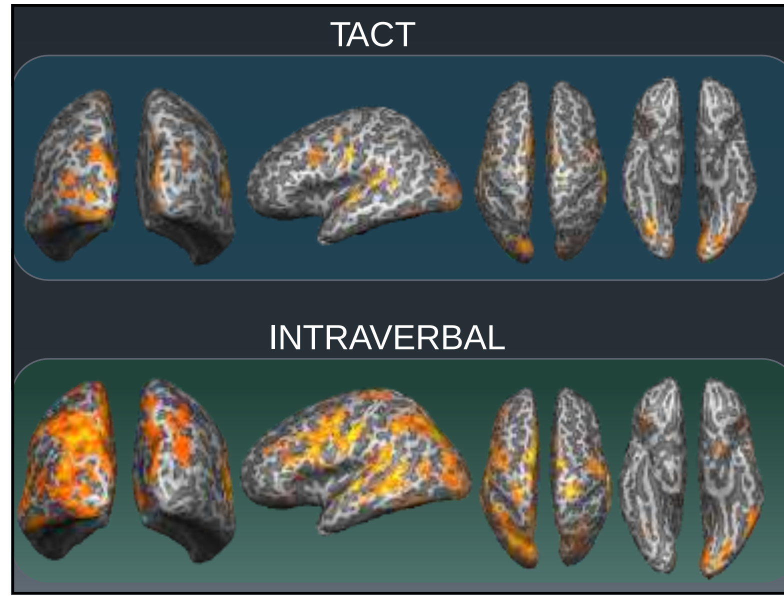
Teaching intraverbals

Transfer of Stimulus Control from other Verbal Operants

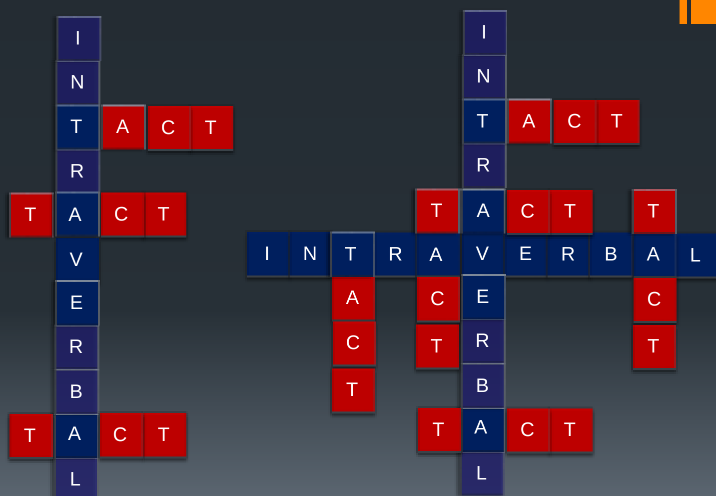
Emergence of untaught IV relations from Tact and Selection

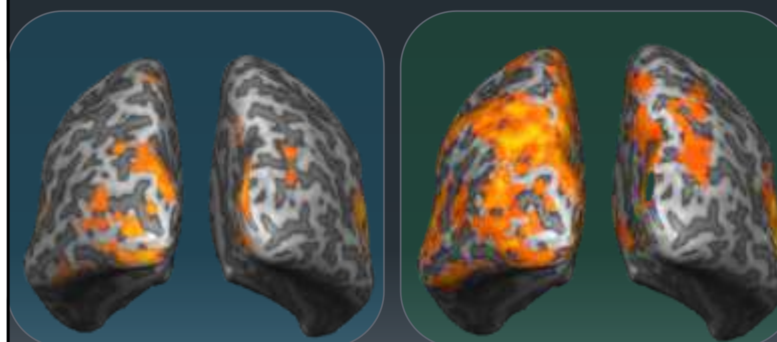
Facilitation of IV responses through the activity-related enhancement of synaptogenesis in nodes of the IV processing pattern: The Crossword Strategy

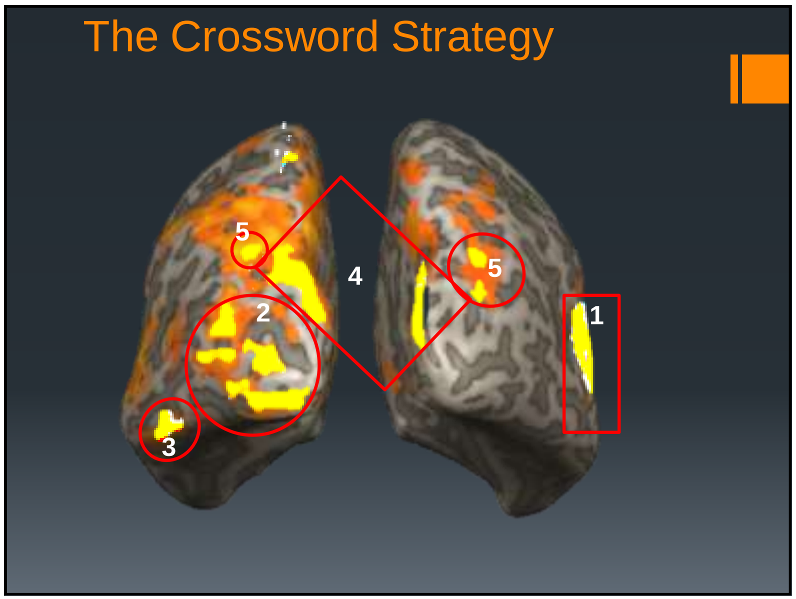

The Crossword Strategy
I N T R A V E R B A L
B E H A V I O R
T A C T
Nomina si nescis
perit et cognitio rerum
Carolus Linnaeus
(Sweeden 1707 –
1778), medical
doctor and botanist
BF Skinner, Verbal Behavior
pg. 480

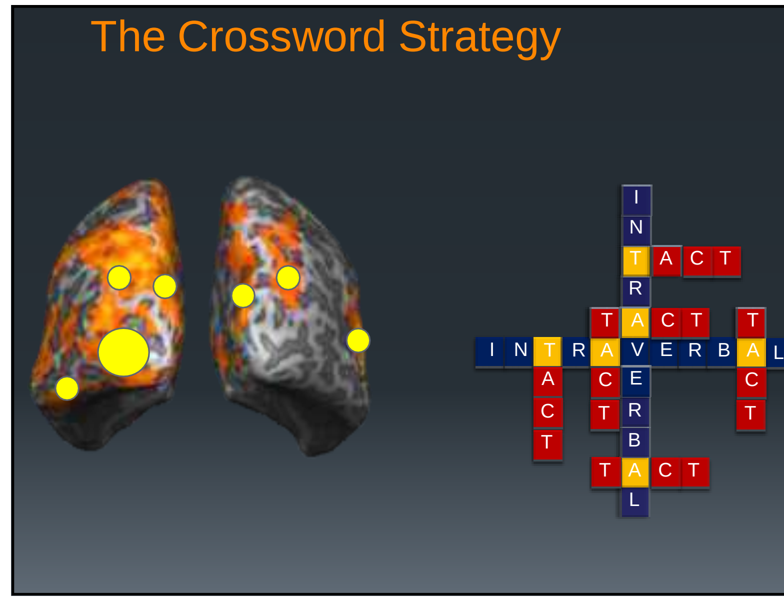

TACT
INTRAVERBAL

The Crossword Strategy

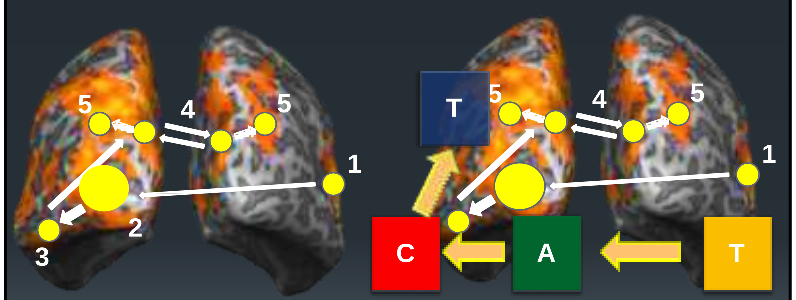





The Crossword Strategy
5
4
5
2
1
3


The Crossword Strategy
I N T R A V E R B A L
T A C T
T A C T
T A C T
T A C T
T A C T
T A C T

The Crossword Strategy



The Crossword experiment: experimental design

AB design in 6 volunteers plus Multiple Baseline across 3 subjects

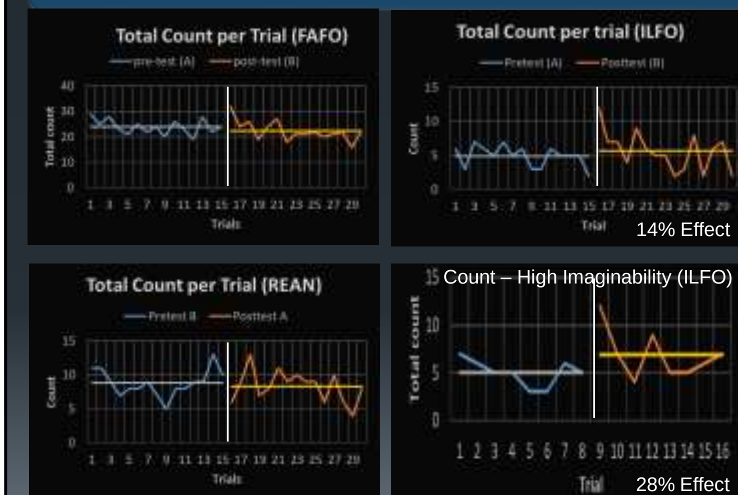
Pre-Test	Treatment	Post-Test
15 stimuli for association (15 trials) 80 sec for free association 5 sec pause in between of two trials	200 tacts (200 trials) 3 sec for tacting 2 sec pause in between of two trials	15 stimuli for association (15 trials) 80 sec for free association 5 sec pause in between of two trials

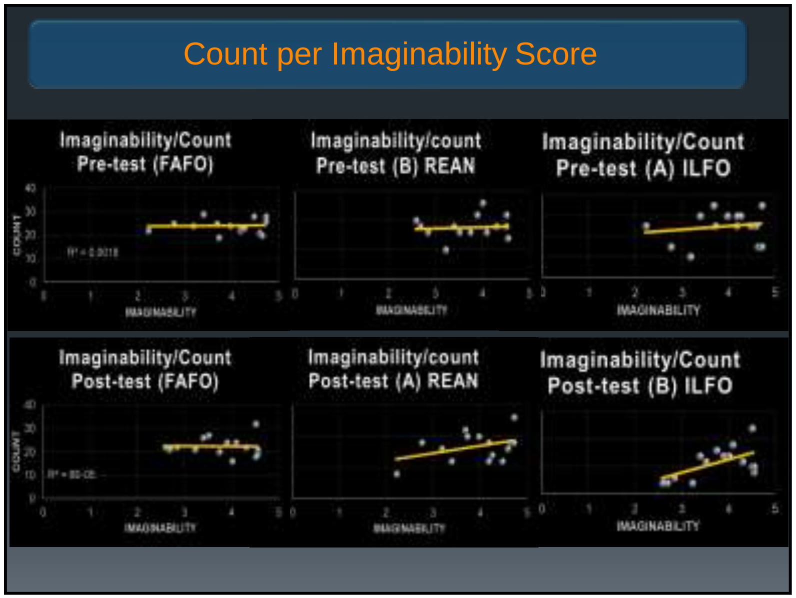
The Crossword experiment: experimental materials

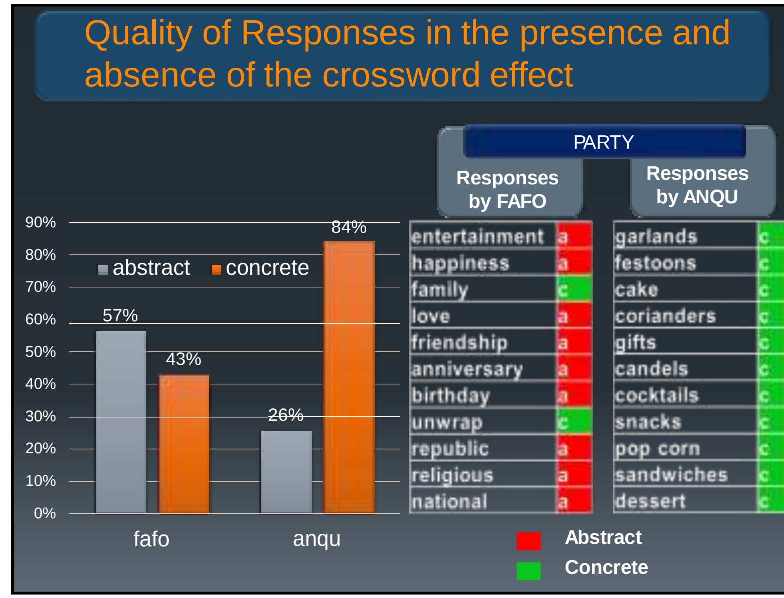
Lists of intraverbals adopted as pre-test and post-test were matched for the following features:

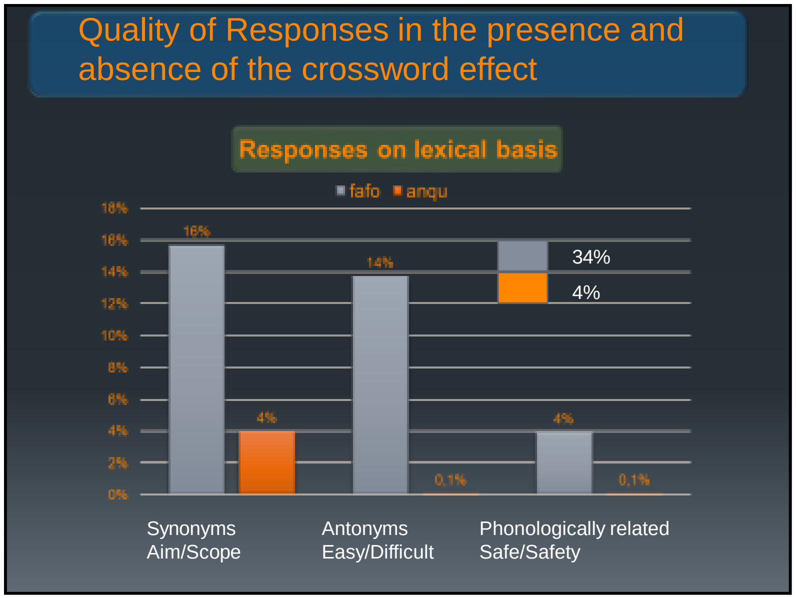
- **Imaginability** (collected by asking to at least 25 participants to rate on a 1 to 5 Likert scale the imaginability of words, namely the easiness to create a mental image for each item)
- **frequency** (collected in corpora of written and spoken Italian language as number of occurrences):
- **Lenght** (calculated in letters and syllables)
- **Phonological counfoundability** (calculated by taking into account the number of phonological neighbors, namely, words which differ from the base word for only one letter, e.g., cane / pane)
- Pre-tests and post-tests were randomized among participants in order to avoid list effects
- Each intraverbal belonged to a specific semantic domain (e.g., food, furniture, sentiments, ecc.), in order to avoid semantic relations among intraverbals and tacts.

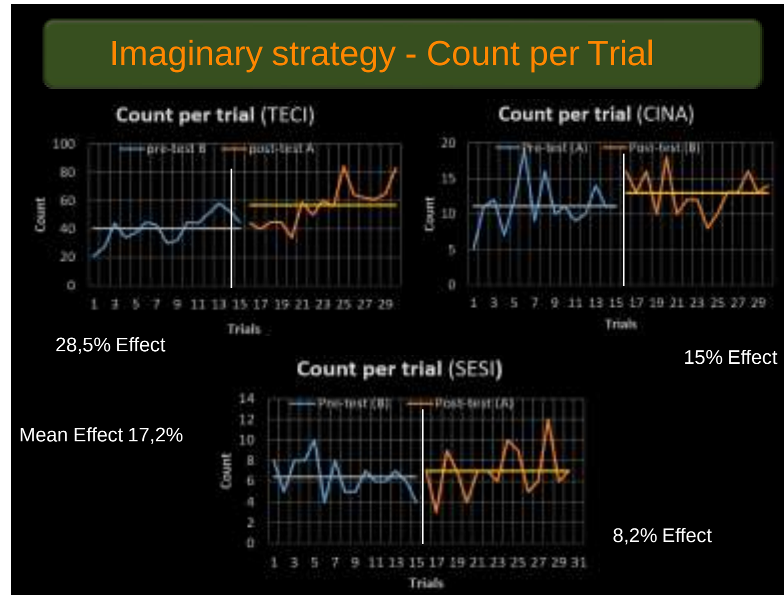
Free Association strategy - Count per Trial

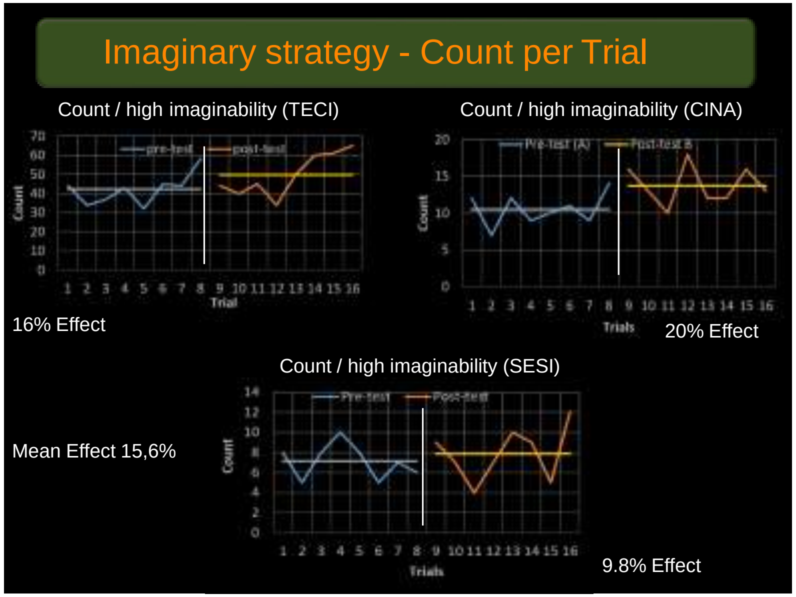


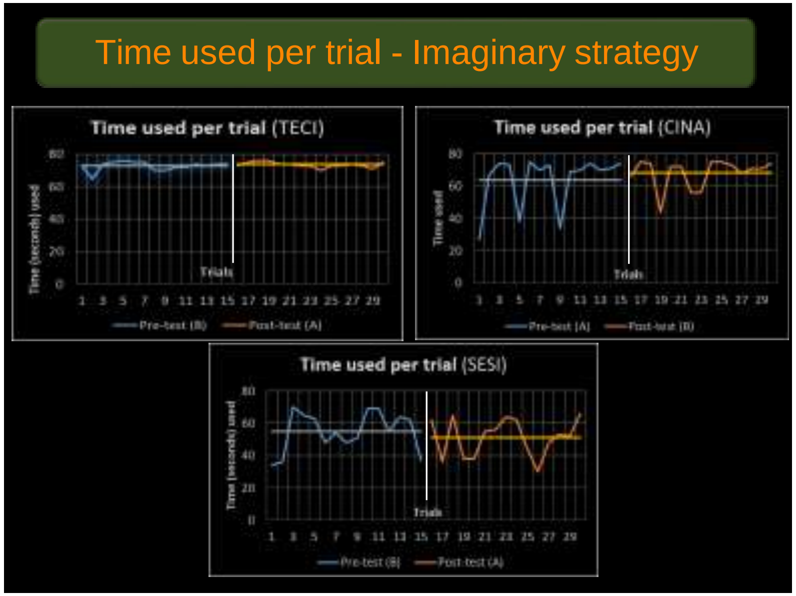

Count per Imaginability Score
Imaginability/Count Pre-test (FAFO)
Imaginability/count Pre-test (B) REAN
Imaginability/Count Pre-test (A) ILFO
Imaginability/Count Post-test (FAFO)
Imaginability/count Post-test (A) REAN
Imaginability/Count Post-test (B) ILFO
IMAGINABILITY
COUNT

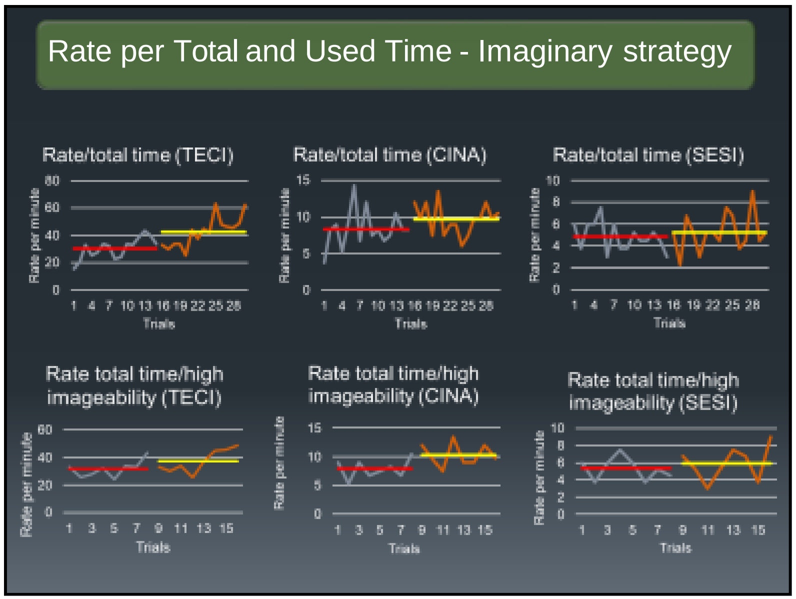

Quality of Responses in the presence and absence of the crossword effect
PARTY
Responses by FAFO
Responses by ANQU
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
abstract
concrete
57%
43%
26%
84%
fafo
anqu
entertainment a
happiness a
family c
love a
friendship a
anniversary a
birthday a
unwrap c
republic a
religious a
national a
garlands c
festoons c
cake c
corianders c
gifts c
candels c
cocktails c
snacks c
pop corn c
sandwiches c
dessert c
Abstract
Concrete

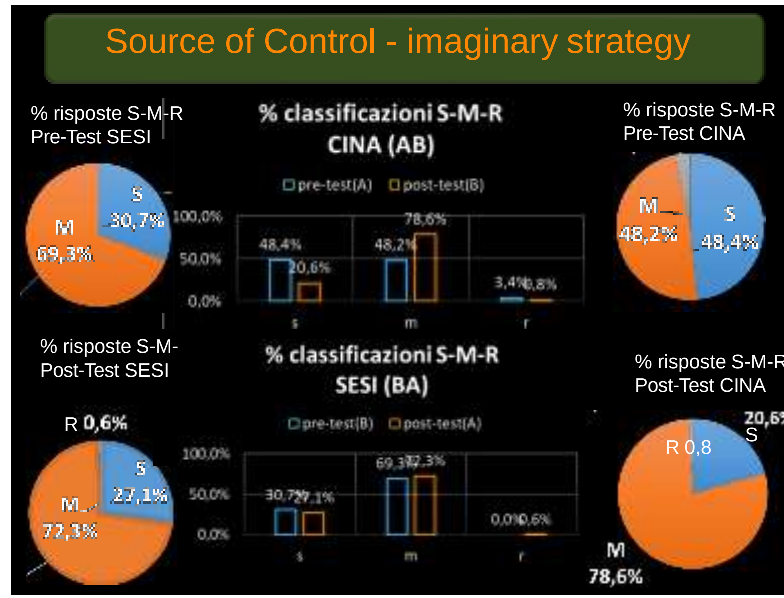

Quality of Responses in the presence and absence of the crossword effect
Responses on lexical basis
fafo
anqu
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
16%
4%
14%
0,1%
4%
0,1%
34%
4%
Synonyms
Aim/Scope
Antonyms
Easy/Difficult
Phonologically related
Safe/Safety

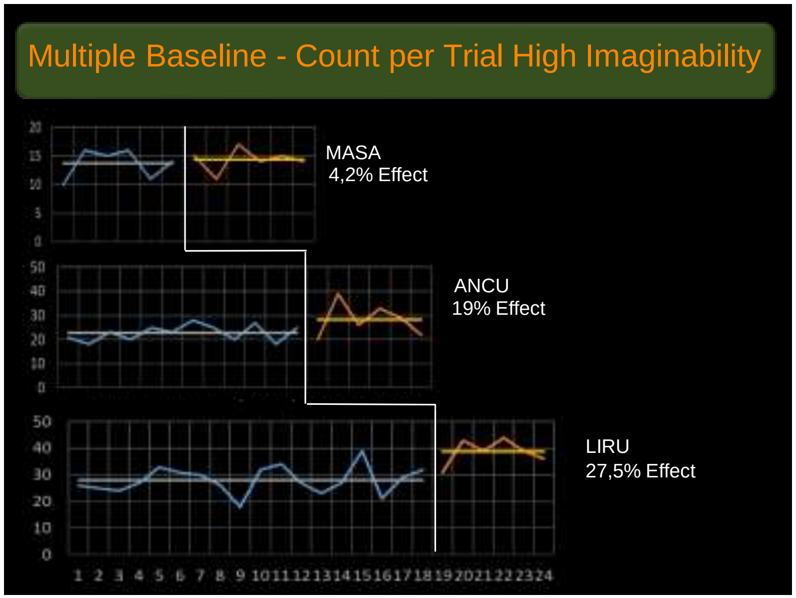

Imaginary strategy - Count per Trial
Count per trial (TECI)
Count per trial (CINA)
Count
Trials
28,5% Effect
15% Effect
Count per trial (SESI)
Mean Effect 17,2%
8,2% Effect

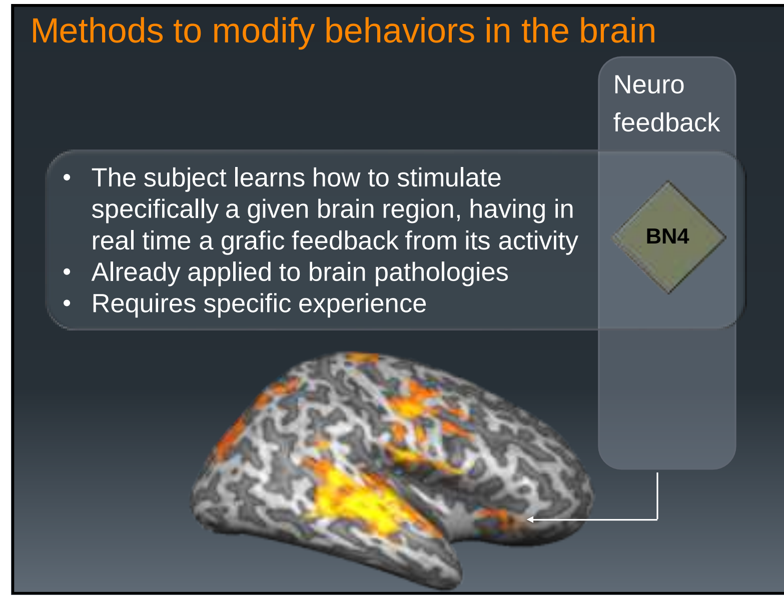

Imaginary strategy - Count per Trial
Count / high imaginability (TECI)
Count / high imaginability (CINA)
16% Effect
20% Effect
Count / high imaginability (SESI)
Mean Effect 15,6%
9.8% Effect


Time used per trial - Imaginary strategy
Time used per trial (TECI)
Time used per trial (CINA)
Time used per trial (SESI)


Rate per Total and Used Time - Imaginary strategy
Rate/total time (TECI)
Rate/total time (CINA)
Rate/total time (SESI)
Rate total time/high imageability (TECI)
Rate total time/high imageability (CINA)
Rate total time/high imageability (SESI)
Rate per minute
Trials


Source of Control - imaginary strategy
% risposte S-M-R Pre-Test SESI
S 30,7%
M 69,3%
% classificazioni S-M-R CINA (AB)
pre-test(A)
post-test(B)
% risposte S-M-R Pre-Test CINA
M 48,2%
S 48,4%
% risposte S-M- Post-Test SESI
R 0,6%
S 27,1%
M 72,3%
% classificazioni S-M-R SESI (BA)
pre-test(B)
post-test(A)
% risposte S-M-R Post-Test CINA
R 0,8
20,6% S
M 78,6%

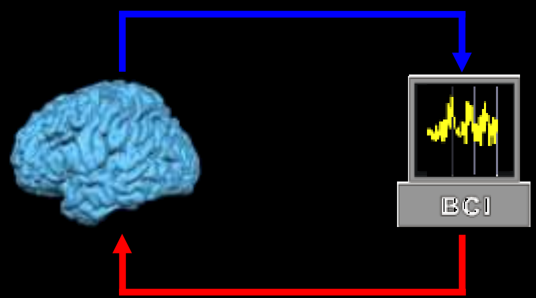

Multiple Baseline - Count per Trial High Imaginability
MASA
4,2% Effect
ANCU
19% Effect
LIRU
27,5% Effect
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Methods to modify behaviors in the brain
Neuro feedback
The subject learns how to stimulate specifically a given brain region, having in real time a grafic feedback from its activity
Already applied to brain pathologies
Requires specific experience
BN4

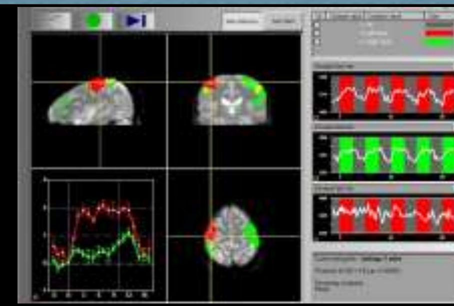
Neurofeedback

Creating a Brain-Computer Interface (BCI)

- Neural activity is transformed into a visible index
- Feedback for learning self-regulation of brain activity



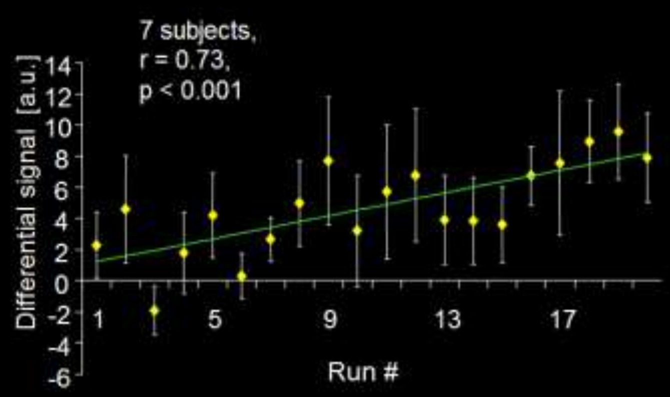
Real-time fMRI neurofeedback



- Real-time fMRI enables monitoring ***online*** changes in the activity of the brain area producing the response.
- The high spatial resolution of fMRI offers the possibility to investigate the control over ***localized*** brain regions.
- Subjects learns to influence their own brain activity from ***one*** or ***multiple*** circumscribed brain regions.

FMRI neurofeedback

Differential modulation – Training effect

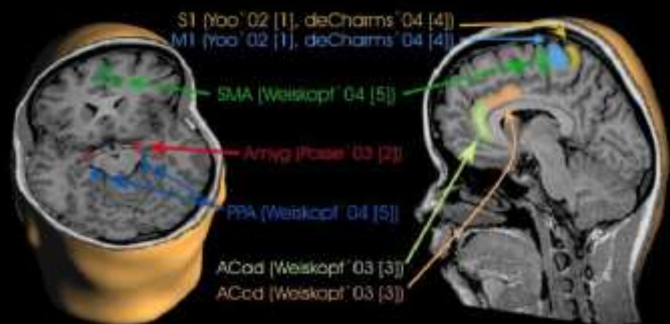


Clinical Implications (on the side of neuroscience)

fMRI Neurofeedback might be an important tool for clinical applications.
It has been, for example, successfully applied to reduce pain perception (DeCharms et al., 2004).

Other clinical applications might be the reduction of auditory hallucinations or the suppression of epileptic seizures or the treatment of phobia.

fMRI neurofeedback studies



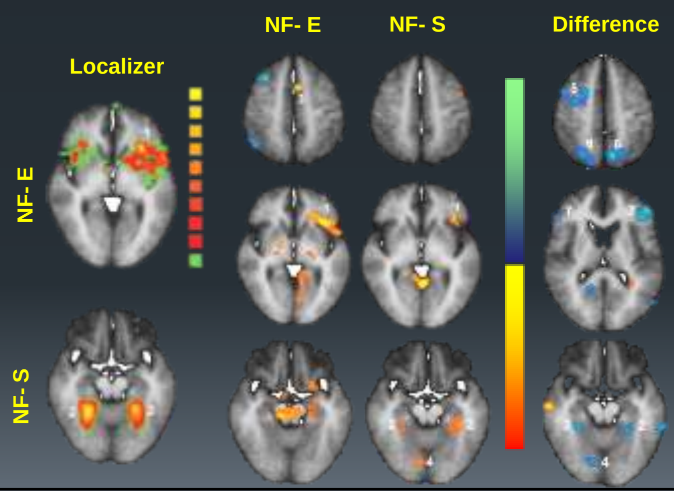
fMRI neurofeedback studies have shown that we are able to modulate different brain areas using several strategies, such as visual or auditory imagery

Targeting the affective brain: Linden, Neuropsychopharm 2018
Real-time fMRI neurofeedback in depression

- Neurofeedback enable subjects to develop personal strategies effective in self-regulating brain areas associated with visual imagery through the feedback of signals that reflect their own neural activation patterns.
- The underlying principle of most neurofeedback protocols is supervised visual imagery training
- With neurofeedback patients' engagement in mental imagery can be enhanced by monitoring and feeding back the associated brain activation.
- Visual imagery can be therapeutic for depression by increasing processing flexibility and capacity for positive imagery production.

Targeting the affective brain: Real-time fMRI neurofeedback in depression

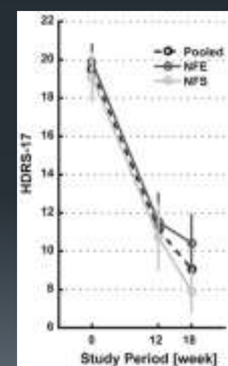
Linden, Neuropsychopharm 2018



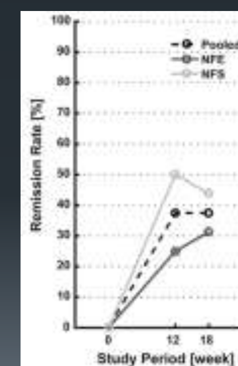
Targeting the affective brain: Real-time fMRI neurofeedback in depression

Linden, Neuropsychopharm 2018

Hamilton Depression Index in NF- E and NF- S



Remission rate % in NF- E and NF- S



Targeting the affective brain: Real-time fMRI neurofeedback in depression

Linden, Neuropsychopharm 2018

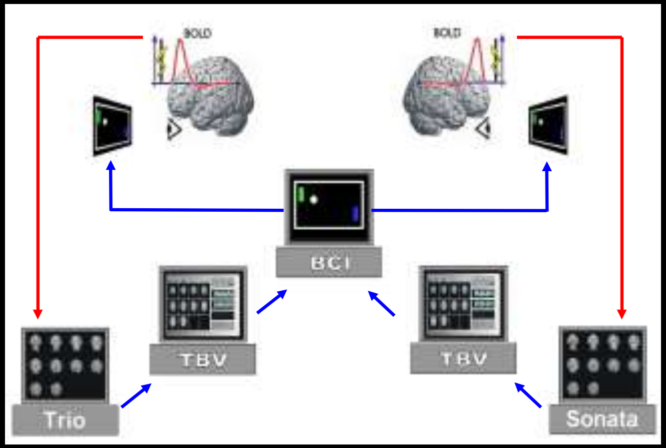
- fMRI neurofeedback training (12 weelk) can reduce depressive symptoms by over 40% (Hamilton Depression Rating Scale (HDRS). The improvements lasted until follow-up (week 18)
- This efficacy is not specific to feedback from emotion-regulating regions.
- Upregulation of emotion areas (NF-E) does not yield superior efficacy compared to upregulation of a control region activated by visual scenes (NF-S).
- Data indicated that the experience itself of successful self-regulation during fMRI-NF training is therapeutic.

Synchro-Scanning and Neurofeedback

Is it possible to couple two brains ?
Can two subjects exchange information based on ongoing fMRI measurements?
How difficult is it to learn to handle the hemodynamic delay?
To what extent does this delay limit brain-brain interactions?
Proof of concept -> BOLD Brain Pong

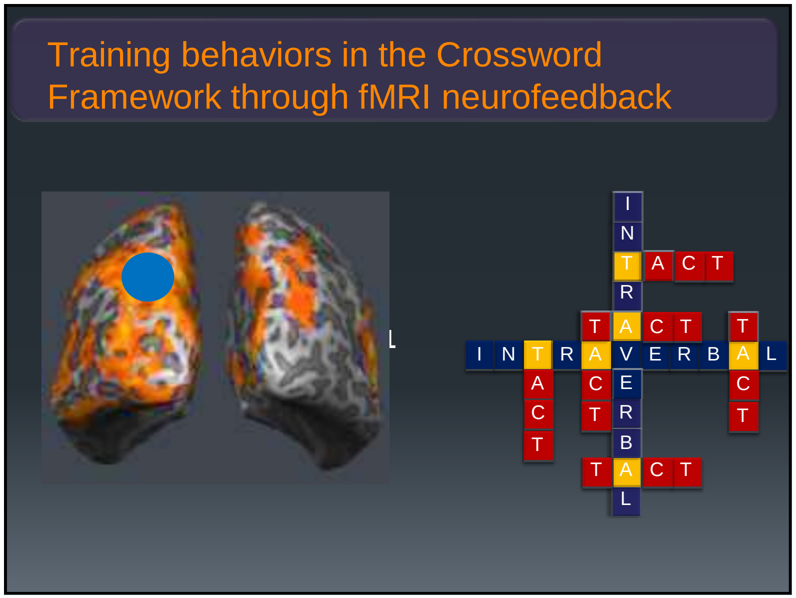
Interactive neurofeedback

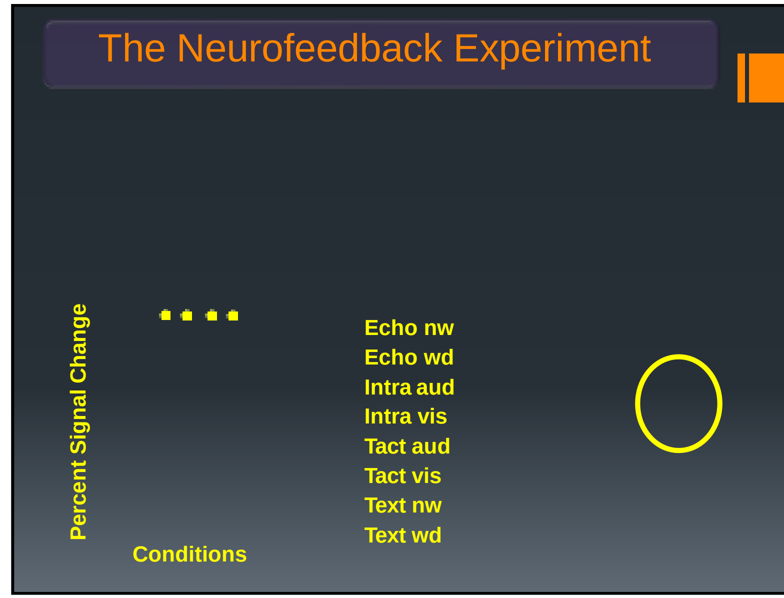
Experimental Setup



Graded Control and Brain Pong

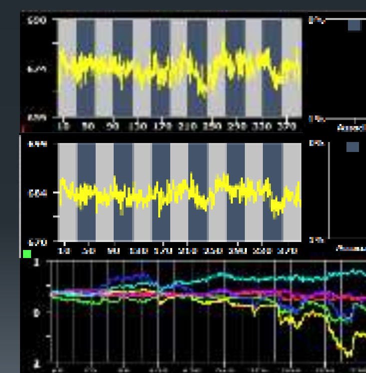
Results – Example game (real-time movie)


Training behaviors in the Crossword Framework through fMRI neurofeedback
I N T R A V E R B A L
T A C T
T A C T
T A C T


The Neurofeedback Experiment
Percent Signal Change
Conditions
Echo nw
Echo wd
Intra aud
Intra vis
Tact aud
Tact vis
Text nw
Text wd

The Neurofeedback Experiment

The Neurofeedback Experiment

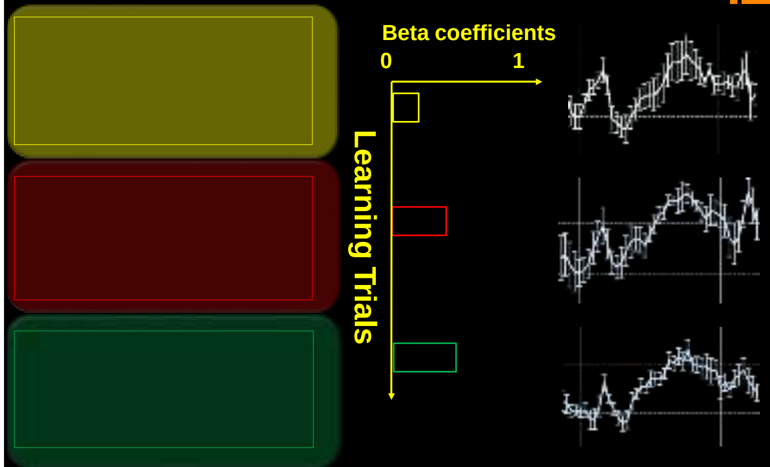


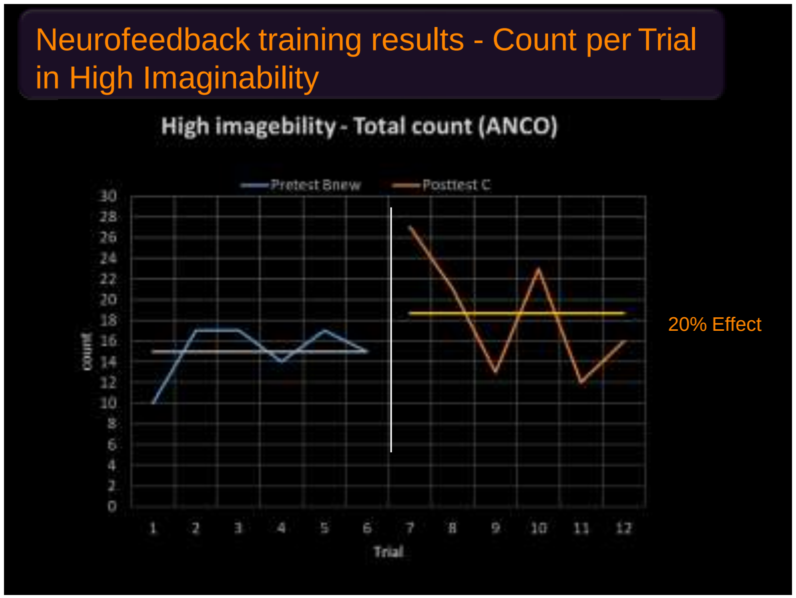
The Neurofeedback Experiment

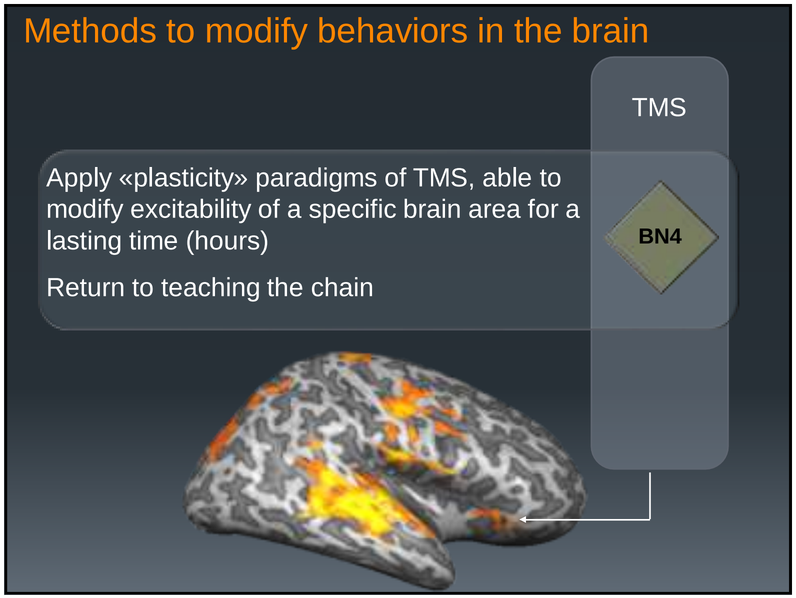
The Neurofeedback Experiment

The Neurofeedback Experiment

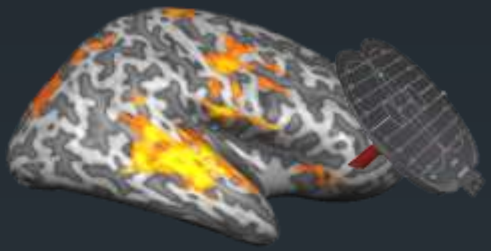
The Neurofeedback Experiment




Neurofeedback training results - Count per Trial in High Imaginability
High imagebility - Total count (ANCO)
Pretest Bnew
Posttest C
count
Trial
20% Effect


Methods to modify behaviors in the brain
TMS
Apply «plasticity» paradigms of TMS, able to modify excitability of a specific brain area for a lasting time (hours)
Return to teaching the chain
BN4

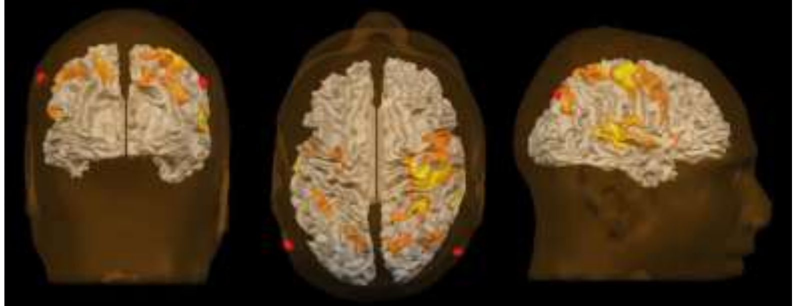
TMS – Transcranial Magnetic Stimulation



Release of brief magnetic pulses, often gathered in pulse trains, able to modify excitability of the specific brain area that is targeted through neuroimaging

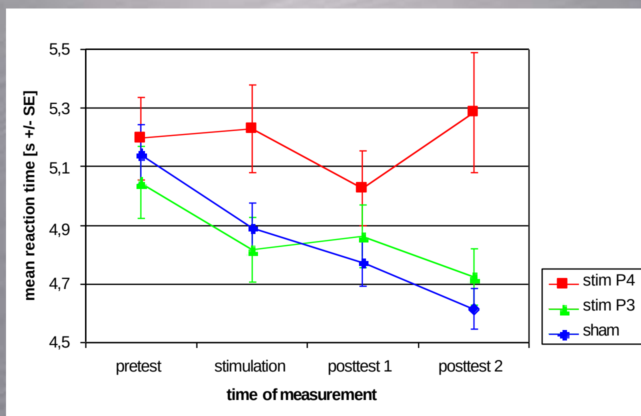
Extensively used since decades to study the conduction of motor information from brain cortex to neuromuscular perifery

Imaginal clock task - *Combined fMRI and rTMS*

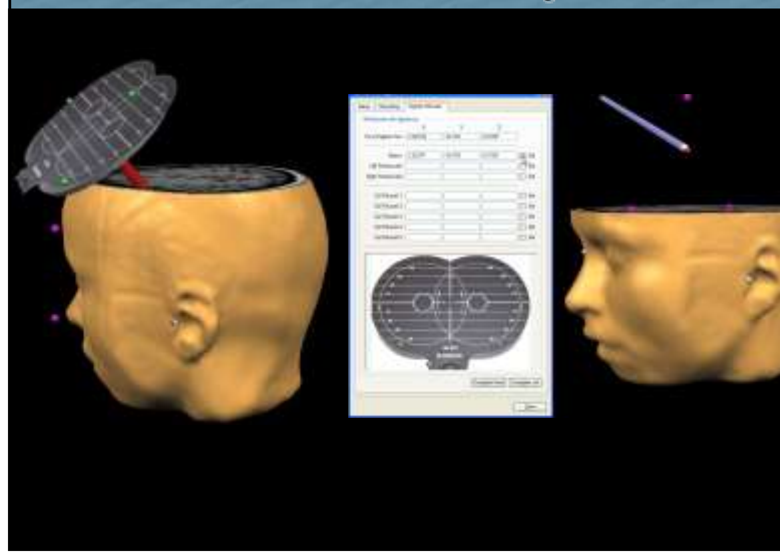


Sack A, Di Salle F. et al., (2002), Tracking the mind's image in the brain II, *Neuron*, **35**, 195-204.

Imaginal clock task - *TMS results*

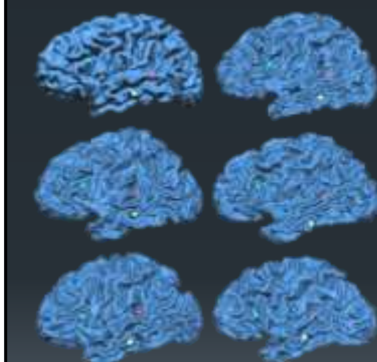


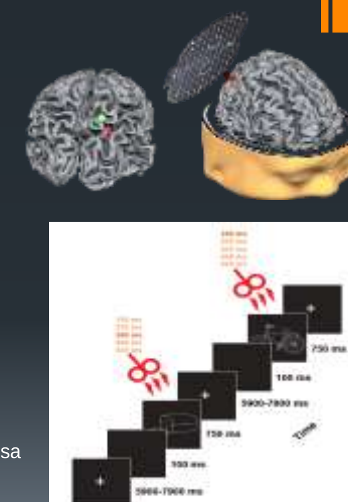
Real-Time TMS Neuronavigation



TMS Neuronavigation - *Example*

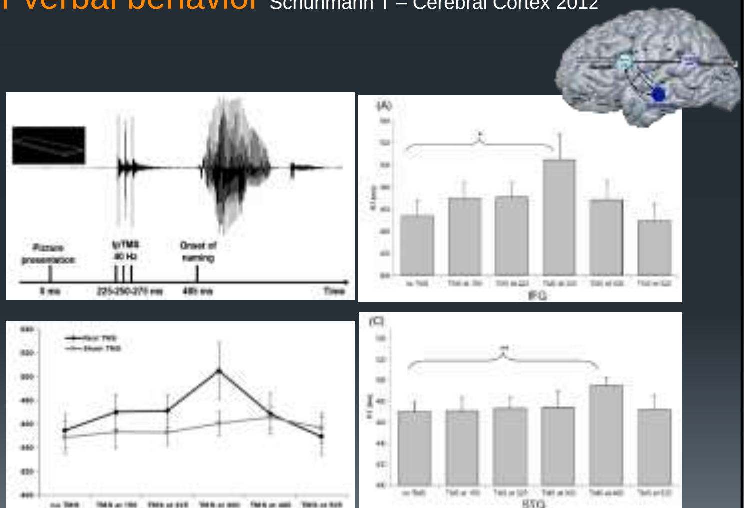
Functional Dissection of the neural network for verbal behavior





Speaking of Which: Dissecting the Network of Language Production in Picture Naming - Teresa Schuhmann – Cerebral Cortex 2012

Functional Dissection of the neural network for verbal behavior Schuhmann T – Cerebral Cortex 2012



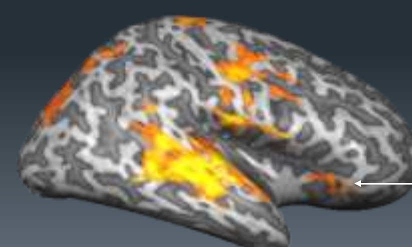
Methods to modify behaviors in the brain

TDCS

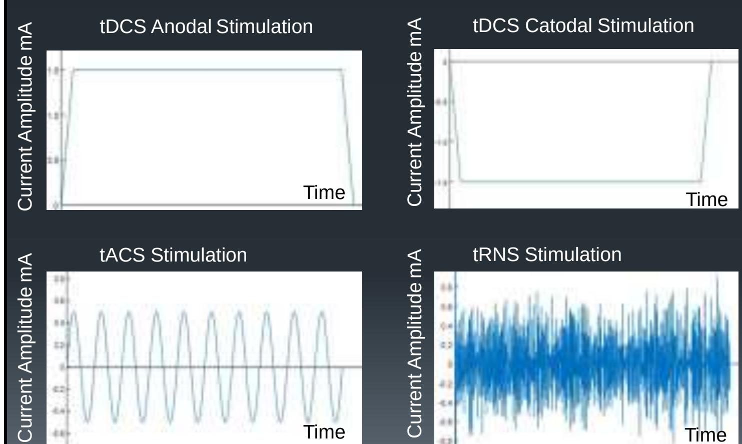
Apply «upregulating» stimulation by TDCS, able to modify excitability of a specific brain area for a lasting time

Return to teaching the chain

BN4



Transcranial electrical stimulation (tES) effects on cortical excitability and connectivity
Reed T, J Inh Met Diseases 2018



Transcranial electrical stimulation (tES) effects on cortical excitability and connectivity
Reed T, J Inh Met Diseases 2018

Neurotrasmitter modulation

- Reduction of GABA
- Increase of Glu/Glm

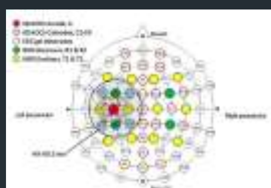
- Modulation of NMDA receptor

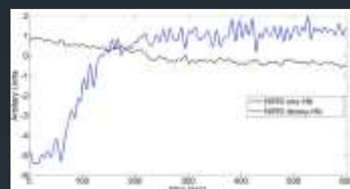
- Increase of BDNF

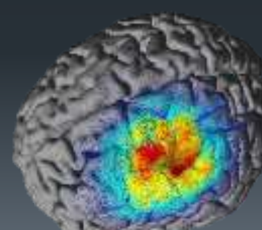
Cortical Stimulation – NIRS, EEG, tDCS

NIRS-EEG joint imaging during transcranial direct current stimulation

Sood M. Journal Neurosci Methods 2016







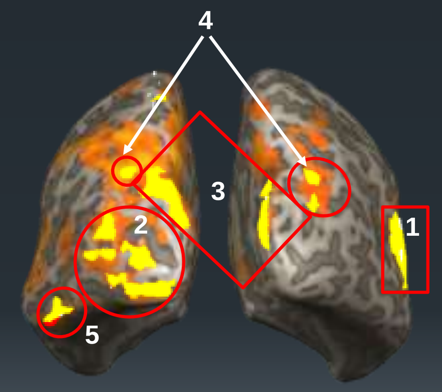
Conclusions

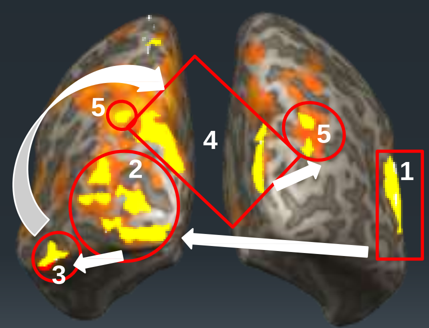
- Modern Neuroimaging has overcome many of the procedural weak points it presented at its beginnings
- It can comply with the requisites Skinner posed, regarding precision, reliability, reproducibility and interpretation.
- Neuroscience does not need to be cognitive, NIMG uses a pure anatomical analysis of results
- New knowledge can be derived by a convergence between the Science of Behavior and the Neurosciences, even in an applied perspective.
- The facilitation effect of training can be used to improve IV performances
- Powerful methods to modify brain behavior are available and their effects are measurable

Results of the Verbal Operant experiment

Temporal dissection of the Verbal Behavior in the brain

Echoic NW, Echoic W, IntraAud, IntraText, TactAud, TactVis, Text NW, Text W





The “word association” experiment

Movie

TRAINING VISUAL IMAGINING FOR COMPLEX CATEGORIZATION TASKS

Kisamore AN, JABA 2011

According to Skinner, word associations are the result of one verbal response serving as a discriminative stimulus that evokes another verbal response.

A series of verbal stimuli are presented to the subject, who is asked to report "the first word he thinks of".

Different subjects give different responses, presumably because of differences in their verbal history or in current conditions or circumstances.